INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI

A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor MI 48106-1346 USA
313/761-4700 800/521-0600

UNIVERSITY OF OKLAHOMA
GRADUATE COLLEGE

BACK BELT EFFECT ON PHYSIOLOGICAL STRAIN AND PERCEIVED DISCOMFORT AND EXERTION DURING A CONTINUOUS ASYMMETRIC STOOP LIFT TASK

A DISSERTATION
SUBMITTED TO THE GRADUATE FACULTY
in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY

By
RICK D. WHITNEY
Norman, Oklahoma

1997

UMI Number: 9817710

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

BACK BELT EFFECT ON PHYSIOLOGICAL STRAIN AND PERCEIVED DISCOMFORT AND EXERTION DURING A CONTINUOUS ASYMMETRIC STOOP LIFT TASK

A DISSERTATION APPROVED FOR
THE SCHOOL OF INDUSTRIAL ENGINEERING

BY

Robert E. Schlegel
Dr. Robert E. Schlegel, Co-Chair

Jerry L. Purswell
Dr. Jerry L. Purswell, Co-Chair

Mark A. Anderson
Dr. Mark A. Anderson

Dr. Adedeji B. Badiru

Michael G. Bemben
Dr. Michael G. Bemben

Richard F. Krenek
Dr. Richard F. Krenek

ACKNOWLEDGEMENTS

I would first like to thank my heavenly father for helping me to meet a difficult, lengthy challenge. I have sacrificed so much for knowledge, and I only pray that through wisdom, I might better serve your will. Thank you for remembering me. Bless me in the future that I may more effectively control my destiny. I thank my dear mother, Neva Whitney, for always being a positive, uplifting force in my life. She has been my inspiration, my beacon of hope, and my source of love for others. I thank my father, Dale Whitney, for helping me to understand perseverance and the limits of man. I thank Maia Artman for her support and companionship for many years. I thank my friend, Dr. Purswell, for his long-devoted patience and for being a source of constant knowledge. I also thank Dr. Purswell for pushing me to press the boundaries of the envelope of life. My career success will be related to his help. I thank my friend, Dr. Schlegel, for his unflailing belief in me; for his resolution of some of the more difficult issues of this study; and for the time he devoted to the tedious editing of this manuscript. I thank Dr. Krenek for his talented insight that assisted me in establishing the limits of the study. I also thank Drs. Krenek, Bemben, Anderson and Badiru for their positive attitudes. A heart-felt thanks goes to George Gibson, who was a steadfast supporter, and an exemplary mentor. I thank Dr. Raman for his belief in me. I thank Heidi Spradley, for providing illuminating wisdom without emotional charge. I thank my Bible study group and all of those at Rivermont who extended gentle kindness and supportive encouragement. I finally thank the Industrial Engineering staff, but special warm thanks go to Jane Smith and Jean Shingledecker for helping me to look through the eyes of others and to more clearly identify what is truly within my power. May God enlighten and provide wisdom to me, so that I become a more faithful servant to his will. May I not lose sight of the struggles of others, or judge the heart and spirit of others through my close relationship with God.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

Figures **Page**

ABSTRACT

This research effort evaluated the effect of wearing an elastic back belt on physiological and perceived strain during a continuous, high-frequency, asymmetric stoop lift task. Specifically, this effort examined the effect of the elastic back belt on work pulse (WP), change in systolic blood pressure during work versus rest (ΔSBP), change in diastolic blood pressure during work versus rest (ΔDBP), lower left back discomfort (LBD), lower right back discomfort (RBD), rating of perceived exertion (RPE), and static lift strength (SLS). A weight of lift of 25% of SLS was continuously lifted and lowered for 120 cycles from a low-lying position in the 90-degree lateral plane to knuckle height in the sagittal plane. Subjects were not allowed to pivot the feet, which were maintained in the near straight-ahead position.

A series of three experiments was performed. The first experiment, performed with two young male subjects of average fitness, demonstrated that a rest period of 10 minutes was a sufficient period of rest prior to work. Belt wearing with a tension of 5.6 kg at all of the weight levels (5%, 15% and 25% SLS) resulted in a lower WP than without belt wearing. The mean differential (belt wearing minus no-belt wearing) WP was significantly the lowest at 25% of SLS. The effect of belt wearing and load weight on ΔSBP and ΔDBP could not be determined due to variation in blood pressure cuff positioning.

The second experiment was performed with four non-conditioned male subjects. A 4-hour back belt tension adjustment session revealed that back belt setting from day-to-day was highly repeatable for the 5% SLS load (7.2 kg; $r = 0.95$, $p = 0.04$) and the 25% SLS load (10 kg; $r = 0.95$, $p = 0.04$), but not for the 15% SLS load (8.8 kg; $r = 0.54$, $p = 0.45$). The tension set for the 25% load was significantly greater than for the 5% load ($F(2,6) = 6.69$, $p = 0.029$), but neither tension was significantly different from the tension set for the 15% load. The results suggest that preferred belt tension is repeatable for low and high load weights. Neither rest period length (5, 10, 15, and 20 minutes) nor back belt wearing during rest significantly affected heart rate, SBP or DBP. The preferred tension did not sufficiently compress the vasculature of the abdomen or trunk nor restrict

venous return or muscle perfusion. It was also shown that preferred belt tension varies with the instructions, the task conditions, and/or the method of tension measurement. Wearing the back belt resulted in a significantly higher ΔDBP ($F(1,2) = 20.2$, $p = 0.046$). Two of the four subjects experienced a significantly higher ΔDBP, and one of these subjects had a significantly higher WP. One subject had a significantly lower WP with belt wearing. The individuals that were least fit, heaviest in weight, strongest, lifted the heaviest load, and had the largest abdominal girth experienced a significantly higher WP and/or ΔDBP indicating greater physiological strain with belt wearing. It is theorized that the submaximal workload associated with belt wearing resulted in a WP that masked the venous return effect on WP for the subject. The weakest, most task-conditioned individual, with the smallest abdominal girth, who lifted the lightest load experienced a significantly lower differential WP, ΔSBP and ΔDBP, indicating augmented preload and intra-muscular tension release vasodilation while wearing the belt. The lower WP with belt wearing indicates that differential WP can be significantly reduced without lifting heavy loads. It is theorized that higher subject fitness combined with smaller abdominal girth reduced the effect of the submaximal workload on cardiac output. Therefore, minimal venous return would decrease pulse rate for these individuals.

The third experiment demonstrated that rest period length combined with a belt tension that did not restrict breathing (7.9 kg) did not significantly affect heart rate, SBP or DBP during rest. The preferred tensions set in the two belt tension adjustment trials at the 25% SLS load were highly correlated ($r = 0.84$, $p = 0.008$). Wearing the back belt resulted in a significantly higher ΔSBP ($F(1,6) = 7.6$, $p = 0.033$). Six of the eight subjects experienced a significantly higher ΔSBP with belt wearing, and one subject had a significantly lower ΔSBP. Four of the subjects with significantly higher ΔSBP with belt wearing also demonstrated significantly higher ΔDBP. The subject that experienced a significantly lower ΔSBP with belt wearing also had a significantly lower ΔDBP. Two of the six subjects that had significantly higher ΔSBP with belt wearing also exhibited significantly higher WP, while two of the six subjects experienced significantly lower WP. In general, subjects with lower body weight, SLS, abdominal girth, and higher task conditioning did not demonstrate a significant WP effect with belt wearing. Subjects that were the least fit experienced a higher WP with belt wearing than without. Subjects that were fit, had the highest body weight, SLS, and lifted the heaviest loads had a lower WP with belt wearing than without. The individuals that had the highest body weight, SLS and abdominal girth experienced significantly higher ΔSBP and ΔDBP with belt wearing. The load weight, body weight, abdominal girth and fitness of the participant were theorized to be the four most important determinants of the effect of the tightly tensioned back belt on differential physiological strain during the high-frequency asymmetric stoop lift. The LBD was significantly lower with belt wearing ($F(1,6) = 6.05$, $p = 0.049$). Five subjects had significantly lower LBD with belt wearing than without. Three of these subjects were among the subjects with the four largest abdominal girths. These three subjects also experienced higher physiological strain with belt wearing than without. The lower LBD with belt wearing might be attributable to an improved postural stance between lifts.

The individuals that participated in Experiment 3 would strongly consider wearing the back belt in this type of lifting task. The primary factors related to this decision were the perceived support and help provided by the back belt. The support that the back belt provided was directly related to the perceived pressure applied to the low back. The help that the belt provided was inversely related to the temperature of the belt. The comfort of the belt was directly associated with the pressure that the belt exerted on the abdomen.

The repetitious nature of the task, the improved myocardial perfusion due to the higher ΔDBP, and the speculated increase in venous return due to wearing the back belt would appear to mitigate the elevated ΔSBP, and abate the myocardial infarction risk. Individuals with coronary artery disease should still avoid strenuous static resistance tasks and breath-holding during lifting with or without the back belt.

It appears that back belt wearing during the high-frequency asymmetric stoop lift increased physiological strain. No study has demonstrated that the back belt provides a biomechanical benefit during this lifting task. Further studies are required to determine if a physiological / biomechanical trade-off exists with belt wearing during the continuous asymmetric stoop lift. In addition, individuals with chronic compartment syndrome might be at a greater risk for muscle ischemia and tissue damage due to the possibility of increased intramuscular tissue pressure in the deeper contraiateral paraspinals with belt wearing. Therefore, the back belt is not recommended for use in this type of lifting task. However, if the back belt is worn, then individuals should not tension the back belt too tightly and should pivot with the feet when lifting loads in the lateral plane.

BACK BELT EFFECT ON PHYSIOLOGICAL STRAIN AND PERCEIVED DISCOMFORT AND EXERTION DURING A CONTINUOUS ASYMMETRIC STOOP LIFT TASK

CHAPTER 1

INTRODUCTION

Continuous, high-frequency asymmetric stoop lifting of low-lying loads is performed in many work environments for work periods that exceed two hours. Workers often wear back belts while lifting, although the physiological responses to back belt lifting are not conclusively known. Waters, Putz-Anderson, Garg, and Fine (1993) speculated that tasks involving frequent bending and twisting for periods longer than 15 minutes may result in local muscle fatigue (LMF). In addition, NIOSH (1994) has suggested that wearing a back belt might temporarily increase cardiovascular strain.

Hunter, McGuirk, Mitrano, Pearman, Thomas, and Arrington (1989) speculated that wearing a back belt during exercise might pose a greater risk for those individuals having a compromised cardiovascular system. However, Contreras, Rys, and Konz (1995) found that belt wearing did not negatively affect cardiovascular strain when the weights lifted were within the NIOSH (1991) Recommended Weight Limit (RWL).

Madala (1996) demonstrated that belt wearing did not negatively affect pulse rate for subjects lifting heavier weights, but significantly increased strain for other subjects lifting lighter weights. These mixed results suggest that it is important to further examine the effect of the elastic back belt on physiological strain during production-oriented lifting tasks across longer work periods. The nature of the continuous, high-frequency asymmetric stoop lifting task may contra-indicate the use of lifting belts based on induced physiological strain.

The elastic back belt has been promoted as a device that may reduce trunk muscle fatigue. It has been shown to slightly reduce contralateral trunk muscle activity, spinal compression, and anterior-posterior shear forces in both symmetric and asymmetric lifts, although some individuals experience an increase in spinal loading (Granata, Marras, and Davis, 1997). Intra-abdominal pressure (IAP) has been speculated to reduce trunk muscle extensor activity (Bartelink, 1957; Morris, Lucas, and Bressler, 1961; Gracovetsky, Farfan, and Helleur, 1985). However, a previous study has demonstrated that a larger IAP with elastic back belt wearing does not result in a reduction in extensor muscle activity (McGill, Norman, and Sharratt, 1993). It is believed that back belt wearing increases torso stability (McGill, 1993). Also, a large, pulsed IAP applied at the proper phase of the cardiac cycle may provide a cardiovascular benefit (Christensen, Hamilton, Scott-Douglas, Tyberg, and Powell, 1992).

Heavier weights of lift, higher body weights and longer moment arms to the trunk center of mass potentially increase intra-muscular pressure (IMP) during asymmetric stoop lifting. Greater IMP increases muscle pump and venous return

(Hargens, Millard, Petersson, and Johansen, 1987), but may result in local muscle fatigue (LMF) and elevated blood pressure. Heavier lifting efforts have also been associated with greater severity of injury and more total lost work days (Chaffin, Herrin, Keyserling, and Faulke, 1976).

Higher lift frequencies and heavier weight levels combined with movement against the resistance of the belt (McGill, Sequin, and Bennett, 1994) may increase work intensity and IMP during work and recovery. An increase in IMP might prevent adequate blood perfusion to the trunk muscles. Muscle tension, external pressure, IMP and hormonal and chemical by-products in the muscle stimulate an increase in heart rate and blood pressure (Humphreys and Lind, 1963).

In summary, there are a number of physiological mechanisms that may influence easily measured cardiac parameters during asymmetric stoop lifting while wearing an elastic back belt. The general purpose of this study is to further define and explain these physiological changes.

1.1 Problem Background

Over 30% of all jobs involve some degree of manual lifting (NIOSH, 1981). Over 80% of the lifting tasks in industry involve trunk twisting at some point during the lift (Drury, Law and Pawenski, 1982).

Many job and task designs in industry cause the worker to lift with an asymmetric lift (torso twisted, laterally bent and flexed). Job designs that center on productivity and involve physical work with time standards based on subjective fatigue estimates may cause the worker to make posture and motion compromises. The nature of the task, combined with the fitness of the worker, may result in loads being lifted with an asymmetric stoop lift. Narrow aisles, congested floor spaces, low shelf heights, and obtuse angles between the origins and destinations of the lift are additional task conditions that can cause the worker to stoop with an asymmetric trunk posture.

High-frequency lift requirements may also cause the worker to lift asymmetrically. Continuous, high-frequency asymmetric stoop lifting is performed in many work environments, including the loading and unloading of parcel, freight, food and beverage delivery trucks, and in palletizing and depalletizing operations.

Asymmetric stoop lifting is more time efficient, and aerobically less costly than moving the entire weight of the body by repositioning the feet (Gagnon, Plamondon, and Gravel, 1993). At the same time, workers are less sensitive to the perceptual stresses of lifting in a twisted posture, or are willing to accept a greater level of stress during trunk asymmetry (Garg and Banaag, 1988). Also, workers are willing to accept higher workloads and higher perceived stress at the higher lift frequencies (Garg and Saxena, 1979).

Lifting in a twisted posture reduces the strength capacity of the torso in extension (Kumar and Garand, 1992). The patterns of trunk muscle activity and the intensity of muscle activation are influenced by the posture of the trunk, and the direction of the external force (Kim, Chung, and Lee, 1994). Asymmetric lifting increases the activation of the lower trunk muscles, with the contra-lateral muscle groups being fatigued the most (Kim et al., 1994). An increase in trunk postural maintenance is required with the stoop lift in the asymmetric posture. The static postural component may decrease trunk muscle efficiency and increase metabolic cost (Humphreys and Lind, 1963). Static muscle loading frequently results in LMF due to the increase in muscle tension and the augmented IMP resulting in the accumulation of metabolic waste (Kahn and Monod, 1989).

Asymmetric lifting results in greater trunk muscle coactivation including the activation of smaller muscles (Seroussi and Pope, 1987). The contraction of smaller muscles increases the risk of muscle fatigue, muscle sprain, muscle strain, and low back pain (LBP; Kumar, 1984). The central nervous system incorporates muscle coactivation to increase trunk stability during the asymmetric stoop lift, but with the increase in stability is an increase in antagonistic muscle activity, and physiological strain.

In addition, heavier weights of lift, higher body weights, and longer moment arms to the trunk center of mass increase force and torque requirements during the asymmetric stoop lift. IMP is linearly related to force or torque (Sadamoto, Bonde-Petersen, and Suzuki, 1983). An increase in IMP will squeeze blood out of the muscle and propel it back to the heart (Hargens, Millard, Petersson, and Johansen, 1987). This may be beneficial to the function of the cardiovascular system. However, as IMP increases, blood flow through the muscle will decrease and reduced microcirculation may cause ischemia. This may result in LMF. Also, a sufficient increase in IMP will elevate blood pressure (Mitchell, 1990).

During work, fluid is taken up by the active muscle, and the muscle swells. The muscle swelling is related to the work intensity (Gullestad, Yaru, Hargens, Lieber, O'Hara, and Akeson, 1984). Muscle swelling can occur within seconds, whereas restoration of muscle volume is a slow process (Sejersted and Hargens, 1986). An increase in the weight of lift combined with high-frequency lifting may not allow sufficient time for the muscle volume to be restored between lifts.

Kim et al. (1984) examined a work strategy involving lifting a light weight in an asymmetric posture at a high frequency. They found that this approach resulted in earlier and greater fatigue in the muscles contralateral to the direction of the external load, than lifting a heavier load at a lower frequency.

High-frequency lifting may not allow sufficient muscle recovery time. The extensor muscle workload associated with raising and lowering the weight of the torso combined with the postural support role of the low back muscles in the asymmetric posture and the compartmental nature of the deeper erector spinae muscles may result in high intra-muscular pressures in these muscles. Consequently, blood flow through the deeper lumbar muscles may be reduced. Lactic acid formation may increase in the deeper paraspinals, increasing muscle tissue acidity (Sejersted, Hargens, Kardel, Blom, Jensen, and Hermansen, 1984).

Subsequently, peripherally induced, efferent responses from the central nervous system may increase cardiac output and blood pressure in an effort to increase muscle perfusion pressures (Kaufman, Rybicki, Waldrop, and Ordway, 1980). Conduction velocity of the nerve signals may decrease, and electro-mechanical coupling and force production may become impaired (Bigland-Ritchie and Woods, 1986).

Secondary muscles that are not as fatigued, but are not as efficient for the loading may become active to perform movement and stabilize the postural load (Parnianpour, Nordin, Kahanovitz, and Frankel, 1988). Furthermore, muscle control and force generation efficiency are reduced when fatigue builds up in any particular group of muscles (Brown, 1973). The active muscle mass and cardiovascular response may increase (Lind and McNicol, 1967). A greater effort, as occurs with fatigue, will elevate the pulse rate and blood pressure response, metabolic cost and potentially cardiovascular strain (Bezucha, Lenser, Hanson, and Nagle, 1982).

The duration, workload, and work-rest cycle of the lifting task determine whether the anaerobic or aerobic energy systems are used. High-frequency asymmetric stoop lifting of heavier loads for a prolonged duration may increase oxidative debt. If the oxygen debt from a prior work period is not recovered, then the cardiovascular responses will increase in the succeeding work periods due to the reduced state of the metabolic substrates within the active muscles.

Back belt wearing in industry has escalated during the last five years, and has become a fundamental component of many corporate safety programs. A CTDNews (1993) poll confirmed that 88% of 120 North American corporate respondents preferred that their employees wear back belts. However, recent litigation brought against 30 major belt manufacturers (CTDNews, 1995) has validated the need to define physiological guidelines for back belt wearing.

The elastic back belt has been promoted as a device that may reduce trunk extensor muscle fatigue. It has been speculated that trunk extensor muscle activity may be reduced through the intra-abdominal pressure mechanism (Morris, Bressler, and Lucas, 1961; Gracovetsky et al., 1977). However, this was not demonstrated in a previous back belt study (McGill et al., 1990).

A significant increase in IAP with back belt wearing occurs primarily with heavier weights of lift (Morris et al., 1961; Hemborg, Moritz, and Lowing, 1985). IAP has also been shown to increase in the latter lifts when the repetitive squat lift was performed (Lander, Hundley, and Simonton, 1992). The increase in IAP may be due to trunk muscle fatigue.

Wearing an elastic back belt during the asymmetric stoop lift may result in a lower IAP effect in comparison with other lift techniques. The capacity of the abdominal muscles to generate IAP may be reduced in the twisted posture but increased with flexion (Marras and Mirka, 1991a; Marras and Mirka, 1991b).

Also, an increase in IAP at the beginning of the stoop lift with belt wearing may result in a flexor moment, thereby increasing trunk extensor muscle activity (Grew, 1980). In addition, during lifting with the torso flexed, an augmented IAP is accompanied by an increase in trunk muscle coactivation (Krag, Gilbertson, and Pope, 1985), which increases antagonistic muscle activity.

The Valsalva maneuver is one breathing technique used to increase IAP, especially when fatigued. However, the Valsalva is associated with an increase in trunk muscle coactivation (Kumar and Davis, 1973; Krag et al., 1985).

Hunter et al. (1989) showed that wearing a rigid weightlifter's belt while using a cycle ergometer or performing a dead lift significantly increased blood pressure.

However, pulse rate increased only during the cycle exercise. The rate pressure product (pulse rate x systolic blood pressure) increased in all exercises. The increase in blood pressure during the dead lift was likely due to the pressor reflex, the Valsalva maneuver and mechanical compression of the vasculature. The increase in pulse rate and systolic blood pressure in the cycling task may have been partially due to an increase in IMP since both pulse rate and blood pressure were elevated in the resting state. However, the primary increase was due to an increase in physiological work from reduced cycling efficiency due to the added motion resistance associated with belt wearing. The researchers speculated that back belt wearing might place an added strain on the cardiovascular system.

In a high-frequency knuckle to shoulder lift, Madala (1996) demonstrated that the elastic back belt significantly increased work pulse for the weaker subjects lifting lighter loads, but lowered work pulse for the stronger subjects lifting heavier loads. The change in systolic blood pressure was not significant with belt wearing. The belt may have increased the muscle pump for the subjects lifting heavier weights using larger active muscle masses.

Elevated IAP levels may either increase or decrease stroke volume and cardiac output depending on the existing systemic vascular conditions that exist between the abdomen and thorax (Takata, Wise, and Robotham, 1990). An increase in left ventricular preload with belt wearing may decrease pulse rate and cardiovascular strain. A large pulsed IAP applied at the proper phase of the cardiac cycle may provide a cardiovascular benefit. Christensen et al. (1992) demonstrated that the largest pulsed abdominal compression of those tested (25, 50 and 100 torr) was shown to improve cardiac output and coronary blood flow in dogs if applied during diastole. Also, sustained IAP levels exceeding 25 mmHg have been shown to affect cardiovascular and pulmonary function in humans (Deibel, Dulchavsky, and Wilson, 1992). Repetitive lifting and the powerful muscle pump combined with the Valsalva maneuver assist the heart muscle in maintaining or augmenting stroke volume (MacDougall, Tuxen, Sale, Moroz, and Sutton, 1985).

Back belt wearing has been speculated to provide the worker with a psychological cue to turn with the feet instead of the trunk during lifting (Lavender, Thomas, and Andersson, 1995). The rigid back belt has been shown to increase the passive resistance to movement with increasing trunk flexion (McGill, Sequin, and Bennett, 1994). In addition, the elastic back belt has been shown to significantly decrease the range of motion, and velocity and acceleration of the trunk in the cardinal planes (Lavender, Thomas, Chang, and Andersson, 1994; Granata et al., 1997).

Some resistance to movement occurs with a sagittal plane lift, but more occurs with the asymmetric lift (Lavender et al., 1994). This was thought to be due to the width of the elastic belt used, and the ability of the belt to connect the pelvis with the thorax. In addition, the abdominal compartment volume is restricted by the trunk muscle alignment in the twisted and flexed posture. Consequently, the abdomen may bulge outward increasing belt tension.

The abdominal muscles must work against additional belt resistance during trunk bending, flexion and twisting (McGill et al., 1994). The elastic belt may increase trunk muscle workload due to the larger force required to overcome belt stiffness. These events would potentially increase physiological strain, namely pulse rate and systolic blood pressure. If the belt does not substantially increase trunk muscle workload, intramuscular pressure or ischemia, then diastolic blood pressure would not be expected to increase.

The back belt has also been demonstrated to diminish the variations in trunk muscle switching strategies and activation levels, such that fatigue may occur sooner for some muscles than when the belt is not worn (Lavender et al., 1994). These events may lead to an increase in the active muscle mass, and an increase in the activity of the fast twitch muscle fibers. An increase in the active muscle mass and utilization of the fast twitch muscle fibers has been related to a larger blood pressure response (MacDougall et al., 1994; Staunton, Taylor, and Donald, 1964).

Disc shearing forces are also increased with asymmetric lifting, and this can be injurious to the facet joints (Adams and Hutton, 1981). Granata et al. (1997) demonstrated that the elastic back belt reduced spinal compression and anterior-posterior shear forces in both symmetric and asymmetric lifts. Reduction in trunk motion was accomplished by recruiting greater pelvic angles, and increasing pelvic velocity and acceleration in the sagittal plane. However, some individuals experienced an increase in spinal loading with elastic back belt wearing (Granata et al., 1997). The pattern of the belt effect was not influenced by the weight of lift.

High lift frequencies and heavy weight levels, combined with the external pressure added by the belt (McGill et al., 1994) may lead to increased intra-muscular pressures and reduced perfusion of the trunk extensors during the work and relaxation phases of lifting. The compartmental nature of the deeper erector spinae muscles and the obliquity of these muscles during the asymmetric stoop lift also promotes large intra-muscular pressures. Moreover, the increase in muscle swelling that occurs with work, combined with the external pressure from the belt, may further elevate intramuscular pressure. An increase in IMP may promote ischemia in the deep lumbar muscles. An increase in IMP or ischemia will increase blood pressure (McClosky and Mitchell, 1972). A coincident increase in heart rate and blood pressure potentiates myocardial work.

Studies have shown that the deeper fibers in some muscles are the aerobic fibers (Sejersted et al., 1984). Thus, a sufficiently elevated IMP may promote anaerobic metabolism and reduce transmission of force to the tendons (Sejersted and Hargens, 1986). With repetitive fatigue, the ischemic muscle fiber tissues may become damaged, and chronic extensor muscle weakness may occur. Muscle weakness results in increased loading of the passive structures of the spine that are less resilient to stress and strain (Roy, Deluca, and Casavant, 1988). This may eventually lead to chronic LBP.

In summary, it is hypothesized that the belt may increase trunk muscle workload and IMP in the high-frequency asymmetric stoop lift, and may induce an increase in ischemia, and LMF. Consequently, the augmented workload and/or IMP may increase work pulse, blood pressure, low back muscle discomfort, and perceived exertion. In addition, repetitive fatiguing lifts performed with the Valsalva maneuver can progressively increase blood pressure (MacDougall et al., 1994).

The back belt may increase the efficacy of the abdominal muscle pump and increase venous return and preload resulting in a lowered pulse rate. However, it is theorized that the decrease in pulse rate is not conclusively related to reduced myocardial work, since systolic blood pressure may be elevated, and cardiac output may be increased. Finally, belt wearing during the high-frequency stoop lift of low-lying loads in the lateral plane does not appear to promote a biomechanical benefit. However, one previous back belt study demonstrated that the elastic back belt reduced trunk muscle compression forces and anterior-posterior shear forces for some subjects during the asymmetric stoop lift (Granata et al., 1997).

It is theorized that wearing the back belt increases physiological workload, IMP and muscle pump during the high-frequency asymmetric stoop lift. The increase in physiological workload may either increase or decrease work pulse depending on the masking effect of the increased preload. However, the increase in workload would be expected to increase systolic blood pressure. Belt wearing may also increase IMP in the contralateral trunk extensors, and reduce blood flow to these muscles thereby increasing blood pressure, and the likelihood of LMF.

1.2 Research Study Objectives

This research effort comprised a series of three experiments. The experiments were conducted during the Spring 1997 semester at the University of Oklahoma, and spanned a period of four months (February - May 1997). In each of the experiments, subjects used the asymmetric stoop lift technique to lift and lower a tote box containing weight equivalent to a fixed percentage of that subject's static lift strength (SLS). The weight was moved between a support surface in the 90-degree lateral plane and a support surface in the mid-sagittal plane for a period of two hours. Six lifts and six lowers were performed each minute. The primary objectives of the research effort were to:

1. evaluate the effect of belt wearing, time into the work session, and order of belt wearing on work pulse, change in systolic blood pressure, change in diastolic blood pressure, low back discomfort, and rating of perceived exertion,
2. evaluate the relationships among the criterion measures, and subject and task factors for the belt conditions, and
3. examine the relationships among measures of belt effectiveness (support, help and compliance) and the sensory dimensions of temperature, restriction, circulation, pressure, and comfort.

It was necessary for many secondary objectives to be accomplished in order to satisfy the primary objectives. The secondary objectives for Experiment 1 were to:

1. determine if a linear prediction equation could adequately explain the relationship between stretched belt length and belt tensile force,
2. determine the lift frequency, weight of lift, and lift duration acceptable to the young male subject of average fitness, and
3. determine the weight of lift and lift duration that result in the largest belt effect for work pulse, change in systolic blood pressure, change in diastolic blood pressure, lower left and right back discomfort, and rating of perceived exertion.

The secondary objectives for Experiment 2 were to:

1. determine the repeatability of belt tension setting between sessions conducted on different days, and between trials conducted within the same session,
2. determine if belt tension varied as a function of the weight of lift and subject characteristics,
3. determine if the tension set for a 25% MVC weight of lift differed significantly from the back belt tensions set in Bowen, Purswell, Schlegel and Purswell (1995), and in Madala (1996),
4. evaluate the effect of pre-work rest duration on pulse rate, systolic blood pressure and diastolic blood pressure with and without belt wearing,
5. evaluate the belt wearing effect on pre- and post-asymmetric stoop lift strength, and
6. estimate the number of subjects required for different powers of the test using the back belt effect sizes and estimates of variability.

The secondary objectives for Experiment 3 were:

1. determine the repeatability of belt tension setting between trials conducted within the same session,
2. determine if belt tension varied as a function of subject characteristics,
3. evaluate the effect of pre-work rest duration on pulse rate, systolic blood pressure and diastolic blood pressure with and without belt wearing, and
4. evaluate the effect of belt wearing on pre- and post-asymmetric stoop lift strength.

CHAPTER 2

LITERATURE REVIEW

2.1 Low Back Injuries - Causes and Prevention

Humans have been afflicted with LBP since the earliest of times. Ancient Egyptians suffered from sciatica, and lumbago was prevalent in the 16th century (Snook, Campenelli and Hunt, 1978). A specific cause for LBP is not known. In industry, LBP is treated as an injury and not as a disease, such as cumulative trauma disorders (CTDs). Therefore, it is difficult to determine injury causation because often the medical diagnosis is often not supported by objective criteria designed to identify the cause of the injury (James, 1985).

Among the risk factors for LBP are manual materials handling (MMH), lifting, twisting and lumbar muscle fatigue. Although a single overexertion can result in an acute injury to the spine, repetitive loading increases the exposure of the muscles, tendons, ligaments, vertebrae, and discs to fatigue, and also to microscopic tissue injury (Owen, 1986). These "microtraumas" appear to be cumulative and lead to degeneration of the tissues of the spine (Moretz, 1987). Moreover, a single overexertion may combine with the cumulative degeneration to result in a more severe injury (Owen, 1986). An initial episode of LBP is highly related to future LBP events (Bond, 1970). This illustrates the importance of preventing a first-time occurrence of LBP. Reducing repetitive trunk muscle fatigue may be one of the first steps to prevent LBP.

Weak low back muscles are related to the chronic LBP condition (Leino, Aro, and Hassan, 1987). Weak trunk muscles and reduced flexibility of the low back and hamstrings were found to be residual signs among those with recurring or persistent low back trouble (Fin Biering-Sorensen, 1984). Strengthening the trunk muscles has been shown to reduce the frequency of LBP and injury cases (James, 1985).

The exact mechanism by which muscle fatigue leads to injury is not known. However, it is theorized that weak back muscles are less able to support the spine and this will increase the demands on the more passive elements during lifting (Roy et al., 1989). The occurrence of lumbar muscle fatigue during stoop lifting may decrease the ability of the back muscles to counterbalance the anterior shear forces produced by the abdominal muscles (McGill, 1993). Also, if an imbalance of strength exists on one side of a lumbar vertebral joint then lateral disc shearing may occur. Trunk muscle coactivation helps prevent strain of the articular structures.

Trunk muscle fatigue is often attributable to the maintenance of static trunk postures or to the static trunk muscle component of a dynamic lifting task. Counteraction of antagonist or balancing muscle groups, or counterbalancing the effects of gravity in the maintenance of posture or in torso stabilization increase the static component (Simonson, 1971). An increase in the trunk muscle static component may increase IMP and potentially decrease blood perfusion through the paraspinal muscles. Consequently, the extensors may be deprived of oxygen-rich nutrients and become more dependent on glycogen, resulting in the formation of lactic acid. A lack of blood flow through the muscle prevents the washing-out of these metabolic waste-products, and consequently the work efficiency of the lower back muscles decreases. These events promote the occurrence of LMF. Moderate increases in heart rate, and dramatic increases in blood pressure may occur. Also, repetitive static loads and fatigue may result in muscle tissue, tendon, and joint inflammation and deterioration.

The static component of lifting is higher with asymmetric trunk postures than with symmetric postures, and the combination of lifting, bending and twisting is the most frequent cause of back injury (Andersson, 1981; Rowe, 1983). Snook (1978) reported that 79% of low back injuries were due to lifting, bending and twisting. Kelsey, Githens, and White (1984) found that the combination of flexion, twisting and lateral bending was associated with higher levels of LBP and injury. Also, greater lifting efforts have been shown to result in greater severity of injury and more total lost work days (Chaffin, Herrin, Keyserling, and Faulke, 1976).

The nature of the lifting posture determines the type of low back injury that is likely to occur. Flexion of the trunk without twisting increases the compressive load and promotes the posterior herniation of the nuclear material through the annulus. Lifting heavy loads in a neutral position stresses, and may lead to the fracture of, the vertebral end-plates of the disc body. Lifting in a twisted posture will increase shear forces, and the facet joints will likely be the first to sustain torsion injury (Adams and Hutton, 1981).

A back injury reduces the worker's ability to function and is often associated with pain, many back ailments, and with disability. Back injuries and LBP represent a large percentage of the injury incidents in industry. Over 30% of the total injuries in industry are back related (De Ruiter, 1990). Also, back injuries and LBP were associated with 31% of all worker compensation claims in the United States in the latter 80's and early 90's (National Safety Council, 1992). Through a review of a large database of worker's compensation claims, Marras, Karwowski, Smith, and Pacholski (1993) determined that over 45% of compensation costs were attributable to back injuries. LBP cost in the U.S. is exorbitant, accounting for 27 million lost workdays per annum at a cost of $25 to 50 billion (Gates, 1988).

Industry has attempted to control low back injuries and costs through proactive and reactive approaches. Snook (1987) and others have established that the primary preventive approaches used by industry are:

1. selection of workers,
2. appropriate lift training,
3. design of the task to fit the worker,
4. use of mechanical lifting aids,
5. strength and fitness training, and
6. using acceptable workload limits.

Selection of workers for the job has not been successful due to the inability of researchers to develop normative databases to clarify the relationship between strength, endurance, fatigue, and cardiovascular measures, and LBP. Also, companies often do not have the on-site expertise to develop physical performance measures that will ensure worker success in the long-term performance of the task. Commercial lift analysis equipment exists, but in most cases the equipment is expensive and requires an understanding of the physical demands of the task, and of human strength, endurance and aerobic capacity. Also, complications are added with this approach, since hiring managers need to be knowledgeable of the rights of the disabled worker according to the Americans with Disabilities Act.

Appropriate lift training and instructions have not been shown to be effective (Rowe, 1971). A frequent management response to the problem of twisting is to train the worker not to twist. However, it is difficult to achieve a lasting effect when twisting requires less energy expenditure than foot movement (Garg, 1989). Body mechanics training in a simulated work environment has been effective, but the use of proper body mechanics in the actual work environment is poor (Carlton, 1987). This suggests that worker compliance is a major obstacle that needs to be resolved in order to successfully reduce low back injuries (Davies, 1978).

Designing the task to fit the worker is only effective to the extent that the design is ergonomically sound, and safe. Also, it is limited, once again, by the level of commitment of the worker to observe and practice good lifting techniques. Another problem is that proper lift techniques often depend on the specific task and work station.

Mechanical lifting aids are used in industry, but production standards are often hindered by such devices because they require additional coupling and product handling time in most cases. Also, equipment cost may be prohibitive in view of the short-term tangible benefits. High-frequency material handling may be hindered by semi-automatic mechanical lifting aids.

Strength and fitness training have produced a positive effect on reducing or preventing the onset of LBP according to some studies (Cady, 1979). A few studies have demonstrated that strength training also aids in the recovery from LBP (Cady, 1985). However, other studies have shown that strength and fitness training have not resulted in decreases in LBP (Berkson, Schultz, Nachemson, and Andersson, 1977).

Using acceptable workload limits has not been successful. The redesign of products and tasks such that the weights lifted are lower than the NIOSH (1991) recommended weight limit (RWL) for the task has not occurred in industry. Many manufacturers feel that the RWL's are too conservative and that following the guidelines would result in a loss of productivity at a tremendous capitalization cost. Studies must be performed to validate the relationship between physiological strain, the RWL, and the Lifting Index (Waters, Putz-Anderson, Fine, and Garg, 1993).

Snook (1987) provided evidence that several of the above approaches have been ineffective in the prevention of LBP. Another problem with evaluating the efficacy of these approaches is that injuries often occur away from the work environment (Owen, 1986).

Another component of the multidimensional approach that corporations have taken to reduce low back injuries is to advocate the use of industrial back belts. Back belt companies have aggressively marketed their products with strategies that suggest that the back belt reduces fatigue, and consequently injuries. Researchers who have evaluated the effect of the back belt on fatigue during sagittal plane lifting tasks have failed to demonstrate a reduction in extensor muscle fatigue (Cirello and Snook, 1995). The belt does not appear to reduce the fatigue of the superficial dorsal muscles of the lumbar spine, and therefore, the potential relief to the deeper extensors would appear improbable.

The trunk muscle arrangement is complex with 22 pairs of muscles crossing the lumbar spine. Different muscle activation strategies can be employed by different individuals performing the same lifting task. Perhaps, the deeper compartmental lumbar muscles are more fatigued with belt wearing, or the spinae of the thoracic region may become more fatigued. No theoretical support exists for a reduction of trunk extensor muscle fatigue with elastic back belt wearing during high-frequency asymmetric lifting performed continuously over moderate work periods.

Granata et al., (1997) demonstrated that the elastic back significantly decreased spinal loads, but the applied lifting moments were increased. The decrease in spinal loads was accomplished through a decrease in left erector spinae muscle activity (4% of MVC), a decrease in rectus abdomini activity, and an increase in internal oblique activity. Although the back belt reduced trunk motions, the differences with belt wearing were not sufficient to significantly lower the probability of low back pain (Granata et al., 1997). In addition, intersubject variability was high, and some subjects experienced an increase in spinal load while wearing the back belt.

Prior belt studies have failed to demonstrate that the elastic back belt is effective in reducing low back fatigue, the perception of fatigue, LBP or injury. In a recent NIOSH (1994) publication, *The Workplace Use of Back Belts*, it was determined that insufficient data exist to support the use of the back belt in decreasing the biomechanical loading of the trunk or in reducing LBP or injury. The report also suggested that wearing a back belt might cause a temporary increase in cardiovascular strain. One study has demonstrated that the use of a rigid weightlifter's belt during a static dead-lift or dynamic cycling task may increase cardiovascular strain (Hunter et al. 1989). However, two studies (Contreras, 1995; Madala, 1996) suggest that task and subject characteristics interact with the belt factor in the determination of physiological strain.

None of the previous research studies have evaluated the effect of the back belt on heart rate, blood pressure, body part discomfort or the rating of perceived exertion during the continuous asymmetric stoop lift task. Moreover, none of the previous back belt studies have evaluated the effect of the belt on heart rate and blood pressure for continuous periods of lifting equal to or longer than one hour. It is plausible that asymmetric stoop lifting combined with back belt wearing increases physiological workload and the intramuscular pressure in the lower back muscles.

Increased cardiac output for a workload of less than 50% of maximum VO_2 uptake will be achieved primarily by an increase in stroke volume and pulse rate, and above 50%, primarily by pulse rate (Lewis, Taylor, Graham, Petinger, Schutte, and Blomqvist, 1983; Gay and Rothenburger, 1991). If a large static component is not present, then a moderate increase in systolic blood pressure will accompany the increase in cardiac output. However, diastolic blood pressure would not increase appreciably, and may even decrease (Bezucha, Lenson, Hanson and Nagle, 1982).

A sufficient increase in static loading and intramuscular pressure increases anaerobic metabolism, and both systolic and diastolic blood pressure (Lind et al., 1964). These events could increase lumbar muscle fatigue (Edwards, 1986), which could reduce asymmetric stoop lift strength. A higher intramuscular pressure, ischemia, or local muscle fatigue will decrease neuromuscular efficiency (Bigland-Ritchie et al., 1986a). The peripherally induced response from elevated intramuscular pressure in the deeper muscles, the larger active muscle mass, and the potential ischemia that may occur, all increase heart rate and blood pressure (Sundberg and Kaijser, 1992; Lewis, Taylor, Graham, Pettinger, Schutte, Blomqvist, 1983). Moreover, the perceived effort and the actual muscle force will adjust the efferent response from the central nervous system, increasing heart rate and blood pressure (Mitchell, 1990).

A combined increase in pulse rate and blood pressure will increase myocardial work. In addition, it is speculated that wearing the back belt during a moderate duration work task that involves a heavy weight of lift, a high lift frequency, and an awkward trunk posture will increase the potential for trunk muscle fatigue. However, the pulsed

IAP provided by the frequent lifting task and belt wearing may augment venous return and decrease cardiovascular strain (Christensen, Hamilton, Scott-Douglas, Tyberg and Powel, 1992). The effect of belt wearing on physiological strain must be quantified to allow discernment of the additional stress that the belt may impose on the worker during the performance of the asymmetric stoop lift.

2.2 Back Belt Wearing: Speculation on the Benefits of Back Belt Wearing and Presentation of Demonstrated Effects

Several studies have demonstrated mixed results on injury reduction with back belt wearing. Walsh and Schwartz (1990) evaluated back belt wearing and lift training effectiveness in preventing low back injury with 90 grocery warehouse workers. Belt wearing combined with training aided in the prevention of injury and decreased lost time incidents due to back injury, and did not decrease abdominal strength or production rate. High risk individuals with previous LBP also demonstrated a large decrease in reinjury rate with belt wearing and training.

Udo (1993) studied for 5.5 months, sixty male workers whose task it was to carry bags of rice, load the rice onto trucks, and drive the trucks. Udo found that wearing a preventive back belt significantly decreased the subjective incidence of LBP, and decreased the incidence of lumbar strains by 16.7% in the rice field work.

Mitchell, Lawler, Bowen, Mote, and Purswell (1994) performed a retrospective study of 1316 Air Force Base Civil Service workers over a six-year period. Leather belts were used in the first 2 years of the study and velcro belts were used thereafter. The researchers found that belt use was of limited effectiveness in preventing an initial injury, and provided almost no benefit in preventing a reinjury. Those workers wearing back belts had a lower incidence of lost time days, but the average cost per injury was higher.

Reddell, Congleton, Huchingson, and Montgomery (1992) evaluated lift training and belt use in 642 baggage handlers. Injury rates, restricted workdays, and workers compensation rates were not significantly different with the belt. The reinjury rate was higher for workers that had worn the belt and then ceased belt wearing.

Brown, Peek-Asa, Zhou, Samaniego, and Kraus (1996) performed a retrospective epidemiological study on the effect of using the industrial back belt (without any additional safety or training measures) on 36,000 workers of the Home Depot company across a period of six years. The workers had 31 injuries per million work hours without the back belt, and 20 injuries per million work hours with belt wearing, a 34% reduction. Time lost from work was not recorded. A potential confound of the study results was the increased use of pallets and forklifts during the study period. The effect of this implementation was not known. The researchers concluded that the back belt was of some benefit in reducing low back injuries, especially for male workers under the age of 35 and workers over the age of 55. The belt was not significantly effective in reducing injuries for male workers between 35 and 55 years of age.

Two major theoretical constructs exist that support a reduction in injury propagation with back belt wearing. The first and most prominent theory is an increase in intra-abdominal pressure (IAP) with back belt wearing, and the potential extensor muscle relief provided through the IAP mechanism. However, IAP has not been consistently shown to reduce trunk extensor muscle activity or low back compression forces (McGill, 1993; McGill, Norman and Sharratt, 1990). McGill (1993) speculated that the belt may aid in reducing the shear forces resulting from the weight of the torso and external load in the hands, and Aspden (1987; 1988; 1989) suggested that IAP may stabilize the spine, thereby reducing shear forces. Granata et al. (1977) demonstrated that some subjects had a significant reduction in anterior-posterior shear forces and low back compression forces with elastic back belt wearing during the asymmetric lift. Contralateral erector spinae muscle forces were only minimally reduced (4% MVC). However, some subjects demonstrated an increase in spinal loading with belt wearing. The authors suggested that the effect of back belt wearing on biomechanical response varies with the individual subject.

The second theory is that the back belt may reduce the range of motion and high-level motion components in the sagittal, lateral and coronal planes, and consequently reduces the compression and shear forces. Lavender, Thomas, and Andersson (1995) showed that the elastic back belt reduced trunk range of motion and high level motions, especially in the 90-degree lateral plane. Other researchers (Lantz and Shultz, 1986a, 1986b; Lander, Simonton, and Giacobbe, 1990; Lander, Handley, and Simonton, 1992) have demonstrated trunk range of motion reductions when orthopedic devices were worn. Granata et al. (1997) also demonstrated that the elastic back belt significantly reduced trunk range of motion and high level motion components.

Finally, it is possible that an augmentation of IAP with back belt wearing may increase or decrease venous return and cardiac output depending on the pressure gradient that exists between the thoracic cavity and the abdomen. Some studies have shown that sustained IAP increases stroke volume and cardiac output (Loyd, 1983; Robotham, Wise, and Bromberger-Barnea, 1985). Studies have also demonstrated that large, pulsed IAP elevations increase cardiac output and coronary blood flow (Christensen et al., 1992). However, an increase in cardiac output does not appear likely with lighter weights of lift and smaller active muscle masses and sustained exertions.

An increase in the weight of lift increases IAP, and an increase in the active muscle mass augments the muscle pump activity of the trunk muscles (Hargens et al., 1987). Rythmic IMP elevations increase blood flow to the central column (MacDougall et al., 1985). The amplitude of the muscle pump action and intermittent IAP elevations would be decreased with lower IMP. In addition, the effect of sustained elevated IAP levels on venous return is dependent on the intra-thoracic pressure. Large intra-thoracic pressures in combination with high IAP levels have been shown to decrease venous return (Takata, Wise, and Robotham, 1990). However, some researchers suggest that cardiac compression caused by the rise in intra-thoracic pressure would assist the heart in maintaining stroke volume if rhythmic contractions are interspersed with relaxation (MacDougall et al., 1994). In summary, heavier weights of lift, larger active muscle masses, and rhythmic IAP elevations combined with normal breathing appear to increase the likelihood of increased preload and stroke volume, and reduced pulse rate.

2.2.1 Intra-abdominal Pressure and Extensor Muscle Relief

Researchers and back belt companies have proposed that the back belt may reduce low back fatigue or increase lumbar muscle endurance, and thus reduce LBP and injury. The major mechanism underlying a speculated reduction in trunk muscle fatigue is the proposed increase in IAP with a potential reduction in trunk muscle extensor activity (Cresswell and Thorstensson, 1989; Gracovetsky, Farfan, and Helleur, 1985).

An increase in IAP occurs with the lifting of heavy weights, with an increase in the horizontal distance of the load from the spine, with increased trunk flexion, and with load acceleration and deceleration (Nachemson and Morris, 1964; Davis and Troup, 1964; Marras, Joynt, and King, 1985). The IAP created by the combined action of the pelvic floor, abdominal muscles, and diaphragm is theorized to act across the surface of the diaphragm imparting a thrust that is transmitted to the thoracic spine and the shoulders through the ribs, consequently reducing erector spinae activity and disc compression forces (Bartelink 1957; Morris et al., 1961; Davis and Troup, 1964).

Gracovetsky et al., (1977) suggested that the pulling of the lateral margins of the lumbodorsal fascia by the transverse abdominis and internal obliques results in a hoop tension, which can, with lumbar flexion and IAP, support the external load with a smaller compressive penalty. However, McGill and Norman (1987) concluded that the lumbodorsal fascia could not produce a significant extensor torque. Aspden (1989) speculated that higher IAP levels would aid in positioning the reaction moments of the upper body and load inside the arch of the spine, increasing the stability of the spine, and preventing high shear forces in the lumbar area.

Other research studies have inferred that activation of the abdominals and reciprocal activation of the extensors reduces any benefit that the increase in IAP may provide (McGill and Norman 1987; McGill et al., 1990; Krag et. al., 1986; Nachemson, Andersson, and Schultz, 1986). IAP activity has been shown to be related to increased activity in the rectus abdominis and abdominal obliques (Grillner, Nilsson, and Thorstensson, 1978), the external obliques (Kumar, 1980), and the transversus abdominis and internal obliques (Cresswell, 1994). An increase in abdominal muscle activity during the stoop lift may increase the stability of the trunk, but may also increase lumbar muscle activity and compression forces.

The diaphragm and transversus abdominis appear to increase IAP without the penalty of an increased flexor load (Cresswell, 1993). However, the transversus is more active with load handling in combination with the Valsalva maneuver (Cresswell and Thorestenson, 1989). The Valsalva maneuver is common in straining efforts such as are encountered with heavy loads or that may occur with fatigue. The Valsalva results in greater intra-thoracic pressure and IAP (Hemborg, Moritz, and Lowing, 1985; Grillner, 1978). Also, the Valsalva action has been shown to increase trunk muscle coactivation (Kumar and Davis, 1973; Krag, Gilbertson, and Pope, 1985), and to increase spinal compression (Nachemson, Andersson and Schultz, 1986). The Valsalva maneuver also increases pulse rate and blood pressure (Mantysaari, Antila, and Peltonen, 1984).

Cresswell, Grunstrom, and Thorstensson (1992) demonstrated that when isometric trunk flexor torques were imposed upon a maximal Valsalva, the activity of the transversus was constant while other abdominal muscles increased their activity.

However, the imposition of extensor torques on the Valsalva resulted in concomittant transversus muscle activity and a decrease in the activity of the other abdominal muscles. The transversus may be the primary muscle responsible for the changes in intra-abdominal pressure during extension, and the use of this muscle may not result in a flexor penalty.

Higher IAP levels are correlated with higher effort levels (Kumar and Godfrey, 1986) and with greater hip torque (Davis and Troup, 1964). Many studies demonstrate a high correlation of IAP with lumbar moments and extensor muscle activity (Grew, 1980; Kumar and Davis, 1983; Kumar, 1980). Greater muscle effort as occurs with fatigue or with heavy weight lifting will increase the muscle tension, intra-muscular pressure, coactivation, and the stiffness and compression of the vertebrae (McGill, Seguin, and Bennett, 1994). It appears that the magnitude of IAP that would be required to substantially offset the extensor load would not be attainable without significant activity in the abdominal muscles and large external loads (Morris et al., 1961).

Repetitive lifting of heavy weights in industry occurs, but not as frequently as the repetitive lifting of lighter weights. Marras, Lavender, and Leurgans (1993) reported average weight levels in industry of approximately 10.6 kg, and Snook (1981) reported average weights of lift of 15.9 kg. Lifting these weight levels while wearing an elastic belt would not require an abdominal exertion sufficient to obtain a significant IAP effect, unless muscle fatigue or a perceived stress was present. For example, Nachemson, Schultz, and Andersson (1983) reported inconsistent trends in IAP and EMG with corset, jacket and brace wearing during isometric flexion, extension, lateral bending and torsional tasks with load weights of 15 kg and 20 kg.

Hemborg, Moritz, and Lowing (1985) evaluated the effect of a non-elastic lumbar support and a leather weight-lifters belt on erector spinae activity in 20 male LBP patients. The patients lifted the torso with and without the belts. IAP increased with the devices before, during and after each lift. The activity of the abdominals and erector spinae was not significantly different with the belt. Moreover, low back muscle activity was increased when the patients lowered the trunk with the support belts on.

Kumar and Godfrey (1986) evaluated six types of spinal supports using load weights of 7 and 9 kg in symmetric and asymmetric stoop lifting. They noted an IAP level of 45 mmHg without the support. The IAP did not increase significantly with brace wearing, but was higher with corset wearing in the symmetric and asymmetric planes.

Hilgen (1990) had subjects lift loads less than and greater than those suggested by NIOSH from floor to knuckle height at a rate of one lift per minute, while wearing an elastic back support. The belt had little effect on IAP and not wearing a belt at all resulted in the lowest average muscle activity.

An elastic lumbosacral corset inflated to the limits of comfort has been shown to increase resting, standing IAP by 10 to 15 mmHg, but the peak pressure during lifting was not increased (Morris et al., 1961).

Harman, Rosenstein, Frykman, and Nigro (1989) had subjects wear a traditional weightlifter belt and perform a 90% one time maximum repetition (1-RM) dead lift. Peak, cumulative, and average IAP were significantly higher with the belt. Even with heavier weights, IAP may not be significantly increased with rigid belt wearing. Ligget (1989) had 12 elite or master ranked male competitive power lifters wearing competitive weight lifters belts lift 25, 50 and 75% of maximum dead lift weight. IAP and ITP were increased, but not significantly with belt wearing. Narrower stances resulted in higher IAPs.

Woodhouse, McCoy, Redondo, and Shall (1995) had subjects squat lift a box four times at 90% 1-RM with no belt, with a Pro-flex back support, a leather weight training belt, and a leather weight training belt with rigid abdominal pad. The devices did not significantly increase IAP or change lift kinematics.

An increase in IAP with belt wearing does not consistently result in a decrease in extensor muscle activity. Lander, Hundley, and Simonton (1992) evaluated the effect on IAP and mean EMG of the external oblique and erector spinae muscles of using a weight training belt during 8-RM lifts using the parallel back squat. IAP increased significantly from the first to the last trial and there was a 25-40% increase in IAP with the belt.

The increase in IAP may have been due to increased use of the hip extensors in the later trials. However, the back belt did not significantly alter the muscle activity of the trunk extensors. The activity of the vastus lateralis and biceps femoris was significantly greater with the belt, suggesting that the worker may use the hip and buttock muscles more with the belt than without in the squat lift.

Grew and Deanne (1982) evaluated the effect of elastic corsets on muscle activity in different postures and tasks and demonstrated that IAP increased at rest and with activity. However, the reduction in trunk muscle activity was inconsistent with corset wearing. Morris, Lucas, and Bressler (1961), Jones, McEnvoy, Mills, and Perkins (1985), Lander, Simonton, and Giacobbe (1990), and McGill, Norman, and Sharratt (1990) have all shown decreases in either flexor or extensor muscle activity, although the decreases were not always significant.

McGill et al., (1990) had six subjects wear a weightlifters belt, and an industrial back belt in lifting weights ranging from 72 to 90 kg using the squat lift and dead lift. They demonstrated that breath-holding with belt wearing and breath-expiring with belt wearing resulted in IAP levels that were significantly larger than those found with breath-holding alone. However, extensor muscle activity was decreased with breath-holding but was not further decreased when the belt was worn. The elastic industrial belt resulted in similar IAP levels as were demonstrated with the rigid weightlifter's belt and trunk muscle activity results were similar as well. This study showed that elastic back belt wearing can increase IAP with heavy static loading, but still a reduction in extensor muscle activity was not present.

Lander (1987) had subjects lift 70, 80 and 90% of 1-RM using the parallel squat while wearing a light leather belt or a heavy leather belt. The light weight belt significantly increased IAP at the 90% load level. The wider supports increased IAP more during the seated posture. Extensor activity increased with the heavier belt.

Studies have shown that subjects with LBP developed higher relative IAP levels with corset wearing than those individuals without LBP who did not wear the belts (Fairbank, O'Brien, and Davis, 1980). Other studies have demonstrated that IAP was not influenced by abdominal muscle fatigue, and that individuals with LBP developed IAP levels that were higher than non-LBP patients for the same weight of lift (Legg, 1981). Abdominal strength training has been shown to reduce the activity of the abdominal obliques during the generation of IAP (Legg, 1981). The corset may provide passive support to the abdominal wall and allow LBP workers or workers with weak abdominal muscles to generate IAP levels comparable to the normal worker with lower abdominal muscle activity. However, the corset is fastened at higher tension levels than the industrial back belt. The tighter tensions may potentially decrease the volume of the abdominal compartment and increase resting IAP to a greater extent than the typical back belt.

The elastic belt does not provide a rigid surface against which the abdominals can press. However, the stiffness of the elastic belt increases with bending and twisting (McGill et al., 1994). Also, in the fully stooped posture, an increase in IAP may create a flexor moment (Grew, 1980). It does not appear that the elastic back belt would be effective in reducing trunk muscle extensor activity through an increase in IAP, especially in the stoop lower combined with the Valsalva maneuver. However, the transversus, diaphragm and internal oblique muscles have been shown to increase IAP without a counterbalancing extensor force during trunk extension (Cresswell, 1993; Cresswell and Thorstensson, 1989; Cresswell, Grundstron, and Thorestensson, 1992). The effect of the back belt on the activity of these muscles is unknown. However, the restriction of the abdominal compartment through the wearing of the back belt may increase the efficacy of these muscles in elevating IAP, possibly without an additional flexor penalty. If this is the case, the wearing of the back belt could increase trunk stability without additional compression forces during trunk extension. This may provide a basis for the finding of Granata et al. (1987) that compression forces were reduced for some subjects with back belt wearing.

2.2.2 Back Belt Wearing Effect on Strength and Fatigue

Only a few studies have evaluated the effect of the back belt on strength and fatigue. Holmstrom and Moritz (1992) evaluated the effect of a lumbar spinal support on muscle strength and endurance in construction workers with LBP. After two months of daily use, the support did not influence trunk extensor strength or endurance, but trunk flexor strength was significantly increased. This demonstrates that the back belt increases the passive resistance to bending and increases flexor muscle activity.

Reyna, Leggett, Kenney, Holmes, and Mooney (1995) evaluated the effect of an industrial back belt on lumbar isometric strength using a lumbar extension machine and a dynamic lifting capacity test. Dynamic lifting capacity was measured using a progressive dynamic lift test. There was no significant difference in static strength or dynamic strength with belt wearing.

Woodhouse et al. (1990) evaluated the effect of lumbar/sacral supports on isokinetic lifting capacity during maximal capacity squat lifting trials. The results indicated that there was not a significant difference in peak lifting force, total muscular work, or average muscular power with the belt versus without the belt.

Ciriello and Snook (1995) evaluated the effect on lumbar muscle fatigue of lifting with and without a back belt. Subjects lifted for four-hour periods on four separate days. During two days the subjects lifted with an industrial back belt and on two days they lifted without a belt. A load 28.1 kg was lifted at a rate of four times per minute from the floor to a height of 76.2 cm. After each lifting session, isokinetic endurance tests were performed and electromyography of three back muscle pairs at the L1, L2, and L4 was obtained. Also, a Borg scale assessment and survey were performed. Isokinetic endurance, median frequency slope, Borg scale measures and survey responses were not significantly different between the belt and no belt treatments. The trunk can use numerous muscle groups to generate extensor torque. In addition, it is more likely that the deeper paraspinal muscles of the trunk would fatigue before the superficial trunk muscles.

However, two studies using a psychophysical approach have indicated that the maximum acceptable weight of lift is increased with back belt wearing (McCoy, 1988; Bowen, 1993). But, Amendola (1989) theorized that the psychophysical approach may not be an appropriate technique to assess the back belt's effect on acceptable lift capacity due to the Hawthorne effect. The results suggest that the back belt may increase the perceived stability of the torso. Alterations in afferent and efferent stimuli from the somatosensory system may occur such that the worker feels more secure with heavier loads while wearing a back belt. These sensations could arise from the cutaneous, muscle or joint sensors of the trunk.

It is speculated that the effect of the back belt on physiological strain and psychophysical lifting capability is related to the tension set in the belt. Belt tension levels appear to vary depending on the task conditions (Bowen, Purswell, Schlegel, and

Purswell, 1995). An effort should be made by researchers to measure and report the tensions used in back belt studies (Bowen et al., 1995). Also, the method of measuring and setting belt tension has varied with the researcher.

McCoy et al. (1988) allowed the subjects to set their own tension and then measured the pressure of the belt against the abdomen during lifting. Contreras et al. (1995) controlled tension in the belts through the calibration of 25 mmHg of pressure in a rubber bladder placed under the belt during belt tensioning. The bladder was removed following tension setting. Bowen et al. (1995) performed a study to determine preferred belt tension and MAWL, at the preferred tension, minimal tension and with no belt for floor-to-knuckle and knuckle-to-shoulder lifting tasks. Subjects adjusted the tension in an OK-1 505 belt to a level that was comfortable for repetitive lifting of a 10.8 to 12.5 kg load for a 20-minute trial at a rate of 4 lifts per minute. Each trial was replicated. Subjects were told to adjust the belt straps as often as necessary in order to determine the preferred tension for the lifting task. After each trial, the position of the overlap of the outer belt strap was marked, and the outer belt strap was then unfastened. A Velcro hook attached to a load cell was used to pull the belt strap to the tensioned position, and the tangential force (hoop stress) was measured. The mean of the tensions measured for three trials was defined as the subject's preferred tension. Each subject determined maximum acceptable weight of lift (MAWL) using the preferred tension. The mean preferred tensions for the floor-to-knuckle lift, and knuckle-to-shoulder lifts were 5.8 kg, and 6.45 kg, respectively. Subjects tensioned the back belts to lower tensions for the floor-to-knuckle lift. Subjects lifted 13 to 18% more weight with the belt at the preferred tension, than at the minimum tension and with no belt. The results of this study suggest that workers may cinch the belt to different tensions depending on the task parameters, and the level of belt tension affects the perception of security.

2.2.3 Passive Belt Stiffness, Trunk Motion, and Trunk Muscle Activity

A second potential mechanism by which the back belt is theorized to reduce low back injury is through an increase in passive resistance to trunk movement. Research indicates that three-dimensional trunk velocity is associated with low back pain in industry (Marras, Lavender, and Leurgans, 1993). Studies have shown that the rigid back belt increases stiffness during bending in the lateral and coronal planes but not in the sagittal plane (McGill, Seguin, and Bennett, 1994).

It is suspected that the reason the rigid belt did not produce an increase in stiffness in the sagittal plane is that the abdominal muscles reflexively contracted inward during flexion. Also, the narrow rigid or elastic belt resides between the thorax and iliac crest and does not conjoin the pelvis with the thoracic region of the spine. Consequently, the rectus abdominis fibers would curve inward during contraction, and the thorax and lumbar spine would be free to move during flexion. In addition, sagittal bending is accompanied by pelvic rotation after the first 30 degrees. These events may reduce the passive resistance afforded by the belt, and the resistance to bending in comparison with asymmetric lifting. In sagittal plane stoop lifting, the muscles primarily contract in the anterior-posterior plane. However, in asymmetric stoop lifting the lines of action of the rectus abdominis and ipsilateral obliques would tend to bulge outward increasing belt strain and movement resistance.

In support of the previous statements, Lavender et al. (1995) demonstrated that in an asymmetric lift, the average and peak velocity, acceleration and range of motion were reduced in the lateral and coronal planes with elastic belt wearing if foot movement was restricted. The motion responses decreased more with belt wearing in the 90-degree lateral plane than in the smaller displacement angles in the lateral plane. Variation in trunk muscle activation patterns was lower with belt wearing, and it was speculated that this might result in repetitive stress to the same muscle groups. In a related study, Magnusson, Pope, and Wilder (1996) found that wearing a lumbar support changed the pattern of motion and reduced the amount of flexion in comparison with not wearing a support during lifting.

Walters and Morris (1970) investigated the effect of corsets and braces on trunk muscle activity during standing and walking. At rest, the corsets or braces either decreased or had no effect on abdominal muscle activity. Extensor muscle activity was not affected at rest. However, during a fast walk, trunk muscle activity was increased. It is speculated that additional trunk muscle activity was required to overcome the passive stiffness of the corset. Grew and Deanne (1982) demonstrated that rigid and long corset and brace wearing decreased spinal movement.

Hilgen (1990) demonstrated that subjects lifted faster with the Pro-Flex back belt, and that the middle portion of the lift was fastest with the belt and the end of the lift was the slowest. The elastic belt resulted in the lowest erector spinae and external oblique activity when the trunk flexion angle was less than 10 degrees, with the most trunk muscle activity at the greater flexion angles.

Granata, Marras, and Davis (1997) evaluated the effect of several belt types on trunk motion, muscle activity and predicted lower back compression forces during symmetric and asymmetric lifting. The lateral plane angle was 60 degrees and the lateral plane height was 70 cm. The wide elastic belt was the only belt that significantly reduced the range of trunk motion, the high level motion in the cardinal planes, trunk muscle activity, and lower back compression and anterior-posterior shear forces. Mean compression forces were reduced 7% in the symmetric lift and 12% in the asymmetric lift, although some subjects experienced an increase in spinal loading with back belt wearing.

The decrease in trunk motion was associated with an increase in pelvic motion. The activity of the left erector spinae was reduced by 4% of MVC, and the activity of the rectus abdomini was reduced. The activity of the left internal oblique was increased. Granata et al. (1997) speculated that the reduction in spinal load was due to the redistribution of muscle forces. They suggested that the wider elastic belt conjoins the pelvis with the thoracic region of the spine providing greater resistance to trunk flexion, and lower coactivation. The worker might use more pelvic tilt rotation than lumbar rotation while wearing a wide elastic back belt. However, a task design that requires maximum lumbar and pelvic flexion will force the worker to move against the added resistance of the back belt.

Lantz and Schultz (1986a, 1986b) demonstrated that the elastic corset restricted trunk motion, but the effects on trunk muscle activity were inconsistent. Lander, Hundley, and Simonton (1992) evaluated the effect of a weight training belt on subjects during a parallel squat lift. There was a faster velocity of lift with the belt, and in later trials. Lander, Simonton, and Giacobbe (1990) evaluated subjects wearing a light-weight belt and heavy belt during parallel squat lifts. Lifts were performed faster with the belt, and belt wearers had greater relative hip extension than knee extension at the beginning of the lift. These results suggest that the belt wearer may lift with the more powerful hip muscles, resulting in a faster lift velocity.

Some authors suggest that workers may exhibit more trunk flexion with belt wearing (Lander et al., 1990), while others have empirically observed reduced flexion during lifting (Magnusson, Pope, and Wilder, 1996). The former results may be due to the type of belt that was used. Also, the belt may provide sensory stimuli that provide certain subjects with a false-sense of security. Bourne and Reilly (1991) theorized that the rigid belt can reduce the degree of hydrostatic compression that occurs in the spine during work. This may prevent injury to the endplates, but disc strain may increase when the spinal discs are resistant to bending.

2.2.4 Back Belt Effect on Venous Return and Cardiac Output

An examination of back support device studies revealed that 10 of the 12 prior studies demonstrated an increase in IAP with back support wearing, and 6 resulted in a significantly large positive differential IAP. A rhythmic intra-abdominal pressure augmentation with back belt wearing may provide "muscle pump" action to the abdominal cavity increasing venous return to the heart, thereby increasing stroke volume and reducing heart rate. This action combined with increased IMP will promote a greater venous return.

Luca, Cirera, Pagn, Feu, Pizcueta, Bosch, and Rodes (1993) discovered that sustained increases in IAP significantly reduced cardiac output due to a reduced blood flow in the inferior vena cava associated with an increase in systemic vascular resistance and a mild increase in mean arterial pressure. After the IAP was released, cardiac output increased and systemic vascular resistance decreased.

Christensen, Hamilton, Scott-Douglas, Tyberg, and Powell (1992) applied pulsed compression (25, 50 and 100 torr) to the abdominal cavity of dogs prior to chest compression. The largest pulsed abdominal compression applied from late diastole to late systole provided the greatest improvement in cardiac output and carotid and coronary blood flow. This pattern is similar to what occurs in weight lifting. Abdominal compression is increased at the beginning of the lift and then the chest muscles are increasingly fixated by the activity of accelerating the external load.

Respiratory patterns and breath-holding affect venous return (Gay and Rothenburger, 1991). An increase in abdominal pressure during inspiration increases venous return, while during expiration an IAP increase decreases venous return. Increased IAP in combination with intra-thoracic pressure is associated with the Valsalva maneuver. The Valsalva involves forced expiration against a closed glottis which momentarily increase intra-thoracic pressure, and arterial blood pressure. However, if the exertion is sustained, venous return and cardiac output decrease, and blood pressure declines. Reflex mediated increases in pulse rate and vascular resistance occur, and blood pressure increases (Gay and Rothenburger, 1991). At the termination of the Valsalva, venous return and cardiac output return to normal, but blood pressure remains elevated (Gay and Rothenburger, 1991).

Loyd (1983) demonstrated that IAP levels as low as 5 mmHg increased venous return if the vascular volume was high. Diebel, Dulchavsky, and Wilson (1992) suggested that the rise in IAP that can affect cardiovascular function is extremely variable, but several studies indicate levels exceeding 25 mmHg can interfere with cardiovascular and pulmonary function. Significant hemodynamic effects have been associated with steady-state IAP increases of 40 mmHg or larger in dogs (Kashtan, Green, Parsons, and Holcroft, 1981) and in humans (Burchard and Slotman, 1985). Barnes, Tomoshige, and Scully (1974) found that as IAP was increased to 40 mmHg, there was a 36% reduction in cardiac output in piglets. Masey, Koehler, Rock, Pepple, Rogers, and Traysetman (1985) also demonstrated that sustained IAP decreased venous return.

Takata, Wise, and Robotham (1990) advised that there is conflicting evidence on the effect of IAP on venous return and suggested that the effect varies with vascular conditions related to the inferior vena cava pressure at the thoracic inlet and the transmural pressure at the abdominal inlet required for closing. An elevated IAP decreases the distension range of the diaphragm into the abdominal compartment, and causes pressure waves to be transmitted to the arteries and heart, reducing venous return and increasing peripheral resistance during expiration but increasing blood flow in inspiration. However, IAP either increases or decreases venous return depending on the initial systemic vascular volume. A low vascular volume results in a decrease in venous return, while a high vascular volume increases venous return.

High IAP levels are only achieved with moderate to heavy weights of lift, and with the Valsalva maneuver. Tight abdominal binding elevates average IAP and peak IAP. Morris et al. (1961) reported IAP levels of 9 mmHg with no external loading, 30 mmHg with load magnitudes of 26 kg, and 64 mmHg with weights of lift of 45 kg in the dynamic leg lift with a corset. An inflatable bladder increased resting IAP by 10 to 15 mmHg. An IAP level of this magnitude will not likely result in a hemodynamic effect during rest.

2.3 Task Contra-indications to Back Belt Wearing

At least five hypotheses can be formulated to contraindicate belt use during high frequency, asymmetric stoop lifting of low-lying loads for moderate durations.

1. The back belt may increase IAP, decrease venous return and cardiac output, and increase cardiovascular strain,

2. The nature of the asymmetric stoop lift technique may diminish the potential IAP benefits associated with wearing a back belt,

3. The back belt increases resistance to trunk movement in bending and twisting. This may increase the postural maintenance component, the physiological workload, pulse rate, and systolic blood pressure,

4. The back belt might apply external pressure to the compartmental paraspinals, thereby increasing intramuscular pressure. This combined with an increase in work intensity due to the resistance of the back belt might increase IMP during work, and muscle relaxation pressures during recovery,

5. The higher frequencies of lift in combination with back belt wearing might not allow enough time for muscle recovery between lifts. This might increase muscle relaxation pressure, recovery pulse rate and blood pressure. Also, longer periods of lifting may increase the likelihood of local muscle fatigue, and higher blood pressure levels.

Section 2.3.1 below presents the functional mechanics of the elastic back belt, and discusses how the belt resists trunk motion and increases external pressure. Section 2.3.2 describes prior back belt studies that have evaluated the effect of the back belt on physiological response. Section 2.3.3 describes how the nature of the asymmetric stoop lift may prevent an increase in IAP with belt wearing from being beneficial. Section 2.3.4 describes why the use of the back belt may increase cardiovascular strain. Section 2.3.5 explains how the back belt may increase physiological workload, and Section 2.3.6 posits how wearing the back belt may increase intramuscular pressure and physiological strain.

2.3.1 The Functional Mechanics of the Industrial Elastic Back Belt

The resistance to trunk movement offered by the back belt increases with the trunk bending angle (McGill, Sequin, and Bennett, 1994). A wide belt might conjoin the pelvis to the thoracic spine (Granata et al., 1997), and this further inhibits lumbar spine flexion. Displacement of the belt straps during bending will increase belt stiffness. A stiffness effect is observed more with asymmetric lifting than with symmetric lifting. This might be due to the more coupled lines of action of the muscles in these planes. As the trunk is flexed asymmetrically, the ipsilateral obliques, rectus abdominis and erector spinae bulge outward due to their shortened and more oblique lines of action. The hip on the contralateral side is abducted slightly. Individuals with large abdominal girths that protrude in the normal standing posture might experience more resistance during lateroflexion due to the bulging outward of the rectus abdomini. An increase in belt stiffness increases circumferential stress, resistance and physiological work. Equation 2.1 demonstrates the relationship between belt tension and the circumferential stress in the belt.

$$\text{Belt Tension} = \text{Belt Thickness} * \text{Belt Width} * \text{Belt Stress} \qquad \text{(Equation 2.1)}$$

The stress in the belt is related to the pressure of the belt against the trunk musculature by Equation 2.2.

$$\text{Belt Pressure} = \text{Belt Stress} * \frac{\text{Belt Thickness}}{\text{Belt Radius of Curvature}} \qquad \text{(Equation 2.2)}$$

Equation 2.2 shows that as the circumferential stress increases, the normal pressure of the belt against the trunk muscle surface increases. Individuals with protruding abdomens experience an increase in abdominal girth during lateroflexion. An increase in belt strain will occur with lateroflexion. An increase in belt strap displacement will increase tensile force and the pressure of the belt against the trunk musculature. The pressure augmentation will vary along the trunk muscles due to the different degrees of rigidness of the trunk surface. The supple nature of the abdomen will allow the belt to press into its structure, whereas, the rigidness of the dorsal muscles will not. This will increase the friction forces of the belt against the paraspinals, and may increase the external pressure of the belt over these regions. In addition, high frequency lifting, fatigue or belt wearing may increase the velocity and acceleration of the trunk. A more rapid belt strain may increase the magnitude of the force impulse required by the trunk muscles.

2.3.2 Prior Back Belt Studies and Physiological Response

Four prior back belt studies have evaluated the effect of the back belt on physiological strain. Aleksiev, Magnusson, Pope, Coblin, and Luoto (1996) found that standard flexible back supports did not affect the cardiovascular responses of normotensive subjects during isometric or dynamic lifting at 50% MVC. Evidently in the task selected, the belt tension did not significantly alter IAP and ITP. This is not unusual since the use of the Valsalva is frequently increased with fatigue but without fatigue is usually not necessary with loads less than 1-Repetition Maximum (MacDougall, Tuxen, Sale, Moroz, and Sutton, 1994).

Hunter, McQuirk, Pearman, Thomas, and Arrington (1989) demonstrated that the weight-lifters belt increased pulse rate, systolic blood pressure and myocardial work during an aerobic cycling task and systolic blood pressure and myocardial work in the 60% 1-Repetition Maximum isometric dead lift. The subjects exercised on the cycle ergometer at 60% VO_2. The increase in pulse rate and systolic blood pressure during the cycling task might have been due to an increase in IMP, because pulse rate and systolic blood pressure were higher with belt wearing prior to exercise. The increase in physiological strain during exercise might also have been due to an increase in physiological workload due to belt resistance during cycling.

The increase in blood pressure in the dead-lift with the rigid belt can be attributed to the mechanical compression of the vasculature, and the pressor response combined with the Valsalva maneuver (MacDougall, Tuxen, Sale, and Moroz, 1985). Belt wearing augmented IAP and ITP during the performance of the Valsalva maneuver. Pulse rate did not significantly increase with belt wearing in the dead lift, but the product of pulse rate and systolic blood pressure significantly increased. Pulse rate normally increases with the Valsalva, but returns to resting level more rapidly than blood pressure at the termination of the Valsalva maneuver (Gay and Rothenburger, 1991).

While these tasks are atypical industrial work tasks, the results suggest that wearing a tightly cinched belt during the lifting of a heavy load while expiring against a closed glottis will increase cardiovascular strain. The results from the cycling task suggest that the belt may increase intramuscular pressure and physiological work. The task was performed at a high percentage of maximum aerobic capacity causing cardiac output increases to be augmented solely by increases in pulse rate, and not stroke volume.

In another recent study, Contreras (1995) evaluated the effect of three elastic belts on cardiovascular response during a standing task and in a sagittal plane lifting task performed at a frequency of 4 lifts per minute with a load weight of 6.5 kg (NIOSH RWL) for 8 minutes. The belt tension was controlled through calibration of 25 mmHg of pressure in a rubber bladder placed under the belt during belt tensioning. The bladder was removed upon calibration. Four free-style lifting tasks were used, a floor-to-knuckle and floor-to-shoulder, lift and lower.

Differential blood pressure and pulse rate were not significantly different in the standing or lifting task conditions with belt wearing. The lack of a pulse rate response in the standing task would be expected since the belt did not provide enough external pressure to increase IMP or to displace blood from the encased trunk muscles. In the lifting tasks, the frequency of lift was set at the NIOSH (1991) lower frequency bound for the use of the physiological approach, and the period of lifting was short. The weight of lift was not heavy enough to warrant the use of the Valsalva maneuver and differential IAP was evidently not significantly increased with belt wearing in this lifting task. The subjects lifted in the sagittal plane so the resistance effect of the belt on physiological workload was lower than in lateroflexion. Any increase in cardiac output was augmented by an increase in stroke volume since wearing the belt probably aided in pushing blood back to the heart. In addition, the intensity and duration of the work was not sufficient to significantly increase the muscle volume and IMP. Therefore, the external pressure of the belt did not significantly affect intramuscular pressure and muscle relaxation pressure between lifts. These conditions would support the lack of a pulse rate or blood pressure change with belt wearing. In a more recent study, Madala (1996) evaluated the effect of an industrial back belt on pulse rate, blood pressure and recovery duration during a knuckle-to-shoulder arm lifting task. Subjects lifted 35% of 1-RM at a rate of 6 lifts (lowers) per minute for five 4-minute periods and then rested until pulse rate recovered to 20 beats above the resting pulse rate. The subjects rested for 9 minutes prior to each lifting session and the mean heart rate during this interval was used as the resting heart rate. Pulse rate was continuously measured every 15 seconds. A lower heart rate limit (20 beats per minute above resting heart rate) was used to identify the end of the recovery period. The mean of the systolic blood pressure measured at four, seven and ten minutes during the initial rest period was used as the baseline blood pressure. The work pulse and blood pressure measures were normalized with respect to the resting levels for each subject for each session. Pulse rate was measured continuously during recovery, and blood pressure was measured immediately after the last lift and at the end of every recovery period. The average weight lifted was 10.7 kg (23.73 lbs). This weight was slightly lower than the NIOSH RWL (for lifting only) of 12.7 kg (27.89 lbs). However, it was considerably higher than the suggested NIOSH RWL for both lifting and lowering.

The results of the study indicated that pulse rate, blood pressure, and recovery times did not differ significantly between the two belt conditions. However, the weakest subject lifted the lightest weight and experienced a significant positive differential work pulse with belt wearing, while the strongest subject lifted the heaviest weight and experienced a significant negative differential work pulse.

Stronger individuals experience higher IMPs than weaker individuals during a nonfatiguing lift task at the same percentage of MVC (Heyward and McCreary, 1975). A larger IMP would augment the muscle pump and aid in returning blood to the central column. The positive differential work pulse for the weaker subjects might be due to an increase in physiological work or static load with belt wearing. The lack of a differential blood pressure effect suggests that the workload intensity was not high enough to increase differential muscle volume or IMP with belt wearing. Also, the workload in combination with belt wearing did not increase IMP or IAP enough to significantly affect hemodynamic response.

2.3.3 Back Belt Wearing, Asymmetric Stoop Lifting, IAP, and the Valsalva Maneuver

A common lifting technique used in industry is the stoop lift. The stoop lift has a lower physiological cost than the squat lift because the worker does not have to vertically raise the weight of the trunk, and the weaker, untrained quadriceps are not as stressed. In a stooped posture, the body weight and weight of the load ventral to the L5/S1 disc results in mainly a shearing force with lowered compression in comparison with the squat lift (Grew, 1980).

Also typical in the industrial environment is the asymmetric stoop lift. IAP is affected by the posture of the trunk. Some studies have shown that IAP is higher with the trunk extended (Grew, 1980) while other studies have shown that IAP is increased with the trunk flexed (Davis and Troup, 1964). Still other researchers have found that

IAP is increased with lateral bending and twisting (Andersson, Ortengren, and Nachemson, 1977; Bartelink, 1957), and that IAP is highest in the combination of rotation and flexion (Andersson et al., 1977).

Andersson et al. (1977) concluded that IAP and disc compression forces increased with trunk rotation at all flexion angles. The larger compression force reflects greater trunk muscle coactivation. Also, the myoelectric activity of the extensors are larger in trunk rotation than with lateral bending of the trunk. IAP is also larger with the trunk rotated and flexed to greater angles (Andersson et al., 1977).

Kromodihardjo and Mital (1985a) and Kumar (1980) demonstrated that IAP increased with asymmetric lifting. Kumar (1980) had subjects lift a weight of 10 kg from the ground to knuckle height in the sagittal and non-sagittal planes. In the ground-to-knuckle lift in the lateral plane, the peak IAP was 55 mmHg and the sustained average IAP was 35 mmHg. The results indicated that IAP was larger during lateral lifting and in ground-to-knuckle lifts than in ground-to-shoulder lifts (35 mmHg versus 25 mmHg). The sustained IAP levels were highest for the lateral lifts in all conditions. IAP was highly correlated with average external oblique activity and erector spinae activity for all of the planes of lifting. However, a high level of antagonistic muscle activity was found in the abdominals and posterior back muscles in lateral flexion and axial rotation.

Other researchers have reported decreases in IAP during twisting but increases during flexion (Marras and Mirka, 1991a; Marras and Mirka, 1991b). Marras, King, and Joynt (1986) demonstrated that IAP decreased with greater degrees of asymmetry combined with smaller trunk flexion angles. However, trunk muscle coactivation increased with greater trunk asymmetry and flexion. The difference in muscle activity between the right and left erector spinae increased with trunk asymmetry. This study indicated that larger antagonistic muscle activity occurs with asymmetric trunk loading, and that IAP may not be an effective mediator of the increases in compression and shear force that result from the increase in trunk muscle coactivation with twisting.

Garg and Herrin (1979) demonstrated that IAP was higher in the stoop lift than in the squat lift, but Troup, Leskinen, Stalhammer, and Kuorinka (1983) found the opposite. With trunk flexion, the IAP moment increases due to the larger antero-posterior diameter of the trunk. This results in potentially larger extensor muscle relief. However, the external moment, and tension in the erector spinae is larger in a stooped posture. Also, the shorter muscles of the rectus abdominis have diminished effectiveness in producing active tension in a stooped posture (Cresswell, 1993). It is possible that the passive stiffness of the abdominal muscles and the restricted abdominal volume due to the inward contraction of the abdominal muscles in the flexed posture aids in elevating IAP (Cresswell, 1989).

The internal and external obliques, transversus abdominis increase IAP during stoop lowering (Cresswell, Grundstrom and Thorstensson, 1992). However, the external obliques have an anterior and lateral force component. This has been shown to increase the flexor and lateral moments that would need to be balanced by the erector spinae and internal obliques (Cresswell et al. 1992), and increase trunk muscle coactivation (Pope, Anderson, Broman, and Svenssoin, 1986). The activity in all of the muscles and IAP increased during trunk lowering with an additional load (Cresswell, 1993). Researchers have also shown that IAP may produce a flexor moment in the stooped posture if the rib cage is anterior and caudal in relation to the pelvis in this posture (Greg and Herrin, 1979; Grew, 1980).

The volume of the thoracic cavity is also decreased in a stooped posture and the volume of air in the lungs for compression is decreased. This lowers the level of ITP that can be generated. The lower ITP level may decrease the IAP magnitude that can be obtained at the beginning of the lift.

IAP may not provide extensor muscle relief at the beginning of the stoop lift. The activity of the erector spinae is low in the fully flexed posture due to the support of the trunk by the ligamentous system. Consequently, the majority of the anterior shear force is due to the external obliques and interspinous and supraspinous ligaments, and less posterior shear results from the activity of the erector spinae. Peak elevations in IAP occur at the beginning of the lift (Andersson et al., 1977) when the ligamentous system is most active. The peak shear force occurs immediately prior to the peak muscle moment (Potvin, McGill, and Norman, 1991).

IAP has not been shown to be higher at 90 degrees of flexion versus 60 degrees of flexion, even though the external moments are larger (Morris, Lucas, and Bressler, 1961). These results suggest that IAP might aid in increasing spine stability during the lift, but its ability to reduce extensor muscle activity is dubious.

Belt wearing during stoop lifting may augment IAP, especially at the beginning and termination of the lift and at the extremes of axial rotation and lateral bending. An increase in IAP would most likely occur through the reduced abdominal compartment volume, the pressing of the abdominal muscles against the belt, and through the use of the Valsalva maneuver, which has been demonstrated to increase trunk muscle coactivation.

Pope, Anderson, Broman, and Svenssoin (1986) demonstrated that the Valsalva contracts the internal and external obliques. This would potentially negate any IAP extensor muscle relief. However, Creswell, Grundstrom, and Thorstensson (1992), and Cresswell (1993) showed that the external obliques decreased their activity, and the internal obliques, transversus and diaphragm muscles increased their activity to elevate IAP during torso extension with progressively increased external loads. The transversus and diaphragm muscles do not appear to augment the flexor component. The effect of wearing the back belt on the mechanical efficiency of these muscles has not been examined. Also, an increase in IAP with belt wearing at the beginning of the stoop lift would not appear to reduce the activity of the erector spinae. The first 30 degrees of extension is accomplished by the hip extensors, and the erector spinae would not benefit directly from an increase in IAP. The primary extensor muscle benefit from IAP will occur in the middle portion of the lift, when the erector spinae maintains the most favorable length-tension position. However, the stiffness of the belt may be reduced in the upright posture, and with this decrease in stiffness is a reduction in the external pressure that the belt applies to the abdominal muscles. If belt wearing increases IAP during the asymmetric stoop lift then shear forces may be reduced (Aspden, 1988). However, an increase in trunk muscle coactivation or an increase in the activity of the transversus abdominis or internal obliques would be expected. Granata et al. (1997) demonstrated that anterior-posterior shear forces were reduced in the asymmetric lift when subjects wore an elastic back belt. They attributed the decrease in shear force to a redistribution of trunk muscle forces with belt wearing. The internal oblique activity was slightly increased, the rectus abdomini activity was decreased and the erector spinae activity was minimally reduced (4% of MVC). The muscle force redistribution may have been due to the decrease in lumbar spine motion and the increase in pelvic motion with belt wearing. The diaphragm and transversus muscles and IAP may have also contributed, but this is not known.

One prior back belt study has addressed the relationship between back support wearing and IAP during stoop lifting. Another back belt study addressed the effect of the belt on IAP during the asymmetric stoop lift, and a third evaluated the effect of repetitive heavy lifts with belt wearing on IAP. A final study has evaluated the effect of rigid and elastic belt wearing and breath-holding on IAP.

Hemborg, Moritz, and Lowing (1985) evaluated the effect of the non-elastic lumbar support and the leather weightlifters belt on IAP as each of 20 male subjects lifted and lowered their unloaded carriage 20 times using the stoop lift. IAP was increased with the devices before, during and after each lift. ITP was only slightly increased with belt wearing. The activity of the abdominal obliques and erector spinae were increased in the torso lowering task with belt wearing.

Kumar and Godfrey (1986) examined the effect of six different types of braces on IAP during the symmetric and asymmetric stoop lift as subjects lifted loads ranging from 7 to 9 kg in weight. The peak IAP with the brace was 45 mmHg for the males and 20 mmHg for the females. IAP was not significantly increased with brace wearing.

Lander, Hundley, and Simonton (1992) had 5 subjects wear a heavy weight training belt as they performed 8 consecutive parallel back squats. Belt wearing resulted in a faster velocity of lift, and IAP increased significantly from the first to the last trial. Greater knee and hip extension were associated with belt wearing. The belt promoted the use of the hip extensors and leg muscles. However, trunk muscle activity was not reduced.

McGill, Norman, and Sharratt (1990) had 6 subjects wear a weightlifters belt, and an industrial back belt in lifting weights ranging from 72 to 90 kg using the squat lift and dead lift. McGill et al. (1990) demonstrated that breath-holding with belt wearing or breath-expiring with belt wearing resulted in IAP levels that were significantly larger than those found with breath-holding alone. Trunk activity increased with the belt, but only the abdominal oblique activity was significant. The extensor muscle activity was decreased with breath-holding, but was not decreased further when the belt was worn. The elastic industrial belt resulted in similar IAP levels as were demonstrated with the rigid weightlifter's belt. The trunk muscle activity results were similar as well. This study shows that elastic back belt wearing can increase IAP with heavy static loading, but still a reduction in extensor muscle activity is not present.

The lighter weights of lift combined with belt wearing do not result in a significant increase in IAP (Kumar et al., 1986). The rigid belt results in an increase in trunk muscle activity (Hemborg et al., 1985) due to the resistance afforded by the belt during bending. Belt wearing causes the individual to lift more with the hip and buttock muscles, however, trunk muscle activity is not consistently reduced (Lander et al., (1992; Granata et al., 1997). The elastic back belt significantly increases IAP above that associated with breath-holding alone when heavy weights are lifted, but the belt does not decrease the activity of the trunk extensors (McGill et al., 1990).

Back belt wearing has been shown to increase systolic blood pressure during the dead-lift when the Valsalva is performed (Hunter et al., 1989). The Valsalva-type maneuver is more likely to occur at the higher percentages of MVC, and as the endurance limit is approached (Ng, Agre, Hanson, Harrington, and Nagle, 1994; Fleck and Dean, 1987). Initially, blood pressure is increased with the Valsalva maneuver. If the Valsalva is sustained, blood pressure declines, but at the cessation of the exertion, blood pressure is temporarily elevated and pulse rate decreases (Pate, 1991). An increase in the force of contraction, the relative muscle mass or fatigue will result in a progressive increase in blood pressure during strenuous lifting. A portion of the blood pressure increase is attributable to the Valsalva maneuver. The pressor response and mechanical compression of the vascular system also contribute to the increase in blood pressure with heavy weight lifting (MacDougall et al., 1985).

MacDougall et al. (1985) showed that when subjects performed to failure at 80, 90, 95 and 100% of maximum in arm and leg curls and overhead presses that systolic and diastolic blood pressure were extremely elevated during the contraction phase and declined rapidly as the weight was lowered. Pressures increased progressively with each lift. Immediately following the last repetition, both systolic and diastolic pressures fell below pre-exercise levels before returning to normal after approximately 10 seconds. Other studies have shown that blood pressure increases with successive heavy lifts (Linsenbardt, Thomas, and Madsen, 1992) and that it may remain elevated after the lift is completed (Fox, Crowley, Grace, and Wood, 1966). Holding the breath during the concentric phase of the lift results in the highest blood pressure, followed by exhalation, and inhalation (Linsenbardt et al., 1992). The most trained and heavily muscled subjects have been shown to have systolic blood pressure values considerably higher than the other subjects (MacDougall, Tuxen, Sale, Moroz,. and Sutton, 1994).

The Valsalva may benefit the lifter by stabilizing the spine and improving performance (MacDougall et al., 1985). The use of the maneuver is cautioned against by some researchers because of the potential for creating an ischemic heart condition, as well as an elevated left ventricular pressure head (Lisenbardt et al., 1992). Upon release of a heavy load, a perfusion of the vasodilated muscle mass occurs, as well as a transient undershoot initiated by the baroreceptor and cardiopumonary reflexes responding to the elevation in blood pressure. A larger active muscle mass increases the vasodilative capacity. This undershoot may compromise cerebral blood flow and produce transient symptoms of dizziness (Vitcenda, Hanson, Folts, and Besozzi, 1990) and cause the weightlifter to feel faint (MacDougall et al., 1985). However, MacDougall et al. (1985) suggests that the maneuver appears to be beneficial when rhythmic heavy lifts are performed. He suggests that the rise in intrathoracic pressure with the Valsalva assists the heart in maintaining or augmenting stroke volume, especially if heavy weights are lifted. The rhythmic lifting of a fixed percentage of static lift strength with a large active muscle mass provides a powerful muscle pump that overcomes the intrathoracic pressure to provide adequate diastolic filling. Blood pressure increases to overcome intramuscular pressure. This aids venous return and maintains stroke volume so that cardiac output can be increased (Miles et al., 1987). Venous return and stroke volume may be increased due to the muscle pump during the lowering portion of the lift (Miles et al., 1987). Stroke volume during exercise is determined by ventricular preload, afterload and contractile state (Lewis et al., 1984). Stroke volume increases with a larger active muscle mass during lifting due to the Starling effect (Lewis et al., 1983).

Although blood pressure increases, the Valsalva may provide a protective function for the heart and vessels of the brain (MacDougall et al., 1985). The effect of the elevated blood pressure is unknown. It does not appear to cause increases in resting blood pressure (Astrand, Ekblom, and Messin, 1965), but may cause an increase in myocardial hypertophy with an unknown benefit (Harris and Holly, 1987) or it may lead to severe headaches (Carswell, 1984).

2.3.4 Repetitive Resistance Work and Risk of Myocardial Infarction

Numerous researchers have examined the effect of resistance exercise on cardiovascular function in patients with cardiovascular diseases. Heavy physical exertion can trigger the onset of acute myocardial infarction, particularly in individuals that are sedentary (Mittleman, Maclure, Toffler, Sherwood, Goldberg, and Muller, 1993). Transient myocardial ischemia is a plausible cause for most episodes of exertion-related cardiac arrest in patients with coronary artery heart disease, and often these individuals were not aware of their heart disease prior to collapse (Cobb and Weaver, 1986). Those prone to death due to myocardial infarction include those individuals with a sedentary lifestyle, hypertension, arrhythemia, increased heart rate and diabetes (Wannamethee, Whincup, Shaper, Walker, and MacFarlane, 1995). The increase in pulse rate-systolic blood pressure with strenuous isometric work has been shown to induce a pressure load on the left ventrical increasing the likelihood of myocardial infarction in those with existing cardiovascular disease (Amsterdam, Hughes, DeMaria, Zelis, and Mason, 1974). Also, a higher incidence of arrhythemias has been reported with isometric exercise than with dynamic exercise (Atkins, Matthews, Blomqvist, and Mullins, 1976).

Prolonged or sustained near-maximal static effort should be avoided because of the potentially hazardous effect on cardiovascular response. The associated larger increase in ventricular afterload may have deleterious effects on the heart or the arterial wall in patients in whom there is cardiovascular compromise due to disease (Donald, Lind, McNicol, Humphreys, Taylor, and Staunton, 1967). An increase in systolic blood pressure causes left ventricular hypertrophy and a decrease in diastolic blood pressure tends to reduce coronary blood flow (Fang, Madhavan, Cohen, and Alderman, 1995). However, even with high systolic blood pressure, an elevated diastolic blood pressure would be expected to increase coronary blood flow (Fang et al., 1995) due to increased myocardial perfusion pressure.

Crozier, Ghilarducci, Holly and Amsterdam (1989) found no evidence of arrhythmia, myocardial ischemia or abnormal blood pressure with resistive training performed by cardiac patients at 80% of MVC.

Featherstone, Holly, and Amsterdam (1993) had ten men with diagnosed coronary artery disease perform repetitive, dynamic resistive weight lifting. Diastolic blood pressures ranged from 93 mmHg to 117 mmHg, and systolic blood pressures were between 158 and 174 mmHg. No symptoms of ischemia or significant arrhythmia occurred.

Wiley, Dunn, Cox, Hueppchen, and Scott (1992) demonstrated that isometric exercise training lowered resting blood pressure. They suggested that the pressor response might serve as a stimulus for baroreceptor resetting. These results suggest that a more favorable myocardial oxygen supply-to-demand balance occurs with rhythmic lifting of relatively heavy loads than with a sustained static contraction. Resistance exercise that is rhythmic in nature does not appear to pose an extraordinary risk to those cardiovascular patients that are aerobically trained and clinically stable (Featherstone et al., 1993).

2.3.5 Back Belt Wearing, Asymmetric Stoop Lifting, and Physiological Work

The stoop lift is characterized by a long moment arm for the IAP force vector, greater shear force due to the anterior orientation of the discs and the large trunk flexion angle, and the consequent activation of the interspinous and transverse ligaments. In addition, the activity in the erector spinae is potentiated due to the increased moments that result from the stooped trunk posture and the external load in combination with the long moment arm to the center of the trunk mass (Garg and Herrin, 1979). During asymmetric stoop lifting, the muscles of the trunk are coactivated to balance bilateral trunk muscle force activity and to provide postural stability. The erector spinae are stabilizers, agonists, and antagonists during asymmetric trunk motion (Kim and Marras, 1987). The activity of the contralateral external obliques and ipsilateral obliques and ipsilateral lattisimus dorsi initiate and maintain the asymmetric stoop posture. The activity of the contralateral obliques increases to balance the activity of the more active ipsilateral obliques. This reduces lateral bending shear forces, but increase anterior forces. The contralateral erector spinae must become active to balance the ipsilateral external load (lateral and anterior shear), and to reduce the anterior and lateral shearing moments produced by the abdominal muscles. This aids in stabilizing the torso, but increases the compression forces at L5/S1 (Seroussi and Pope, 1987). An increase in the coactivity of the trunk muscles decreases the efficiency of torso movement, and might increase the physiological workload.

The rigid weightlifter's belt has been shown to increase trunk stiffness in the coronal and transverse planes (McGill et al., 1994). Granata et al. (1997), Lavender et al. (1995), Lantz and Shultz (1986a), Wu (1985), and Grew and Deane (1982) have all shown that trunk movement is restricted during various torso movements with and without trunk loading with different orthotic devices, including the elastic back belt.

Hemborg, Moritz, and Lowing (1985), Lander (1987), and McGill et al. (1990) demonstrated that abdominal muscle activity increased with back belt wearing, but extensor muscle activity did not significantly decrease.

Granata et al. (1997) reported that trunk spinal loading was decreased with back belt wearing due to a reduction in trunk muscle coactivity. Muscle activity was redistributed with belt wearing with only marginal muscle activity changes. Left erector spinae activity decreased, but internal and external oblique activity was potentiated. For some subjects, spinal loading increased. However, the applied moments at L5/S1 increased for all subjects with belt wearing. This is due to the longer moment arm to the center of mass of the torso associated with greater pelvic rotation.

Consequently, the elastic back belt might potentially increase physiological work due to the longer moment arm length between L5/S1 and the torso center of mass, and the external load vector. Individuals with heavier torso weight and/or torso lengths would potentially have a higher differential increase in absolute workload with back belt wearing. The resistance offered by the back belt during the asymmetric stoop lower might result in an increase in flexor and rotator muscle activity that may or may not decrease antagonistic extensor muscle activity, and the active muscle mass. A larger active muscle mass or external load will increase the absolute workload.

The effect of the back belt on muscle activation patterns appears to be subject dependent (Granata et al., 1997). The back belt may benefit the wearer during the load lift due to an increase in IAP associated with a restricted abdominal volume, and the activation of the transversus, internal obliques and external obliques (Cresswell et al., 1993). However, the effect of the back belt on the mechanical efficiency of these muscles is not known. An increase in left internal oblique activity and a decrease in left erector spinae activity with back belt wearing was demonstrated by Granata et al. (1997). Cresswell et al. (1993) also found that internal oblique activity, transversus activity and diaphragm muscle activity increased with progressively elevated trunk muscle loading during extension.

A submaximal workload increase in a dynamic task will increase oxygen uptake, heart rate, cardiac output, and systolic blood pressure with little or no change in diastolic blood pressure (Lewis, Taylor, Graham, Pettinger, Schutte, and Blomqvist, 1983). More specifically, an increase in dynamic work is directly related to the oxygen demand of the active skeletal muscle and is matched by an increase in cardiac output, stroke volume, pulse rate and systolic blood pressure output (Mitchell, 1985). Diastolic blood pressure during exercise remains similar to or lower than resting diastolic blood pressure because of the decrease in total peripheral resistance due to the large widely dilated vascular bed (Bezucha, Lenser, Hanson, and Nagle, 1982). Dynamic steady-rate work will not result in a significant accumulation of blood lactate until approximately 55% of maximum oxygen uptake. At this point there is an increase in the amount of lactic acid in the blood, and heart rate and blood pressure begin to rise due to the increased usage of the anaerobic energy supply. An individual that has an onset of blood lactate at a high percentage of aerobic capacity will experience less physiological strain in prolonged endurance work.

The aerobic capacity of a worker is related to the ability of the worker to handle additional work without a great deal of added physiological strain. An individual who has trained in endurance events will have a greater aerobic capacity due to an increase in stroke volume. The maximum stroke volume is reached at approximately 40 to 50% of maximal oxygen consumption which corresponds to approximately 110 to 120 beats per minute in a dynamic task. The endurance trained individual will also have greater systolic emptying. The ability of the muscle cells to generate energy aerobically will be increased for this individual. The slope or rate of change of the pulse rate for the aerobically fit worker is generally lower for an incremental increase in submaximal work (McCardle, Katch, and Katch, 1991). At a given submaximal oxygen uptake the fit worker will experience a lower heart rate, cardiac output and blood lactate level. The stroke volume will be relatively unchanged and the arteriovenous oxygen difference will be higher (Ekblom, Astrand, Saltin, Stenberg, and Wallstrom, 1968). The aerobically unfit worker exercising at a given submaximal oxygen uptake will experience higher physiological strain and will have less reserve work capacity available in comparison with a more fit worker.

The unfit worker wearing the back belt may experience a greater positive differential work pulse increase and systolic blood pressure increase from the bending resistance afforded by the belt than an individual who is aerobically fit. Body builders and weightlifters may experience lowered blood pressure responses to a given workload due to a desentization of the sympathetic nervous system or a resetting of the threshold of the peripheral baroreceptors (Elkblom et al., 1968).

Manual lifting includes a static, postural component. The wearing of the back belt has failed to demonstrate a decrease in coactivation for all subjects (Hemborg et al., 1985; Lander, 1987; McGill et al., 1990; and Granata et al., 1997), suggesting that it may increase postural maintenance work or decrease mechanical efficiency. In addition, Lander et al. (1994) demonstrated that there was less variation in muscle activation patterns with back belt wearing in comparison with no-belt during the asymmetric lift. This may result in higher fatigue levels for the left erector spinae and internal oblique and right external oblique. The work intensity associated with the static component or the postural maintenance component is directly related to both the active skeletal muscle mass and the percentage of maximal voluntary contraction achieved (Mitchell, 1985).

Static work is associated with an increase in cardiac output due to a disproportionately elevated pulse rate for the level of oxygen uptake (Lind, Taylor, Humphreys, Kennelly, and Donald, 1964), and a large increase in both systolic and diastolic blood pressure (Bezucha et al., 1982). The elevated cardiac output is most often responsible for the increase in blood pressure, and total peripheral resistance and stroke volume are usually not significantly altered (Miles, Owens, Golden, and Gotshall, 1987). With a larger active muscle mass or higher relative work intensity, a greater increase in pulse rate and mean arterial pressure would result due to the greater degree of excitation of muscle afferent receptors (Mitchell, Payne, Saltin, and Schibye, 1980).

Heavy work such as asymmetric stoop lifting adds a static component due to an increase in mechanical inefficiency. In dynamic work with a static component the pulse rate and blood pressure are elevated to reflect the greater intramuscular pressure (Miles, Owens, Golden, and Gotshall, 1987). The cardiac output can be increased by a combination of stroke volume and heart rate in dynamic exercise with a static component. The stroke volume, pulse rate and arterial blood pressure are related to the size of the active muscle mass and the intensity of work in combined static and dynamic work (Heannel, Snydmiller, Teo, Greenwood, Quinney, and Kappagoda, 1992).

The back belt worn during prolonged strenuous work may reduce some of the benefit of evaporation and cause circulatory adjustments. This may cause an individual to have a higher dependence on the anaerobic energy stores due to decreased lactate uptake by the liver due to lower hepatic blood flow and reduced muscle perfusion than if the back belt was not worn. This may result in earlier fatigue (McCardle, Katch, and Katch, 1991).

Studies indicate that systolic blood pressure and diastolic blood pressure are significantly attenuated for 15 minutes to 2 hours following resistance and dynamic exercise (Hannum and Kasch, 1981; Raglin and Morgan, 1987; Kaufman, Hughson, and Schaman, 1987). Resistance levels evaluated for hypotensive recovery have ranged from 40% to 70% MVC, and dynamic workloads have ranged from 50% VO_2 to 70% heart rate range. However, systolic blood pressure has been shown to rise slightly with the onset of fatigue during prolonged dynamic work (50% maximum oxygen uptake for 2 to 8 hours), and to drop more slowly in the rest period when the subject was fatigued than when they were not fatigued (Michael, Ernest, Hutton, and Horvath, 1961). However frequently blood pressure temporarily fell below baseline measures. The patterns of blood pressure elevation during recovery were shown to be inconsistent (Michael et al., 1961).

Systolic blood pressure has been demonstrated to remain significantly elevated for 10 to 15 minutes after resistance exercise (40 to 80% MVC; Brown, Clemons, He, and Liu, 1994; O'Connor, Bryant, Vettri, and Gebhardt, 1993), and following dynamic exercise performed for 30 minutes (70% $VO_{2;}$ Brown et al., 1994), while simultaneously diastolic blood pressure was significantly depressed for 15 minutes. In most of the prior resistance studies, systolic blood pressure and diastolic blood pressure were significantly lower than control values after exercise (Hill, Collins, Curton, and Demello, 1989; Sullivan, Hanson, Rahko, and Folts, 1992).

Numerous studies have evaluated the effect of repetitive heavy lifts (70% to 100% MVC) performed until voluntary fatigue. These studies (MacDougall, Tuxen, Sale, and Moroz, 1985; Wiecek, McCartney, and McKelvie, 1990) demonstrated very high blood pressures and pulse rates during exercise, but after exercise, blood pressure decreased rapidly below control values and returned to normal within 10 seconds. The rapid fall in blood pressure was attributed to the sudden release of muscle tension followed by hypermic dilation of previously compressed vasculature. In addition, these studies revealed that higher blood pressures were obtained for repetitive lifts of percentages of 1-RM than for a single 1-RM lift, and that the highest peak heart rate and blood pressure occurred during the latter repetitions (MacDougall et al., 1985). The contraction of larger muscle masses also resulted in higher blood pressures and pulse rates. The Valsalva maneuver was seen more during the 1-RM lift, and in the latter lifts of each set. The Valsalva potentiates the blood pressure response (Wiecek et al., 1990).

The relationship of indirect blood pressure measures to direct measures, and the relationship of recovery blood pressure to blood pressure during work have been examined. Kirkendall, Feinleib, Freis, and Mark (1980) had subjects perform repetitive leg presses and arm curls, and measured blood pressure indirectly and directly during exercise and immediately after the resistance exercise, and at 60, 90, and 120 seconds after exercise. They found that the indirect measurement of systolic blood pressure underestimated the direct measurement by 12 to 14% during double-leg press exercise, and by 13% during arm curls. The mean systolic blood pressure measured immediately after leg press and arm curl exercise using the indirect approach underestimated the peak systolic blood pressure measured by the direct approach during exercise by 31% and 34%, respectively. The diastolic blood pressure measures during and after exercise were not significantly different between the methods.

2.3.6 Back Belt Wearing, Intra-muscular Pressure, Ischemia and Physiological Strain.

The asymmetric stoop posture decreases the strength capacity of the trunk muscles in comparison with lifts performed with a symmetric trunk posture (Lavender, Tsuang, Anderson, Hafez, and Shin, 1992). Kim, Chung, and Lee (1994) found that the left erector spinae was the most fatigued muscle during the asymmetric stoop lift (load origin located 60 degrees clockwise from the mid-sagittal plane). The postural maintenance activity of the lower left erector spinae is counterproductive to producing the torque necessary to lower the external load. The activation of the abdominals during bending and twisting increases the lateral and anterior forces that need to be counterbalanced. The anterior forces generated by the rectus abdomini decrease with asymmetry and the lateral and torsional forces increase. The posterior and lateral forces produced by the paraspinal muscles are inadequate to counter the increased shear forces. Therefore, the contra-lateral abdominal muscles must be coactivated to balance these forces (Seroussi and Pope, 1987).

Coactivation increases the required muscle activity. The contraction of smaller muscles increases the risk of muscle fatigue, muscle sprain, muscle strain, and low back pain (Kumar, 1984). Pope, Anderson, Broman, and Svenssoin (1986) demonstrated that the antagonistic activity of the lumbar trunk muscles increases during trunk axial rotation. Deluca and Mambrito (1987) found that an increase in coactivation with muscle fatigue resulted in increased joint stiffness and increased compression forces. Seroussi and Pope (1987) demonstrated that coactivation in the anterior and posterior trunk muscles increased with frontal moment arms that exceeded 10 centimeters during loading of the asymmetric torso.

The Valsalva maneuver has also been demonstrated to increase trunk muscle coactivation (Kumar and Davis, 1973; Krag et al., 1985). Abdominal activity is increased with the Valsalva maneuver and the paraspinal muscle activity is not attenuated (McGill, Norman, and Sharratt, 1990). Abdominal activity is increased with flexion, and twisting and with heavier external loads (Cresswell, 1993).

Wearing an elastic back belt during asymmetric lifts has been shown to increase pelvic rotation and reduce trunk flexion. A larger applied moment at the L5/S1 has been observed (Granata et al., 1997). For some subjects, coactivation increased as evidenced by an increase in compression forces with belt wearing.

The cardiovascular reflex mechanisms (pressor reflex) associated with the potential increase in postural maintenance and static loading with back belt wearing involve the activation of group III and/or IV afferents which are capable of elicting increases in heart rate and blood pressure (Mitchell, Kaufman, and Iwamoto, 1983). The afferent fibers from the group III nerve fibers are sensitive to mechanical stimulation and those from the group IV nerve fibers are activated by the accumulation of exercise-related by-products (Wallach and Mitchell, 1983). Both of these afferents contribute to the reflex cardiovascular response associated with an ischemic contraction (Kaufman, Rybicki, Waldrop, and Ordway, 1984).

Arterial occlusion has been shown to potentiate the pressor response to exercise in humans (Staunton, Taylor, and Donald, 1964). Mitchell, Payne, Saltin, and Schibye (1980) demonstrated that pulse rate dropped after contraction with occlusion maintained, but blood pressure remained elevated above pre-contraction levels until the occlusion was removed. The pressor reflex is greater if blood flow to the muscle is occluded (Mitchell, 1985). Mitchell (1990) demonstrated that both the contractile force and the accumulation of metabolic by-products within the muscle trigger afferent responses that result in the reflex activity.

An increase in effort, as occurs with fatigue, results in a greater pressor reflex (Bezucha et al., 1982). Repetitive contractions, leading to fatigue would be expected to increase the active muscle mass and may account for a progressive elevation of blood pressure. Individuals with larger muscle mass will experience the highest blood pressure for a contraction equivalent to a fixed percentage of static muscle strength (Lind and McNicol, 1967; Seals, Washburn, Hanson, Painter, and Nagle, 1983). Blood pressure will increase proportionately with the size of the active muscle mass and the absolute force of contraction (MacDougall et al., 1985).

The rapid attenuation of blood pressure after exercise is probably due to the immediate perfusion of previously occluded muscle mass, as well as the acute pressure undershoot stimulated by baroreceptor and cardiopulmonary reflexes from elevated blood pressure (MacDougall et al., 1985). Blood pressure will increase at lower occlusion levels for strong individuals in comparison with weaker individuals (Heyward, 1975). Intramuscular pressure increases with voluntary contraction, contraction intensity, fatigue, and with external pressure application. Individuals with compartment pressure syndrome have high IMPs in the afflicted muscles at rest (Pedowitz, Hargens, Mubarak, and Gershuni, 1990).

An increase in force or torque results in a linear increase in IMP (Jarvholm, Palmerud, Herberts, Hogfors, and Kadefors, 1989). External muscle compression also increases IMP (Styf, Lundin, and Gershuni, 1994). A sufficient IMP increase impairs blood flow. Insufficient blood flow increases fatigue and decreases endurance. Intramuscular tissue pressure is determined by the tension in the muscle fibers, the depth of the fibers, and the geometry of the muscle fibers (Sejersted, Hargens, Kardel, Blom, Jensen, and Hermansen, 1984). Low compliance within the muscle compartment increases IMP (Sejersted et al., 1984). Muscles that have a pennate or circular structure have fiber geometries in which the direction of muscle fiber force development does not align with the direction of force transmission through the tendons (Sejersted and Hargens, 1986). Fibers will tend to curve and force vectors will be present perpendicular to force in the tendon. These force vectors will elevate IMP (Sejersted and Hargens, 1986).

Intramuscular blood vessels lie mainly between and parallel to muscle fibers so that blood flow is likely to be affected the most in the trunk muscles with a pennate muscle fiber arrangement. Blood flow is first compromised deep in a muscle where the pressure is the highest (Sejersted, Hargens, Kardel, Blom, Jensen, and Hermansen, 1984). The highest density of oxidative fatigue resistant fibers is often found in the central location which is the first area to become ischemic (Sahlin, Edstron, and Sjoholm, 1987).

The pennate structure of the paraspinals, the muscle slips of the iliocostalis thoracis and longissimus thoracis muscle that originate at the lumbar spine and insert to the ribs, and the depth and the longitudinal arrangement of the erector spinae muscle mass at L5 and L4 are in such a configuration that they would tend to promote high intra-muscular pressure. The deep erector spinae at the base of the spine is covered by the thoracolumbar fascia, other muscles, and surrounded by bone reducing their compliance. The compartmental nature of the erector spinae muscles and the depth and circular arrangement of the short transverse spinal muscles that position the vertebrae would also promote an elevated IMP (Clemente, 1986). It is speculated that asymmetric stoop lifting combined with the compartmental nature of the deep lower left erector spinae muscle will increase IMP in these muscles.

Elevated post-exercise IMP is characteristic of the chronic compartment syndrome (Pedowitz, Hargens, Mubarak, and Gershuni, 1990). An increase in IMP during work or recovery elevates blood pressure (Mitchell, 1990; Williamson, Mitchell, Olesen, Raven, and Secher, 1994). High IMPs may also thwart blood perfusion and promote an ischemic condition, which will potentiate the pressor reflex.

Intramuscular blood vessels may become completely occluded with forces that exceed 30% maximal voluntary contraction (Humphreys and Lind, 1963), resulting in an increasing proportion of anaerobic metabolism in the muscle. As the fatigue state increases, more muscle fibers are recruited for the effort and intramuscular tension and pressure increase within the muscle (Edwards et al. 1972; Sejersted et al., 1984). Blood pressure rises linearly over time with fatiguing isometric contractions. Contraction of the fast twitch muscle fibers increases blood pressure more than the activation of slow twitch muscle fibers (Coote, Hilton, and Perez-Gonzalez, 1971).

As a subject's lower left erector spinae begins to fatigue, it is probable that he recruits additional motor units and assessory muscles, resulting in a progressive increase in active muscle mass and an elevation in SBP and DBP due to an increase in effort and ischemia, as well as mechanical compression. The pressor response is potentiated with occlusion, and arterial pressure returns to normal more slowly after the contraction is complete (Kaufman et al., 1980). If external pressure is greater than arterial pressure, then blood pressure falls but remains elevated after the contraction (Lind, McNicol, and Donald, 1966), and does not return to normal until after the restriction is removed (McClosky and Mitchell, 1972).

In combination with the increase in IMP that occurs during muscle contraction, muscle volume increases with work intensity. Muscle volume can vary by 10 to 15% under normal circumstances (Gullestad, Hallen, and Sejersted, 1993). The increase in muscle volume is associated with the intensity of the work and not with blood flow (Gullestad et al., 1993). The combination of hydrostatic and osmotic forces can cause the muscle to swell within seconds, whereas restoration of the muscle volume is a slow process (Sejersted et al., 1986).

Intramuscular water content has been shown to increase with exercise. Such findings suggest that IMP may increase with time (Sjogaard, Kleins, Jorgensen, and Saltin, 1986). Styf, Lundin, and Gershuni (1994) demonstrated that the functional knee brace increased IMP at rest. Muscle relaxation pressure during exercise was also significantly higher and the time to elicit fatigue was 35% shorter than when the brace was not worn. The reason for the increased muscle relaxation pressure was the increased IMP due to the increase in muscle volume of up to 20% developed by muscle during exercise and the external pressure applied by the brace strapping (Styf et al., 1994).

An increase in IMP due to external mechanical compression can squeeze blood from the muscle into the central circulation (Gaffney, Thal, Taylor, Bastian, Weigelt, Atkins, and Blomqvist, 1981), thus benefiting muscle pump activity. Normally, with the centrally mediated reflex response, both pulse rate and blood pressure are potentiated with an increase in intramuscular pressure and/or ischemia. A decrease in pulse rate with the belt may be attributable to an increase in venous return from the abdominal muscle pump, and an increase in parasympathetic activity. A resetting of the baroreceptor limits and a rise in parasympathetic activity may also obscure the pulse rate effects of the elevated sympathetic activity due to the higher intramuscular pressure and ischemic muscle conditions (O'Leary, 1993).

The pulse rate and blood pressure might also be disassociated during fatiguing contractions (Mark, Victor, Herhed, and Wallin, 1985). An increase in parasympathetic activity at the termination of work will reduce pulse rate despite a maintained high sympathetic activity and blood pressure (Stramba-Badiale, Vanoli, DeFerrari, Cerati, Foreman, and Schartz, 1991).

Ischemia in active skeletal muscle induces a reflex increase in systolic arterial pressure and heart rate. When metaboreflex activity is maintained during work, pulse rate and blood pressure are elevated predominantly via activation of the sympathetic nerves of the heart. However, in post-exercise muscle ischemia, blood pressure remains elevated and heart rate decreases. During post-exercise ischemia, parasympathetic activity rises and obscures the effect of sustained sympathetic activity (O'Leary, 1993). With an increase in the total peripheral resistance (TPR), an increase in arterial pressure may also occur without an increase in cardiac output. An increase in TPR typically occurs when blood pressure is not high enough to overcome intramuscular pressure, so that blood can enter and leave the muscle, and maintain venous return and stroke volume so that cardiac output can increase (Miles et al., 1987).

External compression of resting muscles selectively stimulates mechanoreflexes without activating central command mechanisms that would normally occur during voluntary isometric contraction (Osterziel, Julius, and Brandt, 1984). An increase in intramuscular pressure by way of an elevated muscle tissue pressure or the application of an external pressure will stimulate a reflex increase in blood pressure (Osterziel, Julius, and Brandt, 1984). An increase in the mean arterial pressure of subjects during rest was elicited through external compression of the legs (Crandall, Williamson, Potts, Shi, and Raven, 1992). The magnitude of the pressor response (systolic and diastolic blood pressure) was associated with the level of external pressure applied, as well as the quantity of muscle mass compressed. The pressor response appeared in a matter of seconds and remained elevated with the application of constant pressure. The blood pressure increase was attributed to the marginally elevated resistance and to cardiac output. Small, insignificant increases in pulse rate were noted despite significant increases in blood pressure, suggesting that the muscle receptors sensitive to mechanical compression might be responsible for shifting the operating point of the baroreflex.

During back belt wearing, slower blood perfusion to the trunk flexors or rotators may occur during work and recovery due to the higher workload, static component or increased IMP. In addition, the belt may apply enough external pressure to increase IMP during the lift, and to reduce blood perfusion rate between lifts and during rest. This would be more significant after the trunk muscles begin to fatigue, when IMP is already high and/or when muscle volume is increased. The increase in external pressure applied by the belt against the trunk muscles may increase the intra-muscular pressure within the lateral and lower posterior trunk muscles, especially those counterbalancing the external load and weight of the torso. The addition of the external pressure from the belt, especially with heavy external trunk loading, may increase intra-muscular pressure during work due to the increase in workload and external pressure. This may result in a mechanoreflex response that elevates blood pressure, but not pulse rate (Osterziel, Julius, and Brandt, 1984).

High frequency lifting allows little recovery time, whereas restoration of the muscle volume is a slow process (Sejersted et al., 1986). This may cause IMP to remain elevated during recovery resulting in a potentiation of blood pressure. An increase in IMP might also result in a faster rate of fatigue for the lower left paraspinals and rotators, and consequently heart rate and blood pressure would increase during work.

2.3.7 Back Belt Wearing, Asymmetric Stoop Lifting, and Body Part Discomfort

Studies have demonstrated that higher local muscle fatigue and ratings of perceived exertion result during lifting with the trunk rotated. This is due to the smaller cross-sectional area of the trunk rotators and lateral benders. It is thought that these muscles are not as well perfused due to their lack of training and their lower type I fiber content and smaller number of mitochondria.

Ratings of perceived exertion (RPE) have been shown to be higher if the force is distributed across smaller muscle groups. Kumar (1980) demonstrated that asymmetric lifting was more stressful to the subjects. He theorized that this was due to the coactivation of paraspinal and abdominal muscles and the resulting force imbalances and local stress concentrations. Garg and Banaag (1988) found that subjects were willing to tolerate higher perceived stress during asymmetric lifting, and at higher frequencies than at lower frequencies. Mital and Fard (1986) indicated that lifting in the non-sagittal plane was more physically stressful than lifting in the sagittal plane. These issues may have important implications on the perceived stress of high-frequency asymmetric stoop lifting tasks with back belt wearing.

The elastic industrial back belt has not been shown to decrease perceived stress in any study. However, orthotic devices and air belts have been shown to reduce LBP due to the lumbar stabilizing function, and higher external pressures available with these devices.

Million, Nilsen, Jayson, and Baker (1981) found that individuals wearing lumbar supports with low-back pads showed significant reductions in subjective and objective low-back pain measures. Air belts have been shown to significantly reduce the pain associated with mild, severe strains and sprains (Penrose, Chook, and Stump, 1991). The air belt is theorized to apply pressure to the dorsal spasmic muscles, stretch these muscles, and reduce spasm via the stretch-reflex response.

Ciriello and Snook (1995) also found that perceived discomfort was not reduced with belt wearing during a four-hour lifting task. Contreras, Rys, and Konz (1995) found that body part discomfort was not reduced with back belt wearing during a standing task or lifting task. Some of the belts increased discomfort due to heat retainment.

The air belt or a tightly cinched belt may reduce muscle spasms or decrease low-back pain due resulting from pre-existing abdominal muscle insufficiency. The back belt has been shown to reduce peak erector spinae forces during unexpected asymmetric trunk loading (Lavender, Andersson, Corcos, and Thomas, 1996). The back belt may alter the CNS pre-programming (long latency muscle activations) to the trunk muscles. This may decrease peak tonic and phasic extensor muscle forces. An alteration in postural set may allow the worker to relax the trunk muscles more, thus reducing trunk muscle activity, spasm, and peak contraction levels. The passive support to insufficient trunk muscles during standing and bending may be increased. The back belt may decrease the length of the moment arm from the L5/S1 to the center of mass of the abdomen thereby decreasing the anterior moment about the L5/S1. Finally, the back belt may increase muscle temperature and increase neuromuscular efficiency.

CHAPTER 3

EXPERIMENTAL METHODOLOGY

3.1 Overview of the Experimentation

This research effort involved a series of three experiments. In each of the experiments, subjects used the asymmetric stoop lift technique to lift and lower a tote box containing weight equivalent to a fixed percentage of that subject's static lift strength (SLS). The weight was moved between a support surface in the 90-degree lateral plane and a support surface in the mid-sagittal plane for a period of 2 hours. Six lifts and six lowers were performed each minute. The experiments were conducted during the Spring 1997 semester at the University of Oklahoma, and spanned a period of four months (February - May 1997). The main purpose of Experiment 1 was to establish a method for controlling belt tension and to identify an acceptable workload that would result in a meaningful belt effect on the criterion measures. In addition, procedural problems were identified. Experiments 2 and 3 were performed using the acceptable workload identified in Experiment 1. The main objective of Experiments 2 and 3 was to evaluate the effect of belt wearing, work period, and order of belt wearing (belt first and no belt first) on change in pulse rate, change in systolic blood pressure, change in diastolic blood pressure, lower left back discomfort, lower right back discomfort, rating of perceived exertion, and static lift strength. In addition, the relationship of the criterion measures, and subject and task factors across the subjects, between and across the belt levels was investigated. The relationship of these measures and factors was examined for the individual subjects, as well. Experiment 2 also explored the reliability of belt tension setting between sessions, and determined the statistical power of the test for the belt factor for the criterion measures as a function of the number of subjects. Experiment 3 incorporated refinements in procedures developed from the two prior experiments, and used a larger number of subjects. In addition, Experiment 3 examined responses obtained from a belt questionnaire survey. The relationship between measures of belt effectiveness (support, help and compliance) and the sensory dimensions of temperature, pressure, circulation, restriction and comfort were evaluated.

3.2 Facilities and Equipment

3.2.1 Belt Tension Measurement Equipment and Procedure

The equipment used in the measurement of belt tension included:

1. belt stretching fixture,
2. Omega LCCB-50 load cell,
3. PC (Zenith Data Systems 386), and
4. Labtech Notebook software.

The belt tension measuring fixture is displayed in Figure 3.1. The sliding arm was adjusted to the untensioned elastic length of the belt straps. The belt strap tongues were laid across the metal base plates. The inner edge of the metal top plate was positioned at the seam separating the plastic tongue from the power knit material for both belt straps. The metal plates were tightened with a 0.15 cm bolt and butterfly nut.

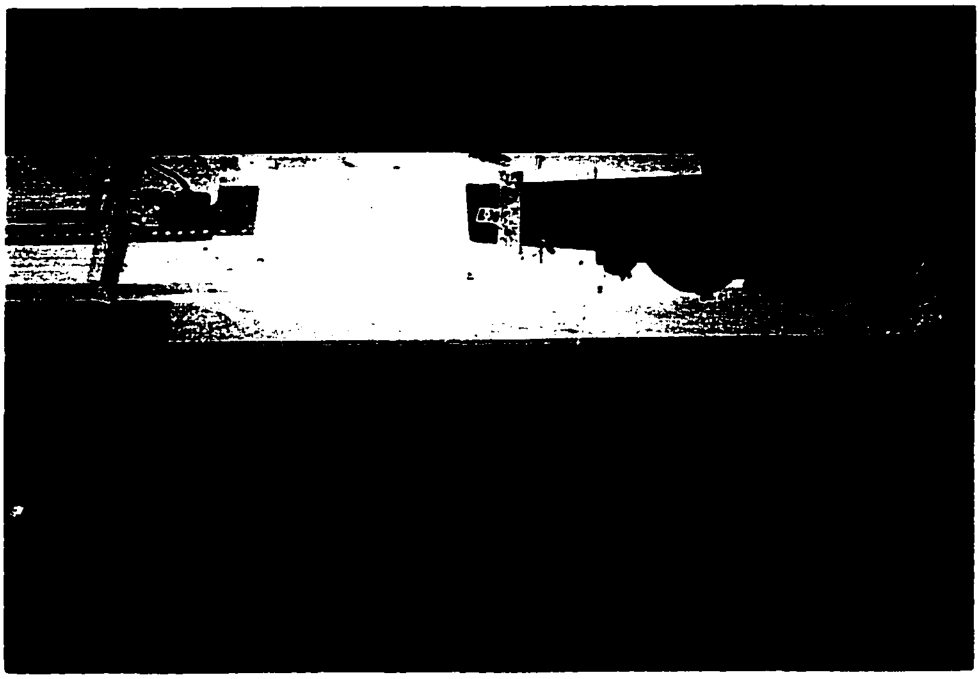

Figure 3.1. Belt Stretching Fixture.

The sliding arm was displaced in increments of 1.875 cm, and for each displacement a bolt-lock was positioned into a 1.25 cm circular hole in a metal girder mounted on the wooden support base. These holes, spaced 0.625 cm apart, traversed the entire length of the metal girder. The belt length displacement capacity of the fixture was 37.5 cm. For each of the displacements, the corresponding tensile force in the belt was measured using an Omega LCCB-50 load cell connected to an Ametek Series 6000 conditioner, the PC (Zenith 386) and Labtech Notebook interface.

3.2.2 Experimental Lifting Equipment

The following equipment was used to perform all of the lifting experiments:

1. wooden tote box (6.2 cm x 4.2 cm x 3.2 cm),
2. two adjustable-height shelves,
3. Polar Vantage XL wrist-mounted heart rate monitor,
4. Polar Vantage XL chest strap transmitter,
5. Omron Automatic Oscillometric Digital Blood Pressure Monitor (HEM 704C), and
6. PC (Zenith 386 Data Systems).

The wooden tote box weighed 3.2 kg and consisted of a rectangular wooden container (26.5 cm x 26.5 cm x 26.5 cm) with attached wooden handles. The handles on the tote box were 35 cm in length and 3.75 cm in diameter. The handles on the tote box were adjusted to an angle of 15 degrees.

Support for the tote box in the sagittal plane consisted of a 180 cm x 90 cm x 45 cm metal frame with a wooden shelf. Each of the vertical support legs of the frame had drill holes 3.81 cm apart. Horizontal support arms could be attached at any height along the support legs. A wooden panel (90 cm x 45 cm) was placed over the horizontal arms to provide support for the tote box. The non-sagittal plane support consisted of a rectangular wood shelf with 0.625 cm holes drilled in each corner. Blocks of wood of different thickness, with 0.625 cm drill holes were placed under the shelf. Dowel rods were inserted through the holes to align and secure the shelf with the wood blocks. The wood blocks were used to raise and lower the height of the support surface to accommodate the arm reach of each of the subjects in the lateral plane.

The Polar Vantage XL chest transmitter transmitted pulse rate data every 15 seconds to the Polar Vantage XL wrist-mounted heart rate monitor. The data collected by the monitor was downloaded to a PC (Zenith 386) using the Polar Interface and the Polar Vantage XL software. To assist the subject in timing his lifts, a timing routine was written in the BASICA programming language.

The Omron Automatic Oscillometric Digital Blood Pressure Monitor (Model HEM-704C) was used to measure blood pressure. The manufacturer-specified precision of the monitor in measuring blood pressure and pulse was ± 2% of the blood pressure reading, and ± 5% of the pulse reading.

To determine the expected repeatability of the Omron blood pressure and pulse measures and to assess the reliability of the measurement procedure used in Experiments 2 and 3, six measurements of the same individual were taken across a one-hour period. Measurements were taken every 10 minutes in the sitting posture with no intervening exercise. Table 3.1 provides the summary results of these measurements.

Table 3.1. Blood Pressure and Pulse Rate Repeatability.

MEASUREMENT TRIAL	SYSTOLIC BLOOD PRESSURE (MMHG)	DIASTOLIC BLOOD PRESSURE (MMHG)	PULSE RATE (BPM)
1	119	79	80
2	117	84	78
3	113	82	80
4	121	81	83
5	118	82	77
6	114	84	75
Mean	117	82	78.8
Standard Deviation	3.03	1.89	2.78
Coefficient of Variation	0.025	0.023	0.035

3.2.3 Static Lift Strength Testing Equipment

The following equipment was used to perform all of the static lift tests:

1. static strength platform,
2. 15" wide pull-bar with chain attachment,
3. Omega LCCB-300 load cell, and
4. Labtech Notebook Software.

Analog outputs from the Omega LCCB-50 load cell were conditioned by the Ametek Series 6000 conditioner and then transmitted to the Labtech Notebook interface on the PC (Zenith 386 Data Systems).

3.3 Subjects

Two male subjects participated in the first experiment. Both subjects were 21 years old. Four male subjects between the ages of 21 and 39 participated in Experiment 2. Eight subjects participated in the third experiment. The subjects in the third experiment were healthy, "fit" males between the ages of 19 and 29.

3.4 Independent Variables

The following three independent variables were examined in the study.

1. wearing or not wearing an elastic back belt,
2. time into task (six 20-minute work periods).
3. weight of lift (5%, 15% and 25% of the static lift strength in the asymmetric stoop posture).

The first experiment used a single weight of lift equivalent to 25% of the static lift strength.

3.5 Criterion Measures

The following eight criterion measures were evaluated in the study:

1. change in pulse rate (work pulse; WP),
2. change in systolic blood pressure (Δ SBP),
3. change in diastolic blood pressure (Δ DBP),
4. rating of perceived exertion,
5. static lift strength in the asymmetric stoop posture,
6. lower left back discomfort (LBD),
7. lower right back discomfort (RBD), and
8. a belt questionnaire survey.

Pre-session and post-session static lift strength in the asymmetric posture were not measured in the first experiment. The following paragraphs describe the criterion measures.

Work Pulse (WP). Work pulse was defined as the difference between the average pulse rate during work and the average pulse rate during rest. Pulse rate measurements were taken with the subject standing. The average pulse rate during work was measured across the last 2 minutes of each work period. The average pulse rate during rest was measured across the last 5 minutes of the initial rest period. The experimenter documented work pulse on a copy of the form in Appendix A.

Change in Systolic Blood Pressure (Δ SBP). The change in systolic blood pressure was defined as the difference between the working SBP (measured 1 minute after the end of each work period in the first experiment and 50 seconds after the end of each work period in the second and third experiments) and the resting SBP (measured at the 20th minute of a 22-minute rest period in Experiment 1, the 20th minute of a 22-minute rest period in Experiment 2, and at the 10th minute of a 12-minute rest period in Experiment 3). The SBP measures were obtained with the subject standing. The experimenter read the digital display on the blood pressure monitor and documented blood pressure on a copy of the form in Appendix A.

Change in Diastolic Blood Pressure (Δ DBP). The change in diastolic blood pressure was defined as the difference between the working DBP (measured 1 minute after the end of each period in the first experiment and 50 seconds after the end of each work period in the second and third experiments) and the resting DBP (measured at the 20th minute of a 22-minute rest period in Experiment 1, the 20th minute of a 22-minute rest period in Experiment 2, and at the 10th minute of a 12-minute rest period in Experiment 3). The experimenter read the digital display on the blood pressure monitor and documented blood pressure on a copy of the form in Appendix A.

Static Lift Strength (SLS). The SLS in the asymmetric stoop posture was defined as the average static lift strength across a 4-second interval following a steady increase up to maximum static lift strength during the first two seconds of the trial. The subject performed pre-session and post-session static lift strength tests for each work session. Body segment orientation with respect to the static strength pull-bar was the same as the body segment orientation to the tote box handles at the beginning of the lateral plane lift. Four static lifts were conducted for each strength test. The subject did not wear a belt during the strength test. The first static lift of the four lifts was a practice trial. The average of the last three static lift strength measures was the mean static strength for the subject.

Rating of Perceived Exertion. Each subject provided a rating of perceived exertion across the session using Borg's (1985) RPE Scale. The RPE was elicited at the 18th minute of the pre-lift rest period in Experiments 1 and 2, and at the 8th minute in Experiment 3. During work, RPE was elicited at minute 18 of each of the 20-minute periods. A score of 20 was considered "very hard" and a score of 6 was considered "very light". The instructions and a copy of the form used for documentation are given in Appendix A.

Lower Left and Right Back Discomfort. At the 18th minute of the pre-lift rest period for Experiments 1 and 2, at the 8th minute of the pre-lift rest period in Experiment 3, and at the 18th minute of each of the six 20-minute work periods, the subject was asked to choose the description that best matched the discomfort in the lower left and lower right back muscles. The body discomfort response scale used was modeled after Corlett and Bishop's (1976) Ratio Scale and is found in Appendix B.

Subjective Belt Questionnaire. At the end of all of the experimental sessions, the subjects were asked several questions about the perceived effectiveness of the belt and their sensory responses associated with belt wearing during the asymmetric stoop lift task. These questions are provided in Appendix C.

3.6 Control Variables

The primary subject controls were:

1. avoidance of medications during the course of the study,
2. no exercise program start-ups for the duration of the experiment, and no strenuous exercise on the day of a session,
3. no use of tobacco products within 3 hours of a session,
4. normal rest the night before testing,
5. no eating within 2 hours of a session,
6. standing resting pulse less than 90 bpm,
7. standing resting systolic blood pressure less than 140 mmHg,
8. standing resting diastolic blood pressure less than 90 mmHg,
9. no residual body part discomfort from the preceding session.

The subjects wore loose fitting clothes (e.g., T-shirts, jeans, or athletic shorts with elastic bands) and tennis shoes for all of the experimental sessions. During work, heart rate was not allowed to surpass 85% of maximum predicted heart rate, which would correspond to an estimated heart rate of 170 bpm for the 20-year-old, healthy male. Also, SBP was not allowed to exceed 225 mmHg and DBP was not allowed to exceed 140 mmHg. RPE was not allowed to exceed 18 on a 20-point scale, and body part discomfort was not allowed to exceed 8 on a 10-point scale. The illumination (approximately 75 foot-candles), temperature (approximately 72 degrees F), and relative humidity (between 55 and 70 percent) comprised the environmental conditions. In addition, each subject worked at approximately the same time of the day during the sessions. The following task attributes were controlled:

1. level of belt tension. A tension of 5.6 kg was set in the belts in the first experiment. Tensions of 4.5 kg and 7.9 kg were set in the belts in Experiment 2 and Experiment 3, respectively.

2. foot position and orientation during the work session. The subject was asked to stand on left and right foot markers in the sagittal plane. The foot markers were placed at the same position and orientation with respect to the tote box handles in the sagittal and lateral planes across the sessions. The inner ankles of the feet were positioned 30 cm apart, and the direction of the feet was parallel with the mid-sagittal plane. Some foot angulation was allowed, but foot placement and foot direction was constant from session to session. A constant foot posture was maintained throughout the period. At the end of each period, the subject moved one step laterally to allow blood pressure to be measured.

3. tote-box position and orientation. The relationship between the middle of the tote box handles and the foot position was held constant throughout the periods and across all lifting sessions. In the lateral plane, the tote box was positioned on the dominant side of the subject, orthogonal to the mid-sagittal plane. The middle of the tote box was aligned with the subject's ankles. The height of the middle of the tote

box handles from the floor and from the subject's right heel were held constant across sessions by adjusting the height of the support surface in the lateral plane, and by adjusting the horizontal distance of the foot markers from the lateral plane support. In the sagittal plane, the tote box was positioned perpendicular to the mid-sagittal plane axis. The middle of the tote box was aligned with the axis that bisected the distance between the inner ankles of the subject. The height of the tote box handles in the sagittal plane and the distance of the posterior edge of the foot markers from the middle of the tote box handles were held constant across sessions. This was accomplished by setting the height of the work surface to the appropriate height for each subject, and by adjusting the distance of the posterior edge of the foot markers for each subject. The front edge of the tote box was always positioned parallel with the front edge of the support surfaces during workstation setup and during the lifts.

4. pull-bar position and orientation. The vertical and horizontal distance of the middle of the pull-bar handles from the right heel of the subject during the static lift strength tests was the same as the vertical and horizontal distance of the middle of the tote box handles from the subject's right heel during the work sessions, and was held constant between work sessions. Heel markers were used to establish the foot position of the subject with respect to the pull-bar prior to the static strength tests.

3.7 Experiment Protocol and Procedures

Each of the subjects participated in the following sessions:

1. familiarization and subject characteristics data collection session,
2. belt tension adjustment sessions, and
3. experimental lifting sessions.

Subjects in Experiment 3 also completed a practice lifting session. The following paragraphs describe these sessions.

3.7.1 Familiarization and Subject Characteristics Data Collection Session

Each subject read, answered and signed a medical history form, a medical history checklist, statement of physical condition, and subject consent form. Copies of these forms are provided in Appendices D through G. The subject was familiarized with the lifting tasks, and any questions were answered. The experimenter recorded subject and task characteristics on a copy of the form provided in Appendix H. The experimenter obtained select anthropometric measurements of each of the subjects, on their dominant side, using a metal tape and cloth tape. Plastic calipers were used to measure breadths and depths. Fat mass was estimated from the girths of the right upper arm, forearm, and abdomen. The equation that was used was obtained from McArdle, Katch and Katch (1991) and is provided below:

$$\% \text{ Body Fat} = (\text{Upper Arm Constant} + \text{Abdomen Constant} - \text{Right Forearm Girth Constant}) - 10.2.$$

The girths were used as indices to a table of conversion constants to predict the percent body fat for young men. In addition, the distance of the subject's hand grasp (metacarpal joint of the third digit) from the floor when the subject rotated the torso to an angle of approximately 90 degrees with the mid-sagittal plane, flexed the torso maximally, and extended the arms vertically downward was measured. The horizontal distance of the subject's hand grasp (metacarpal joint of the third digit) from his right heel in this posture was also measured. These distances were used to establish the position of the middle of the tote box handles from the posterior edge of the subject's right foot marker in the lateral plane during the work sessions. In the sagittal plane the subject's hand grasp height from the floor when the arms were extended forward and downward to an angle of 45 degrees with the horizontal was measured. In addition, the distance from the back of the heel to the middle of the hand grasp in this posture was measured. These distances were used to set the location of the middle of the tote box handles from the subject's right heel in the sagittal plane during the work sessions. The vertical distance to the middle of the tote box handles in the lateral plane was set 3" higher (trunk angle of approximately 90 degrees) than the vertical distance measured when the subject flexed the torso maximally and extended the arms vertically downward. It should be noted that pelvic movement was constrained to approximately 90 degrees due to the tension in the hamstrings.

3.7.2 Belt Tension Adjustment Sessions

Prior to the first belt tension adjustment session, subjects performed a static lift strength test to determine their SLS in the asymmetric stoop posture. Weights of 5%, 15% or 25% of SLS were placed in the tote box for performing the belt tension adjustments in Experiments 1 and 2. A 25% SLS weight was used in Experiment 3.

During each of the belt tension adjustment sessions, abdominal girth was measured with the subject standing erect with the feet parallel and the inner ankles separated by a distance of 30 cm. One end of a sewing tape was positioned one inch above the navel while the other end was wrapped horizontally around the subject.

Abdominal girth was measured prior to each belt tension adjustment session in order to determine if the overlap of the belt straps needed to be adjusted differently to achieve a constant tension. Prior to performing the belt tension adjustment sessions, each subject was fit to the manufacturer's suggested belt size (See Appendix I).

After assigning a belt to a subject, the experimenter computed the difference between the subject's abdominal girth and the length of the inner belt straps. This distance corresponded to the overlap in the two inner belt straps. The experimenter marked this point with duct tape and the subject positioned the inner belt straps to the appropriate overlap. In securing the inner and outer belt straps, the experimenter made sure that the metal stays in the posterior section of the belt aligned directly over the middle of the lumbar erector spinae on either side of the spinal column. On the sides of the subject's lower torso, the belt straps were pulled down over the top edge of the iliac crest, and the middles of the belt straps were set at navel level. Each subject in the first two experiments participated in two belt tension adjustment sessions.

The subjects in Experiment 3 performed one belt tension adjustment session. The belt tension adjustment sessions in the first two experiments were 2 hours long. Six 20-minute belt tension adjustment trials comprised each session. The belt tension adjustment session in Experiment 3 was approximately one-half hour in length, and consisted of two 15-minute belt tension adjustment trials. The trials in Experiments 1 and 2 evaluated tension settings for 5%, 15% and 25% of SLS. Each trial in Experiment 3 evaluated the tension adjustment for 25% of static lift strength. Trials were separated by a 2-minute rest period during which time the experimenter measured and documented the length of the overlap of the two outer belts. During the first trial for each weight of lift, the belt tension was set at either the lower stretch limit or the upper stretch limit for the subject/belt combination. The initial belt tension levels in the first and second trials were counterbalanced across subjects. The mean of the two tension levels recorded in the two trials for each weight of lift was recorded as the acceptable tension level for the subject. Subjects performed their belt tension adjustment sessions at approximately the same time of day as their lifting sessions were performed. The following instructions were provided to the subject prior to each tension adjustment trial in Experiments 1 and 2:

"Adjust the overlap of the two outer belt straps, frequently, until the back belt is tight but still comfortable such that you can handle wearing the belt at this tension for a period of two hours. To tension the belt tighter, undo the cinch straps and pull the left strap further past the middle, and then overlap the right one further to the left for a much tighter fit. If you need a looser tension, undo the right strap and position and secure it further to the left. Remember to adjust the overlap of the belt straps often. If you want to adjust tension, do not worry about lifting when the tone sounds. Just stop lifting and adjust the overlap of the two outer belt straps, and then resume lifting when you are finished adjusting. Once you feel that the belt is snug and as tight as you can get it, and still be comfortable for two hours, you do not need to adjust the belt straps anymore. When you feel that you have adjusted the belt straps to a tension that needs no further adjustment, let me know."

The instructions for Experiment 3 were the same as those for Experiments 1 and 2 except the subject was instructed to tighten the belt as "tight as possible without restricting breathing". Also, a comfortable fit was not mentioned in the instructions for Experiment 3.

During each of the belt tension adjustment trials, the experimenter observed the tensioning behavior of the subject. If the subject repeatedly adjusted the belt straps such that there was very little overlap or a lot of overlap, then depending on the subjects waist size in relation to the size of the belt worn, either a smaller size belt or a larger size belt was provided. Also, if the experimenter observed that a subject did not adjust the belt straps very often, then the experimenter observed the overlap in the belt, and either suggested another belt or encouraged the subject to adjust the overlap in the outer belt straps such that the belt fit was snug and tight. Also, the experimenter prompted the subjects to adjust belt tension every two minutes.

After each of the belt tension adjustment trials, the overlap length of the two outer belt straps was measured with a cloth ruler. The measured overlap distance was input to the force-displacement equation for the belt in order to compute the tensile force in the belt. The repeatability of the two tension settings was determined by computing the Pearson correlation coefficient between settings across all subjects. The significance of the correlation was tested. The average of the tension settings for the two trials for the subject was termed the acceptable belt tension. The average of the acceptable belt tensions (across all subjects) was the tension set for each subject during the lifting sessions (see Appendix J).

3.7.3 Experimental Lifting Sessions

Following the belt tension adjustment sessions, each subject performed the experimental lifting sessions. Experiments 1 and 2 involved two lift sessions. One session was performed with the belt and one session was performed without the belt. Experiment 3 included an additional practice session without the belt to provide some physical training and task learning to reduce carry-over effects. For Experiments 1 and 2, a minimum of 24 hours and a maximum of 96 hours separated the sessions. A minimum of 48 hours and a maximum of 96 hours separated the sessions in Experiment 3 to reduce potential residual fatigue effects. The duration of each session was approximately 3 hours. The order of belt wearing was counterbalanced across subjects. During each session, the following sequence of events occurred.

1. pre-ses+sion static lift strength measurement,
2. initial rest period,
3. work period,
4. blood pressure measurement,
5. rest,
5. work period, and
6. post-session static lift strength measurement.

In the first experiment, after blood pressure measurement, subjects rested until work pulse rate was within 115% of resting pulse rate. In the second and third experiments, 135% of resting pulse rate was used. The sequence of measurements for the initial rest period of Experiment 1 are displayed in Table 3.2. Experiment 2 used the same measurement sequence and times, except the belt was worn during the last 12 minutes of the rest period, rather than the first 10 minutes. Experiment 3 used the same measurement protocol except the rest period was 10 minutes, and the belt was worn during the final 5 minutes of the rest period.

Table 3.2. Measurement Schedule.

Elapsed Time (min)	Belt Wearing Condition	Measurement
0 – 4	Belt	PR
4 – 5	Belt	PR/SBP/DBP
5 – 9	Belt	PR
9 – 10	Belt	PR/SBP/DBP
10 – 11	(Belt Removal)	PR
11 – 14	No Belt	PR
14 – 15	No Belt	PR/SBP/DBP
15 – 18	No Belt	PR
18 – 19	No Belt	PR/LBD/RBD/RPE
19 – 20	No Belt	PR/SBP/DBP
20 – 22	No Belt	Pulse Download; Determination of 135% of Resting Pulse

Legend: PR = Pulse Rate, SBP = systolic blood pressure, DBP = diastolic blood pressure, RBD = low right back discomfort, LBD = low left back discomfort, RPE = rating of perceived exertion

The following sections describe the general procedures used for all of these events.

3.7.4 Pre-Session Static Lift Strength Measurement

Prior to the subject's arrival, the work shelves and the chain on the static strength pull bar were adjusted to the appropriate heights and length. In addition, the foot markers at the lift station and on the static strength test platform were adjusted for the particular subject. Upon the subject's arrival, a SLS test in the 90-degree lateral plane was performed. The Caldwell strength testing regimen was followed (Caldwell, Chaffin, Dukes-Dobos, Kroemer, Laubach, Snook and Wasserman, 1971). A subject performing a static lift strength test is shown in Figure 3.2.

Figure 3.2. Static Lift Strength Measurement.

Subjects exerted a steady pull for two seconds, and then maintained this force for an additional four seconds. The mean force over the four-second period represented the SLS for the trial. Each subject performed four SLS tests. A 2-minute rest period with the subject seated was provided between trials. The first of the four SLS trials was a practice trial. The mean of the SLS measures for the last three trials was the average SLS for the subject.

3.7.5 Equipment Fitting and the Initial Rest Period

After the subject completed the strength test, a Polar Vantage transmitter was strapped around his chest, and a Polar Vantage XL watch monitor was secured to his wrist. The transmitter downloaded pulse data every 15 seconds to the Polar Vantage XL watch monitor. The blood pressure cuff was secured to the subject's non-dominant arm. In Experiment 1 the blood pressure cuff was not worn throughout the work periods and the proper position of the cuff was not marked on the subject's arm. In Experiments 2 and 3, the blood pressure cuff was loosely attached around the non-dominant arm of the subject, and was worn during all rest and work periods. Ink contours around the cuff, and hose were drawn on the subject's arm to ensure proper cuff positioning from trial to trial.

After the subject was fitted with the Polar transmitter and receiver, and the blood pressure cuff, the subject performed the initial rest period. The duration of rest was 22 minutes for the first two experiments and 12 minutes for the third experiment. Heart rate was continuously measured every 15 seconds during the initial rest period and blood pressure was measured every 5 minutes for all of the experiments. These measures were documented on a copy of the form found in Appendix A. During rest and during blood pressure measurement, the subject stood upright, perpendicular to the support shelf, with both feet positioned over the foot markers on the floor (separated by 30 cm), and arms hanging freely. The same posture was maintained during rest and blood pressure measurement across the periods and sessions.

The rating of perceived exertion and body part discomfort ratings were elicited from the subject at the 18th minute of the initial rest period in Experiments 1 and 2, and at the 8th minute in Experiment 3. The experimenter entered the RPE measures on a copy of the form provided in Appendix A, and the body part discomfort responses were documented on a copy of the form provided in Appendix B. After the last blood pressure measurement in all of the experiments, the Polar Vantage XL was removed from the wrist of the subject, the subject's pulse data were downloaded to the PC, and the average pulse rate over the last 5 minutes of rest was calculated using the Polar Vantage interface software. The subject remained standing during the 1-2 minute download, and average resting pulse rate determination. After the average resting pulse rate was determined, a lower pulse rate limit of 115% of the average resting pulse was calculated and input into the Polar Vantage XL for Experiment 1, and 135% was entered for Experiments 2 and 3. After the Polar Vantage XL was repositioned on the wrist of the dominant arm of the subject, the work segment of the session was begun.

3.7.6 Twenty-Minute Work Periods

A tone emitting routine in the BASICA programming language was started by the experimenter. The program sounded a "tone" every 5 seconds. When the tone sounded, the subject rotated and lateroflexed the trunk, maintained the legs as straight as possible (some bending of the knees was allowed), and grasped the tote box in the 90-degree lateral plane (see Figure 3.3). The feet were maintained on the foot markers, pointed straight ahead or at a slight angle to the mid-sagittal axis. The subject lifted the tote box, rotated back to the sagittal plane, and positioned the tote box on the support shelf directly in front of him (see Figure 3.4). Next, the subject returned to the normal standing posture with arms hanging freely downward.

At the sound of the next tone, the subject extended his arms forward, and grasped the handles of the tote box. The subject lifted the tote box from the support shelf, rotated the trunk, and laterally bent and flexed the trunk, extended the arms downward, and lowered the tote box onto the support base in the lateral plane.

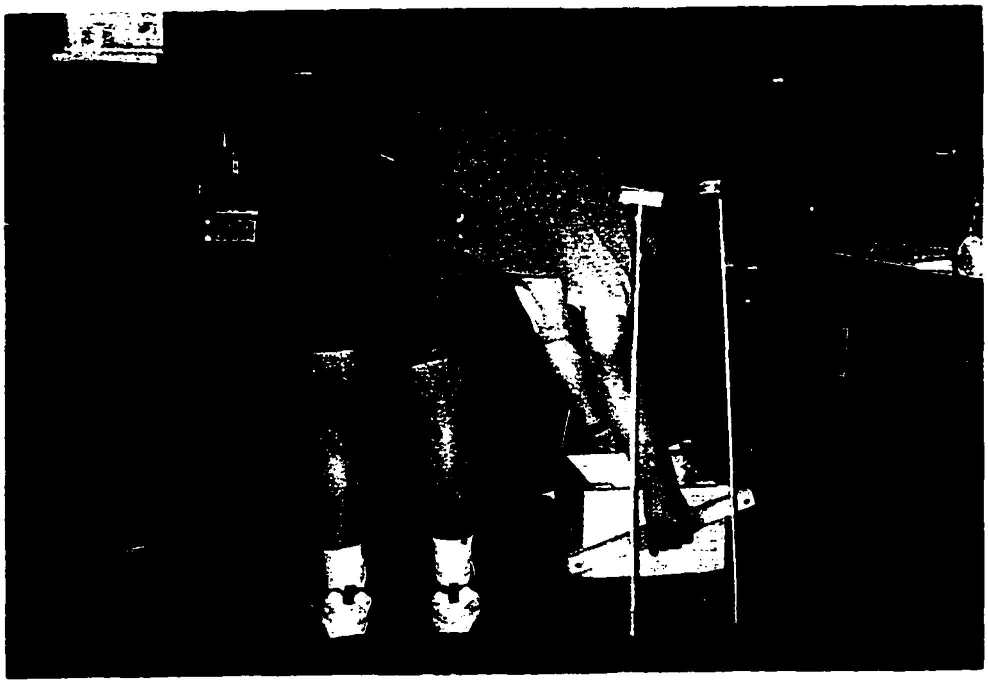

Figure 3.3. Lateral Plane Lift and Lower.

After the tote box was lowered, the subject returned to the normal standing posture with arms hanging freely downward. The subject repeated the lifting and lowering of the tote box when the tone sounded for 120 cycles across the period.

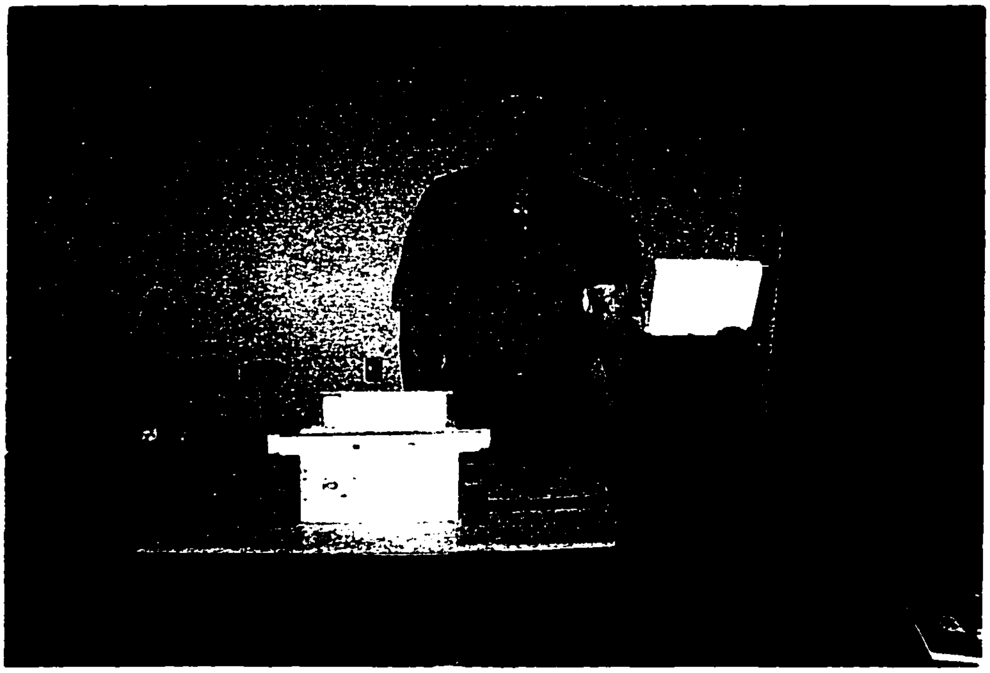

Figure 3.4. Sagittal Plane Lift and Lower.

At the 18th-minute of the period, the experimenter asked the subject to report his rating of perceived exertion. Next, the experimenter asked the subject to report the discomfort level for the lower left back and the lower right back. The sequence of eliciting perceived exertion ratings and body part discomfort levels was randomized across the periods in order to reduce presentation bias. At the end of each 20-minute period, the computer generated a tone that was higher pitched than the tone that was emitted to signal the lift or lower. This provided a signal to the subject and the experimenter that the work period was complete.

3.7.7 Blood Pressure Measurement

At the end of each 20-minute period, the subject returned to the normal standing posture with his arms hanging freely at his sides. In Experiment 1, the blood pressure cuff was quickly placed on the non-dominant arm of the subject and adjusted. In Experiments 2 and 3, the blood pressure cuff was loosely attached to the subject's non-dominant arm throughout the period and was adjusted as necessary after the periods according to the ink contours previously marked. In Experiment 1, fifteen seconds after the tone was emitted that signaled the end of the period, a second higher pitched tone sounded. In Experiments 2 and 3, this tone was emitted five seconds after the higher pitched tone. At this tone, the experimenter depressed the automatic inflate button on the digital blood pressure monitor and the blood pressure cuff automatically inflated. After a period of 45 seconds the digital display on the blood pressure monitor displayed the systolic and diastolic blood pressure, and pulse rate, and deflated. The experimenter documented the blood pressure measures on a copy of the form given in Appendix A.

In Experiment 1, the experimenter removed the cuff, while in Experiments 2 and 3 the experimenter positioned the hose under the cuff, and loosely tensioned the cuff. The subject continued to rest in the standing position until work pulse was lowered to a level that was lower than 115% of resting pulse for Experiment 1, and 135% of resting pulse for Experiments 2 and 3. At this point, the lower limit tone from the watch sounded. At the sound of the tone from the watch, the experimenter started the "tone emitting" routine that signaled the subject to lift and lower. At the sound of the lift tone, the subject began the next work period. The period/blood pressure measurement cycle was performed a total of six times in a session. Figure 3.5 shows a subject having blood pressure measured using the Omron Automatic Oscillometric Digital Blood Pressure Monitor.

At the end of blood pressure measurement (cycle time of 1 minute for Experiment 1, and 50 seconds for Experiments 2 and 3), or at the subject's recovery to the lower limit, the subject immediately began lifting again. In Experiments 2 and 3, following the completion of the six periods, post-session asymmetric strength was assessed.

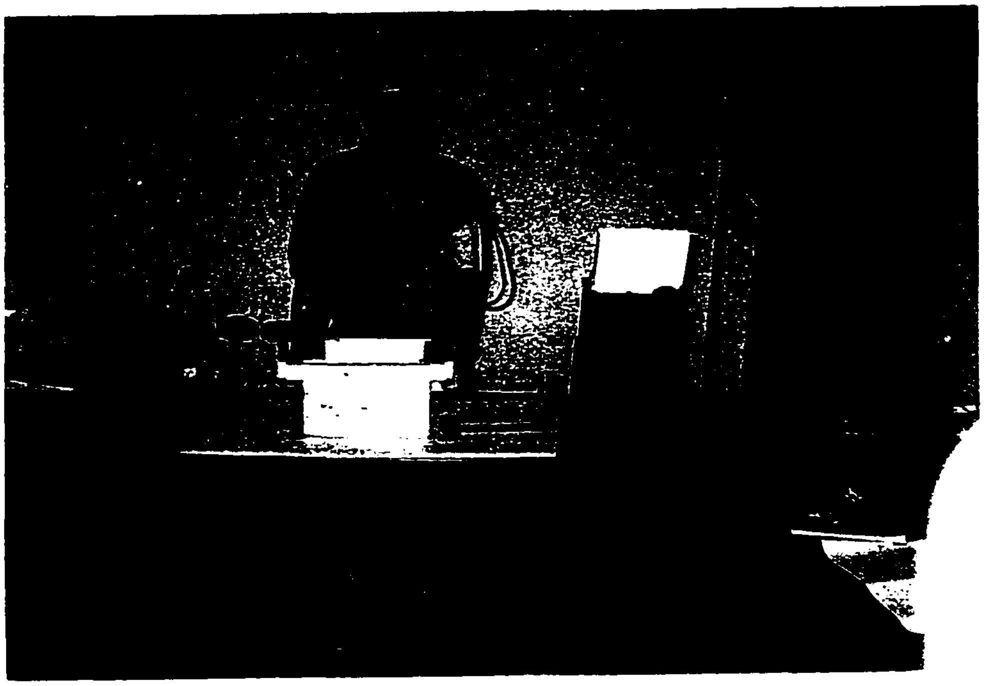

Figure 3.5. Blood Pressure Measurement.

3.7.8 Post-Session Static Lift Strength Measurement

After the completion of the six periods, the subject removed the blood pressure cuff and the transmitter strap and watch, and immediately performed a SLS trial in the 90-degree lateral plane. The procedure for the post-session SLS test was identical to the procedure for the pre-session SLS test (see Section 3.7.4).

3.7.9 Belt Survey Questionnaire

At the end of all of the experimental sessions, the subjects were asked several questions about the perceived effectiveness of the belt and their sensory responses associated with belt wearing during the asymmetric stoop lift task. A copy of these questions is provided in Appendix C.

3.8 Experimental Procedure Differences

Several major differences existed between the experimental procedures used in the three experiments. A summary of the procedures used in the three experiments is provided in Table 3.3.

Table 3.3. Summary of Experimental Procedures.

<table>
<tr><th>EXPERIMENTAL PROCEDURE</th><th colspan="5">EXPERIMENT</th></tr>
<tr><th></th><th colspan="3">EXPERIMENT 1</th><th>EXPERIMENT 2</th><th>EXPERIMENT 3</th></tr>
<tr><td>BELT TENSION ADJUSTMENT SESSIONS</td><td colspan="3"></td><td></td><td></td></tr>
<tr><td>Number of sessions</td><td colspan="3">2 Sessions</td><td>2 Sessions</td><td>1 Session</td></tr>
<tr><td>Number of trials per session</td><td colspan="3">6 Trials</td><td>6 Trials</td><td>2 Trials</td></tr>
<tr><td>Time between sessions (hr)</td><td colspan="3">24 to 48</td><td>24 to 48</td><td>N/A</td></tr>
<tr><td>Duration of trial</td><td colspan="3">20 minutes</td><td>20 minutes</td><td>15 minutes</td></tr>
<tr><td>Instructions</td><td colspan="3">Belt tight but comfortable for a lift duration of 2 hours</td><td>Belt tight but comfortable for a lift duration of 2 hours</td><td>Belt tight but not restrictive to breathing for a lift duration of 2 hours</td></tr>
<tr><td>Weight conditions for belt tension adjustment</td><td colspan="3">5%, 15%, and 25% SLS</td><td>5%, 15%, and 25% SLS</td><td>25% SLS</td></tr>
<tr><td>EXPERIMENTAL WORK SESSIONS</td><td colspan="3"></td><td></td><td></td></tr>
<tr><td>Number of subjects</td><td colspan="3">2</td><td>4</td><td>8</td></tr>
<tr><td>Mean Age (yr), (Stdev)</td><td colspan="3">21 (0)</td><td>29 (9.4)</td><td>22.8 (4.3)</td></tr>
<tr><td>Belt Tension (kg)</td><td colspan="3">5.6</td><td>4.5</td><td>7.9</td></tr>
<tr><td>Weight of lift</td><td colspan="3">5%, 15%, and 25% SLS</td><td>25% SLS</td><td>25% SLS</td></tr>
<tr><td>Mean Weight (kg)</td><td>3.4</td><td>10.2</td><td>16.8</td><td>14.2</td><td>17.9</td></tr>
<tr><td>Stdev (kg)</td><td>0.2</td><td>0.9</td><td>1.4</td><td>4.6</td><td>3.9</td></tr>
<tr><td>Number of work sessions (number of conditions)</td><td colspan="3">6 Sessions (1 for each weight condition with and without the belt)</td><td>2 Sessions (1with belt and 1 without belt)</td><td>3 Sessions (1 practice session without belt, 1 session with belt and 1 session without belt)</td></tr>
<tr><td>Session duration</td><td colspan="3">Six 20-minute lift periods</td><td>Six 20-minute lift periods</td><td>Six 20-minute lift periods</td></tr>
<tr><td>Time between sessions (hr)</td><td colspan="3">24 to 48</td><td>48 to 96</td><td>48 to 96</td></tr>
</table>

Table 3.3. Summary of Experimental Procedures (cont.).

Pre-Lift and Post-Lift Static Strength Measurement			
Number of static strength trials	4 static strength trials performed prior to the belt tension adjustment session.	4 static strength trials prior to belt tension adjustment, 4 pre-session trials and 4 post-session trials.	4 static strength trials prior to belt tension adjustment, 4 pre-session trials and 4 post-session trials.
Rest-time between strength trials (min)	½	2	2
Initial Rest Period			
Rest period length (min)	22	22	12
Belt wearing interval	First 10 minutes	Second 10 minutes	Second 5 minutes
Baseline work pulse measurement	Average from 15 to 20 minutes	Average from 15 to 20 minutes	Average from 5 to 10 minutes
Baseline blood pressure measurement	@ 20 minutes	@ 20 minutes	@ 10 minutes
Rating of perceived exertion and resting body part discomfort measurement @ rest	@18 minutes	@18 minutes	@8 minutes
Experimental Work Periods			
Breathing instructions	None	None	Breathe normally. Do not hold breath.
Work pulse measurement	Last 2 minutes of work period.	Last 2 minutes of work period.	Last 2 minutes of work period.
Blood pressure cuff	Not worn during the lift periods. Ink markings did not outline proper cuff position.	Worn during lift periods. Ink markings outlined proper cuff position.	Worn during the lift periods. Ink markings outlined proper cuff position.
Time after last lift for blood pressure measurement completed	1 minute	50 seconds	50 seconds
Rating of perceived exertion	Elicited at minute 18	Elicited at minute 18	Elicited at minute 8
Body part discomfort	Elicited at minute 18	Elicited at minute 18	Elicited at minute 8
Weight of lift	5%, 15% and 25% SLS	25% SLS	25% SLS
Method of marking foot position	Duct tape marked heel position.	Duct tape marked heel position.	Cardboard cutout marked foot position.

CHAPTER 4

EXPERIMENT 1 RESULTS AND ANALYSES

4.1 Experiment 1 Overview

The overall aim of Experiment 1 was to provide the researcher with a better understanding of the relationship between specific task and subject parameters and the dependent measures. Also, Experiment 1 aided the researcher in identifying and clarifying procedural problems and concerns, and rectifying these issues. The major purpose of Experiment 1 was to identify the workload and duration that would be acceptable to the subject, and at the same time improve the likelihood of obtaining a meaningful belt effect. The following questions were addressed in Experiment 1.

1. Is a linear prediction equation adequate for predicting the relationship between belt length displacement and tensile force?
2. What length of rest prior to lifting will result in a significant effect on pulse rate and blood pressure?
3. What lift frequency, weight of lift, and lift duration will be acceptable to the young male subject of average fitness?
4. What weight of lift and lift duration will result in the largest belt effect size for work pulse, systolic blood pressure, diastolic blood pressure, body part discomfort, and rating of perceived exertion?
5. What changes to the procedures are recommended?

4.2 Experimental Methodology

The facilities and equipment used in Experiment 1 were discussed in Chapter 3, Section 3.2. Two young, healthy male subjects were recruited from the School of Industrial Engineering at the University of Oklahoma to participate in Experiment 1. Table 4.1 provides the characteristics of the subjects and the task.

Table 4.1. Subject and Task Characteristics for Experiment 1.

SUBJECT CHARACTERISTICS	Subject 1	Subject 2	Mean	Stdev.
AGE	21	21	21	0
BODY WEIGHT (KG)	68.8	66.9	67.8	1.8
STATURE (CM)	177.8	176.0	176.9	1.3
ACROMION HEIGHT(CM)	144.8	140.0	142.4	3.4
KNUCKLE HEIGHT (CM)	76.2	73.8	75	1.7
UPPER ARM GIRTH (CM)	31.8	26.9	29.3	3.4
CHEST DEPTH (CM)	24.3	23.0	23.6	0.9
ABDOMINAL GIRTH (CM)	77.5	75.0	17.6	5.2
ABDOMINAL BREADTH (CM)	20.0	19.0	19.5	0.7
HIP GIRTH (CM)	94.0	87.5	90.7	4.6
HIP BREADTH (CM)	25.0	24.5	24.7	0.4
PREDICTED FAT MASS (KG)	10.3	11.6	18.7	1.8
TASK CONTROL VARIABLES				
SAGITTAL HORIZONTAL DISTANCE (CM)	50.8	57.5	54.1	4.7
NON-SAGITTAL HORIZ. DISTANCE (CM)	42.5	43.2	42.8	0.5
SAGITTAL VERTICAL DISTANCE (CM)	91.5	97.5	94.5	4.2
NON-SAGITTAL VERT. DISTANCE (CM)	27.9	42.5	35.2	10.3
STATIC STRENGTH TEST				
STATIC STRENGTH IN ASYMMETRIC POSTURE (KG)	64	66	65	1.4
5% MVC	3.2	3.6	3.4	0.3
15% MVC	9.5	10.8	10.2	0.9
25% MVC (KG)	15.9	17.9	16.9	1.4
BELT TENSION				
BELT TENSION SETTING (KG)	5.6	5.6	5.6	0

The subjects that participated in Experiment 1 performed some form of dynamic exercise at least two times per week. Subject 1 also performed weightlifting at least three times per week. The subjects were the same age, and possessed similar stature, body weight and strength. The independent variables, criterion measures and control variables used in Experiment 1 were defined in Sections 3.4 through 3.6.

4.3 Experimental Procedure

The experiment was conducted in Room S-23 of the Carson Engineering Center. Task familiarization and subject characteristics data collection were performed in the first session, static lift strength and belt tension adjustment were performed in the second session, followed by belt tension adjustment in the third session. The experimental work sessions were completed across the next six sessions.

Four SLS trials comprised the first belt tension adjustment session. The subject rested in a seated position for 30 seconds after each trial (see Section 3.7.4 for procedures). The average of the last three strength trials was the subject's SLS. Each subject performed two 2-hour belt tension adjustment sessions (see Section 3.7.2). Each session consisted of six belt tension adjustment trials of 20 minutes each. The interval between sessions ranged from 24 to 48 hours.

Belt tensioning instructions were provided. The subjects were instructed to tighten the belt to a tension that was tight but comfortable for a period of 2 hours. Two 20-minute belt tension adjustment trials were performed for each weight of lift (5%, 15% and 25% SLS). The average of the tensions determined in the two trials was defined as the acceptable belt tension for the weight of lift. The belt tension data for the two subjects are provided in Appendix J.

After the belt tension adjustment trials were completed, the subjects participated in six experimental work sessions (three weight levels across two belt conditions). Table 4.2 provides the work schedule for the two subjects.

Table 4.2. Experiment 1 Lifting Schedule.

	SESSION					
SUBJECT	1	2	3	4	5	6
1	5%MVC (3.2 kg)/ No Belt	15%MVC (9.5kg)/ Belt	25% MVC (15.9 kg)/ No Belt	5%MVC (3.2kg)/ Belt	15%MVC (9.5 kg)/ No Belt	25%MVC (15.9 kg)/ Belt
2	5%MVC (3.6 kg)/ Belt	15%MVC (10.8 kg)/ No Belt	25%MVC (17.9kg)/ Belt	5%MVC (3.6 kg) / No Belt	15%MVC (10.8 kg)/ Belt	25%MVC (17.9 kg)/ No Belt

At least 24 hours of rest were provided between sessions. Both subjects performed work sessions within 48 hours of the previous work session. The initial rest period was 22 minutes long. If the belt was not worn during the work periods then the belt was not worn during the initial rest period. If the belt was worn during the lift session, then the belt was worn during the first 10 minutes of the rest period.

The experimenter aided the subject in adjusting the overlap of the outer belts to attain a belt tension of 5.6 kg. The experimenter marked the required left belt strap overlap distance on the right belt strap with duct tape. The subject pulled the left belt strap to the proximal edge of the tape, and secured the left belt strap on the velcro on the right belt strap. The subject rested in a normal standing posture.

The schedule for measuring pulse rate, blood pressure, LBD, RBD and RPE is displayed in Table 4.3. Pulse rate was measured continuously during the rest period. Baseline pulse rate measures were obtained from averaging the pulse rate from the 15th to the 20th minute of the rest period. Blood pressure was measured at the 5th, 10th, 15th and 20th minutes of rest. The baseline blood pressure measure was obtained at the 20th minute of the initial rest period.

Table 4.3. Measurement Schedule.

Elapsed Time (min)	Belt Wearing Condition	Measurement
0 – 4	Belt	PR
4 – 5	Belt	PR/SBP/DBP
5 – 9	Belt	PR
9 – 10	Belt	PR/SBP/DBP
10 – 11	(Belt Removal)	PR
11 – 14	No Belt	PR
14 – 15	No Belt	PR/SBP/DBP
15 – 18	No Belt	PR
18 – 19	No Belt	PR/LBD/RBD/RPE
19 – 20	No Belt	PR/SBP/DBP
20 – 22	No Belt	Pulse Download; Determination of 125% of Resting Pulse

Legend: PR = pulse rate, SB*P* = systolic blood pressure, DB*P* = diastolic blood pressure, RBD = low right back discomfort, LBD = low left back discomfort, RPE = rating of perceived exertion

The perceived exertion rating and LBD and RBD measures were elicited at the 18th minute. At the completion of 20 minutes of rest, the Polar watch was removed, the pulse data were downloaded, the lower pulse rate limit was set in the watch, and the watch was repositioned on the subject's wrist. During the download, the experimenter aided the subject in tensioning the belt to a tension level of 5.6 kg. After the 22nd minute of rest, the subject began the first of six 20-minute periods. During the periods, the subject positioned his heels over duct tape markers on the floor. This aided the subject in maintaining approximately the same foot position across the work session. The subject lifted or lowered the tote box every 5 seconds at the sound of a computer-generated tone. Each subject performed 120 cycles of lifting and lowering.

The subjects did not wear the blood pressure cuff during the work periods and the contours of the cuff and hose were not marked to ensure a constant cuff position across measurements. At the 18th minute of each period the LBD, RBD and RPE were elicited from the subject. Immediately after the last lift of each period, the blood pressure cuff was secured to the non-dominant arm of the subject. Blood pressure measurement was begun 15 seconds after the final lift of each period. The cycle time for blood pressure measurement was 45 seconds. The subject rested for the longer duration of either pulse rate recovery to within 115% of the resting pulse rate or completion of blood pressure measurement (approximately 1 min). When pulse rate recovery and/or blood pressure measurement were complete, the subject began the next period. Each subject performed this cycle of lifting, blood pressure measurement, and rest six times for each work session.

4.4 Results and Analyses

4.4.1 Belt Force-Displacement Measures

Linear regression equations were formulated for the small, medium, and large back belts using the SAS REG procedure. Table 4.4 provides the force-displacement prediction models for the small, medium and large belts.

Table 4.4. Belt Force-Displacement Linear Trend Fit.

Belt Size	**Regression Equation**	**Intercept Std. Error**	**Parameter Std. Error**	**R^2**
Small	0.85 kg*displacement(in) – 0.030 kg	0.108	0.018	0.99
Medium	0.75 kg*displacement(in) – 0.021 kg	0.111	0.018	0.99
Large	0.50 kg*displacement(in) + 0.450 kg	0.058	0.01	0.99

The linear prediction model explained 99% of the variability in the actual force values within the data range for all of the belt sizes. The standard error of the estimate for the intercept and slope for the small belt were 0.0438 kg and 0.239 kg/inch, respectively. The model prediction for a displacement of 12 inches was 22.64 lbs (10.3 kg). A 95% probability existed that the actual force was between 22.09 lbs (9.9 kg) and 23.22 lbs (10.5 kg). for a 12-inch displacement in the belt. The human measurement error in setting belt tension was 0.5 inches or 0.95 lb. Therefore, the tension set by the researcher in the small belt for the maximum linear displacement fell within the interval of 21.1 lb (9.6 kg) and 24.2 lb (10.8 kg) with an approximate 95% probability.

The high R^2 obtained for the linear models indicates that the prediction equations explained a large part of the variability in the actual data. The low standard errors for the intercepts and slopes ensured tight confidence intervals for the predicted force. Therefore, the prediction equations were suitable.

4.4.2 Pre-Lift Rest Time

Resting pulse rate data (see Appendix K) across the belt conditions were analyzed using a repeated measures design with time as the within-subjects factor. The ANOVA summary results for the effect of rest time on pulse rate, systolic blood pressure and diastolic blood pressure are presented in Table 4.5. The effect of rest time on pulse rate was not significant at the 0.05 level ($F(3,3) = 6.75, p = 0.076$). The decrease in pulse rate from the 5th minute to the 10th minute was larger than for any other time interval. The effect of rest time on systolic blood pressure was not significant. However, the effect of rest time on diastolic blood pressure was significant ($F(3,3) = 13.08, p = 0.03$). A multiple comparison test demonstrated that DBP for the 5th minute of rest was significantly larger than DBP for the 10th, 15th, and 20th minutes.

Table 4.5. ANOVA Summary for Rest Time Effect on Physiological Response.

VARIABLE	FACTOR	DF	F	P>F
Pulse Rate	Time Time x Subject	3 3	6.75 0.16	0.076 0.923
Systolic Blood Pressure	Time Time x Subject	3 3	1.41 0.52	0.393 0.674
Diastolic Blood Pressure	Time Time x Subject	3 3	13.08 0.10	0.031 0.961

The DBP at 10, 15 and 20 minutes were not significantly different. These results suggest that an initial rest period of 10 minutes would be a sufficient period of rest prior to lifting.

4.4.3 Frequency, Weight and Lift Duration Selection

A period of two hours was selected as the maximum lift duration. Many tasks in industry require continuous work for two hours. The 2-hour work period represents a "moderate duration" continuous lifting task (NIOSH, 1991). The onset of fatigue occurs more rapidly when the relative muscle force exerted is greater than 15-20% of the maximum voluntary contraction (MVC; Kahn and Monod, 1989). To avoid excessive local muscle fatigue, a weight of lift equivalent to 25% of the static lift strength in the asymmetric stoop posture was chosen.

The rate of oxygen utilization should not exceed 50% of the maximum volume of oxygen uptake (MVO_2) for one hour of continuous work, and 33% of MVO_2 for a work period of 8 hours (Rodgers and Eggleton, 1986). The difference between pulse rate during work and rest in a seated position should be lower than 35 beats per minute to avoid fatigue (Grandjean, 1988). The percent of maximum oxygen uptake range associated with work that is dynamic and performed with large muscle groups can be approximated by the percent of maximum pulse rate range (%MPRR; Rodgers et al., 1986).

A software program that incorporated Garg, Chaffin, and Herrin's (1978) metabolic prediction equation for the sagittal plane stoop lift was written in the BASICA programming language. The purpose of the model was to establish initial workload levels that would not be overly fatiguing (e.g., exceed 50% MPRR or 35 bpm above resting pulse rate). The Garg et al. (1978) model predicts energy consumption per lift (kcal/lift). Gender, body weight, load weight, and origin and destination of lift were the original inputs. The model included a resting metabolic rate. The prediction equation was modified to estimate a low and high %MPRR. A metabolic rate of 16 kcal/min, corresponding to the estimated maximum aerobic power of a normal healthy young male in a highly dynamic task (Garg, Chaffin, and Herrin, 1978), was selected as the upper aerobic capacity. The lower aerobic capacity was set at 9.5 kcal/min (mean aerobic capacity of the 50th percentile 40 year old female; NIOSH, 1991). Load weight was input to the model and corresponded to 25% of the static lift strength of the subject. The frequency in lifts per minute was also included in the model. The relationship of maximum pulse rate = (220 – age) was used to estimate maximum pulse rate (Astrand and Rodahl, 1977). The actual pulse rate during rest was entered into the model. Metabolic rate (kcal/min) was converted to an oxygen consumption rate using the general relationship that 1 liter of oxygen consumed is equivalent to an energy consumption of 5 kcal. The percent of predicted maximum pulse rate range and pulse rate were outputs of the model. The following equation was used to obtain estimates for a low and high percent of maximum pulse rate range from which the pulse rate was derived (Rodgers and Eggleton, 1986):

$$\frac{\text{PR@work} - \text{PR@rest}}{\text{Max PR} - \text{PR@rest}} = \frac{\text{VO}_2\text{@work} - \text{VO}_2\text{@rest}}{\text{Max VO}_2 - \text{VO}_2\text{@rest}}$$

where,

PR = pulse rate,

Max PR = estimate of the maximum pulse rate,

VO_2 = estimate of liters of oxygen consumed per minute, and

Max VO_2 = estimate of the maximum liters of oxygen consumed per minute.

The experimenter's estimated pulse rate and %MPRR for a 20.5 kg load (25% of static lift strength) lifted at frequencies of 12 and 15 times per minute was computed. At 15 times per minute, a range of 36.5% to 58.4% of MPRR was estimated. The same load lifted 12 times per minute yielded a range of 32% to 51% of MPRR. Tables 4.6 and 4.7 provide estimates of pulse rate and %MPRR for the experimenter for the 20.5 kg load at 12 and 15 lifts per minute

Table 4.6. Pulse Rate Prediction for Experimenter Lifting 20.5 kg at 15 Lifts Per Minute.

```
WEIGHT = 100 KG,  LOAD WEIGHT = 20.4 KG,  LIFT FREQ = 15 LPM

SUBJECT OF FAIR FITNESS =     58.4% MMPR
SUBJECT OF GOOD FITNESS  =   36.5% MMPR

*********INDIVIDUALIZED DATA FOR  EXPERIMENTER***********

PREDICTED  PULSE RATE FOR FAIR FITNESS =   142.7 BPM
PREDICTED PULSE RATE FOR GOOD FITNESS =    122.6  BPM
```

Table 4.7. Pulse Rate Prediction for Experimenter Lifting 20.5 kg at 12 Lifts Per Minute.

```
WEIGHT = 100 KG,  LOAD WEIGHT = 20.4 KG,  LIFT FREQ = 12 LPM

SUBJECT OF FAIR FITNESS =     51.3% MMPR
SUBJECT OF GOOD FITNESS=    32.1% MMPR

*********INDIVIDUALIZED DATA FOR EXPERIMENTER***********

PREDICTED  PULSE RATE FOR FAIR FITNESS    =  136.2 BPM
PREDICTED  PULSE RATE FOR GOOD FITNESS    =   118.5 BPM
```

After obtaining the estimates for pulse rate, the experimenter lifted a load of 20.5 kg, at a rate of 15 times per minute, for one-half hour without wearing a belt.

The workload resulted in a mean pulse rate of 145 beats per minute (66% of MPRR and a work pulse of 55 beats per minute), a lower left back discomfort rating of 8 (horrible discomfort) on a 10-point scale, and a rating of perceived exertion of 15 (very hard) on a 20-point scale. The actual pulse was higher than the estimated pulse rate. The work pulse greatly exceeded the work pulse recommendations of Grandjean (1988) to avoid fatigue.

After a recovery period of 48 hours, the experimenter lifted the same load at a rate of 12 times per minute for two hours without the belt. The experimenter lifted for six 20-minute work periods. The experimenter rested after every work period until pulse rate returned to within 115% of the resting pulse. Each of the six rest periods was less than 2 minutes.

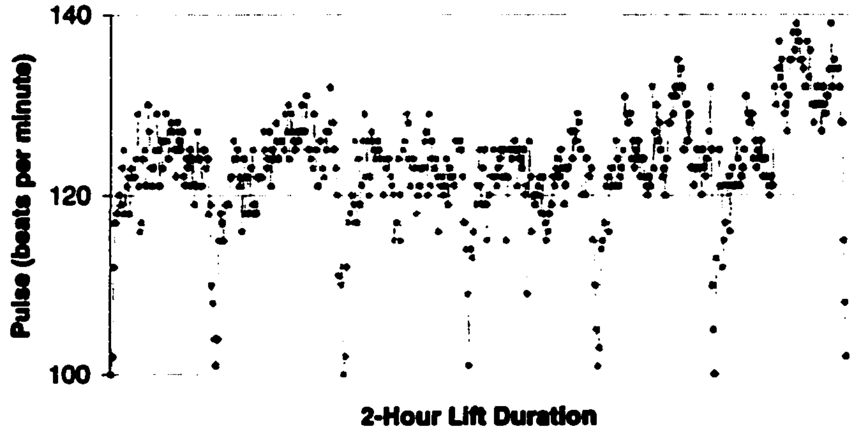

Figure 4.1. Heart Rate Response for Workload of 12 Lifts Per Minute at 45 lbs.

The workload resulted in an average pulse rate of 130 beats per minute during work (see Figure 4.1). The average pulse rate during work was 40 beats per minute above the pulse rate during rest and 43.5% of MPRR. The work pulse of 40 beats per minute was higher than the 35 beats per minute recommended by Grandjean (1988) to avoid fatigue during continuous work. In addition, the resting pulse rate was obtained in a standing posture. The pulse rate in a standing posture is higher than the pulse rate in a sitting posture due to the greater hydrostatic pressure in the leg vasculature.

The workload culminated in an average lower left back discomfort rating of 5 (distressing) and an average RPE of 15 (hard). The experimenter concluded that the load weight of 25% of static lift strength lifted at a frequency of 12 times per minute for two hours would be an acceptable but slightly fatiguing task for the average, healthy young male. This conclusion was supported because the experimenter was older and not "fit", and in general would be expected to have a lower physiological capacity than the average healthy, young male.

4.5 Physiological Strain Data Analyses

The physiological strain data were analyzed using a repeated measures design with belt wearing, weight of lift, and period as within-subjects factors. The experimental model can be stated as follows:

$$y_{ijk} = \mu + B_i + W_j + P_k + S_l + BW_{ij} + BP_{ik} + BS_{il} + WP_{jk} + WS_{jl} + PS_{kl} + BWP_{ijk} + BWS_{ijl} + BPS_{ikl} + WPS_{jkl} + BWPS_{ijkl} + e_{ijkl}$$

where,

y_{ijkl} = criterion measure under consideration

μ = overall main effect

B_i = effect due to belt level, i = 1, 2

W_j = effect due to weight of lift, j = 1, 2 and 3

P_k = effect due to period, j = 1, 2

S_l = effect due to subject, l = 1, 2.

The descriptive statistics for the criterion variables for the subjects averaged across the periods for the different weights of lift are presented in Table 4.8.

Table 4.8. Descriptive Statistics for the Criterion Variables.

MEASURE	5% MVC LOAD		15% MVC LOAD		25% MVC LOAD	
SUBJECTS	BELT	NO BELT	BELT	NO BELT	BELT	NO BELT
	MEAN (STDEV)	MEAN (STDEV)	MEAN (STDEV)	MEAN (STDEV)	MEAN (STDEV)	MEAN (STDEV)
WORK PULSE (BPM)	12.4 (1.8)	16.2 (1.9)	23.7 (2.6)	25.7 (5.1)	25.3 (9.3)	36.5 (9.4)
1	13.2 (2.0)	15.3 (2.1)	22.5 (1.0)	21.6 (1.7)	18.2 (2.6)	28.1 (4.6)
2	11.6 (1.3)	17.0 (1.4)	25.0 (3.1)	29.8 (3.6)	32.3 (7.9)	44.8 (2.6)
ΔSBP (mmHg)	-5.5 (9.1)	9.1 (8.3)	11.1 (8.6)	-2.4 (10.5)	6.8 (7.8)	8.0 (8.5)
1	-11.0 (6.8)	8.8 (6.3)	12.2 (5.7)	-11.7 (4.9)	-0.2 (3.4)	9.0 (11.1)
2	0.0 (7.9)	-2.1 (6.3)	10.0 (11.4)	6.3 (6.1)	13.8 (2.1)	7.0 (7.1)
ΔDBP (mmHg)	8.2 (8.9)	4.0 (4.9)	-0.7 (3.7)	-2.1 (8.9)	-6.8 (10.1)	-5.6 (15.5)
1	6.3 (5.5)	3.5 (5.1)	-0.7 (3.3)	-6.8 (5.4)	-7.0 (2.9)	4.3 (15.9)
2	10.0 (11.7)	4.5 (5.1)	-0.8 (4.5)	2.7 (9.5)	-6.5 (14.6)	-15.5 (6.3)
RPE	9.9 (0.9)	10.1 (1.6)	12.7 (2.5)	11.7 (1.3)	14.0 (1.8)	12.3 (1.4)
1	9.6 (0.5)	8.8 (1.1)	10.6 (1.5)	10.8 (1.2)	13.3 (1.7)	12.3 (1.6)
2	10.2 (1.1)	11.5 (0.5)	14.8 (1.2)	12.7 (0.8)	14.6 (1.6)	12.2 (1.2)
LEFT BACK DISCOMFORT	1.5 (1.2)	2.4 (0.7)	3.3 (2.3)	2.3 (1.6)	4.1 (2.0)	3.3 (1.3)
1	1.2 (0.9)	1.8 (0.4)	1.6 (1.5)	2.5 (1.6)	4.0 (1.8)	3.5 (1.4)
2	2.0 (1.2)	3.0 (0.0)	5.0 (1.7)	2.0 (1.7)	4.0 (2.3)	3.0 (1.1)
RIGHT BACK DISCOMFORT	0.1 (0.19)	0.7 (0.32)	0.6 (0.6)	0.0 (0.0)	0.0 (0.0)	0.3 (0.5)
1	0.0 (0.0)	0.9 (0.2)	0.1 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2	0.2 (0.3)	0.4 (0.2)	1.2 (0.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

The three factor interaction of period, weight, and belt, and the four factor interaction of period, weight, belt and subject were pooled with the error term to provide sufficient degrees of freedom for evaluation of the two-factor interactions, and the simple main effects. The simple main factors, simple interaction factors, and three-way subject interaction factors and significance tests for these factor effects on the criterion variables are provided in Table 4.9.

Table 4.9. ANOVA Summary for the Criterion Measures Across Weight Levels.

FACTOR		WORK PULSE		Δ SBP		Δ DBP		LBD		RBD		RPE	
SOURCE	DF	F	P	F	P	F	P	F	P	F	P	F	P
BELT (B)	1	9.0	0.20	0.2	0.76	0.4	0.60	0.2	0.72	0.1	0.79	9.0	0.20
WEIGHT(W)	2	4.6	0.18	4.6	0.18	2.6	0.28	3.7	0.21	0.5	0.65	6.8	0.12
PERIOD (P)	5	1.8	0.27	0.4	0.84	1.2	0.41	26.9	0.001 ***	0.6	0.71	80.1	0.0001 ***
SUBJECT(S)	1	47.4	.0001 ***	7.9	0.01 **	0.4	0.53	20.8	.0001 ***	21.6	.0002 ***	234.3	0.0001 ***
B x W	2	34.6	0.028 **	1.0	0.49	0.1	0.90	0.8	0.55	2.3	0.32	0.7	0.58
B x P	5	1.72	0.28	1.6	0.31	3.3	0.11	2.3	0.19	1.9	0.23	0.3	0.92
W x P	10	0.97	0.51	17.8	.0001 ***	0.9	0.51	3.9	0.02 *	1.5	0.26	4.7	0.011
W x S	2	37.9	.0001 ***	2.1	0.16	10.1	.001 **	9.2	0.001 **	14	0.001 ***	38.8	0.0001 ***
B x S	1	6.79	0.02 **	3.5	0.07	2.5	0.12	17.8	.0001 ***	15	0.001 ***	6.1	0.02 **
P x S	5	0.13	0.98	0.9	0.45	1.6	0.21	1.35	0.28	0.8	0.58	0.8	0.54
B x W x S	2	0.44	0.65	16.0	0.001 ***	9.6	.001 **	15.4	.0001 ***	27.9	.0001 ***	37.7	0.0001 ***
P x W x S	10	1.77	0.13	0.1	0.99	3.06	0.01 *	0.7	0.68	1.6	0.21	0.7	0.76
B x P x S	5	0.91	0.49	1.4	0.27	1.3	0.31	0.9	0.44	1.6	0.19	2.9	0.04 *
LEGEND: *- P<0.1 * *- p<0.05 * *-p<0.005	Factors: b = belt, W = weight, P = period, S = subject. Criterion Variables: W*P* = work pulse, Δ SB*P* = delta systolic blood pressure, Δ DB*P* = delta diastolic blood pressure, LBD = left back discomfort, RBD = right back discomfort, and RPE = rating of perceived exertion												

4.5.1 Work Pulse

The overall belt effect on work pulse across the weight levels and periods was not significant (*F* (1,1) = 9, *p* = 0.205). The belt x subject, weight x subject, and belt x weight interactions were significant. To further investigate the significant two-way interactions, an ANOVA was conducted on the 4 conditions (2 subjects x 2 belts) for the belt x subject interaction followed by the Newman-Keuls range comparison test.

Separate ANOVAs and multiple comparison tests were also conducted for the subject x weight, and belt x weight interactions.

Analysis of the belt x subject interaction effect revealed that Subject 2 had a significantly lower work pulse with belt wearing (23.0 bpm) than without belt wearing (30.5 bpm). Subject 2's work pulse without belt wearing was significantly higher than subject 1's work pulse with belt wearing and without belt wearing. Subject 1's WP with belt wearing was lower but not significantly different than WP without belt wearing.

ANOVA and comparison tests of the weight x subject factor showed that the 25% SLS load resulted in the highest work pulse for both subjects. Subject 2 had a significantly higher work pulse than Subject 1 at all of the weight levels except at the 5% SLS level. Subject 2 had a work pulse that was significantly higher for each incremental increase in the weight of lift. The work pulses for Subject 1 at the 15% and 25% SLS load were significantly higher than the work pulse at 5% of SLS. The previous results suggest that Subject 2 was more physiologically strained than Subject 1 during the work sessions. This result could be anticipated since Subject 2 lifted a heavier absolute load than Subject 1, and did not regularly participate in resistance training.

Multiple comparison tests on the effect of weight on the differential WP (belt – no-belt) demonstrated that the effect of the belt factor on differential WP was the most negative for the 25% SLS load. Comparisons of the weight-belt conditions showed that the 25% SLS load with the belt resulted in a work pulse that was significantly lower than the work pulse for all of the other weight-belt conditions. The 15% weight of lift without the belt resulted in the next highest WP, but the WP was not significantly different from the 15% and 25% loads with the belt. The WPs for the 5% load with and without the belt were significantly lower than the WPs associated with other weight-belt conditions, but belt wearing did not produce a significant effect at this weight level.

In general, WP was constant across the periods for the 5% SLS load and 15% SLS load for both subjects. However, the 25% SLS load resulted in an increase in WP across the work periods for both subjects, indicating that the heaviest workload was fatiguing, especially for Subject 2. Subject 1 had a maximum pulse rate of 115 bpm (WP of 30 bpm). Subject 2 had a maximum pulse rate of 119 bpm (WP of 47 bpm). Both of the maximum pulse rates occurred in the no-belt session.

4.5.2 Change in Systolic Blood Pressure

Measurement variation may have contributed to a lack of consistency in all blood pressure measures for Experiment 1. The cuff was not worn during the work period, and the position of the cuff on the subject's arm across the measurements might not have been held constant. The main factors of weight, belt and period did not significantly affect the change in systolic blood pressure. The three way interaction of belt x weight x subject ($F(2,20) = 16.0, p = 0.0001$) was significant.

An ANOVA performed on the conditions formed by the belt x weight x subject interaction followed by mean comparison tests demonstrated that ΔSBP for Subject 2 for the 25% weight level with belt wearing was higher than for any other condition (13.8 mmHg). Subject 2's differential ΔSBP's for the belt factor at the 5% and 15%

loads were not significant. However, Subject 2's ΔSBP with and without belt wearing for both the 25% SLS load and the 15% SLS load were significantly higher than his ΔSBP for the belt and no-belt level at the 5% load. A comparison test of the differential ΔSBP at each of the three weight levels (combined belt and no-belt) for Subject 2 demonstrated that the ΔSBP at the 15% load was significantly higher than the 5% and 25% weight levels.

The highest ΔSBP for Subject 1 occurred with belt wearing at the 15% load (12 mmHg). Subject 1 had a significantly higher ΔSBP with belt wearing at this load than without belt wearing. However, Subject 1 had a significantly negative differential ΔSBP for the belt factor for the 5% and 25% load. This might have been due to the order of belt wearing since Subject 1 lifted with the belt second under both conditions, but this does not explain the positive differential for the 15% load.

The negative differential ΔSBP might represent a vasodilative blood pressure undershoot with belt wearing due to the sudden release of the load, and the immediate perfusion of blood into the previously occluded active muscle mass. Hypotension is a common hemodynamic occurrence in the recovery period with nonfatiguing resistance exercise. The hypertensive blood pressure response may be due to the use of the Valsalva maneuver or intramuscular tissue pressure, or ischemia.

In summary, the highest ΔSBP's occurred for the heavier weights of lift, and the lower ΔSBP's occurred for the lowest weights of lift. An exception to this occurred with Subject 1, where the 25% load with belt wearing resulted in a mean ΔSBP that was slightly lower than that observed during rest. However, this may have been due to a carry-over effect, since Subject 1 lifted with the belt last. Blood pressure cuff positioning variation between sessions may have also contributed to the failure to identify significant differences.

The weight x period interaction had a significant effect on ΔSBP (*F*(10,20) = 15.1, *p* = 0.0001). A separate ANOVA and multiple comparison test were conducted to examine the weight x period interaction. The results of the tests showed that none of the weight-period conditions differed significantly in terms of ΔSBP. However, 5 of the 6 highest ΔSBP measures occurred with the 25% SLS load. The later periods with the 25% load resulted in the highest ΔSBP's. However, for the lower weight levels, a distinct period effect was not evident. The highest SBP for Subject 1 was 114 mmHg, and occurred without belt wearing. The highest SBP for Subject 2 was 140 mmHg and occurred with belt wearing.

4.5.3 Change in Diastolic Blood Pressure

The belt, period and weight factors did not have a significant effect on ΔDBP. However, the belt x weight x subject interaction was significant (*F*(2,20) = 9.65, *p* = 0.01). Examination of the results of a means comparison test of ΔDBP at each of the weight levels showed that weight of lift did not result in a significant effect on differential ΔDBP. Means comparison tests of the belt x weight x subject interaction revealed that ΔDBP for Subject 2 at the 5% load with the belt (10 mmHg) was significantly higher than all other conditions. Subject 2 also had a significantly higher and positive differential ΔDBP due to the belt at the 25% load. For Subject 1, the differential effect of the belt on ΔDBP was significantly positive at the 15% load, but significantly negative at the 25% load. The significantly lowest (negative) ΔDBP occurred at the 25% load for Subject 2 without wearing the belt. The mean ΔDBP was higher with the belt for the 5% MVC load, but was similar for the 15% MVC and 25% MVC load levels. The mean ΔDBP decreased with the weight of lift for both belt levels.

The decrease in mean DBP for each of the belt conditions for Subject 1 with the heavier weights of lift may be attributable to a large vasodilative undershoot with the heavier weight levels that was triggered by the suddenly lowered intra-muscular pressure upon load release (MacDougall et al., 1985). This effect would not be expected with occlusion after lifting or with metabolic by-product accumulation. The reason for the significantly higher ΔDBP at the lowest weight of lift with belt wearing and the significantly lower ΔDBP at the heaviest weight of lift without belt wearing is not immediately apparent. Subject 2 lifted with the belt first. An order effect may have contributed. Intra-session blood pressure cuff position variation and measurement artifacts may have also contributed.

In summary, the highest DBP for Subject 1 was 118 mmHg and the highest DBP for Subject 2 was 91 mmHg. Subject 2's ΔDBPs with and without the belt were primarily negative in recovery, whereas Subject 1 experienced a mix of positive and negative ΔDBPs, but primarily negative, both with and without the belt. The negative recovery blood pressure responses are typical of the hypotension that often occurs after resistance exercise that does not result in intramuscular tissue pressure sufficient to trigger a reflex response.

4.5.4 Lower Left Back Discomfort

The effect of the belt factor on LBD was not significant. LBD significantly increased with period across both belt conditions ($F(5,5) = 26.7$, $p = 0.001$), and for each belt condition. The weight x period effect was also significant ($F(10,20) = 3.97$, $p = 0.02$). The pattern of responses showed that the highest LBD ratings were associated with the 25% load for periods 5 and 6, followed by the 15% load for periods 5 and 6. The LBD ratings for the 5th and 6th periods for the 25% load were significantly higher than all other weight-period conditions. All other weight-period conditions were not significantly different.

Lower left back discomfort was lower with the belt for the 5% load, but higher with the belt for the 15% and 25% MVC loads. The belt x weight x subject interaction was also significant ($F(2,20) = 15.4$, $p = 0.0001$). An ANOVA was run on the conditions formed by the subject, belt and weight factors. The Newman-Keuls means comparison test demonstrated that the differential effect of the belt on LBD for Subject 2 at the 15% and 25% loads was significant and positive (more discomfort with the belt). For Subject 1, the differential effect of the belt was negative and significant at the 5% load, but positive (more discomfort with belt) and significant at the 25% load. The belt x subject effect was also significant ($F(1,20) = 15.8$, $p = 0.0001$). Subject 2 had a significantly larger LBD (3.7) with belt wearing than without belt wearing (2.7), and this LBD rating was significantly larger than the LBD ratings for Subject 1 at both belt levels.

The weight x subject interaction had a significant effect on LBD ($F(2,20) = 9.2, p = 0.001$). The LBD for Subject 1 at the 25% load was significantly higher than his LBD at the 5% and 15% loads. For Subject 2 the 15% and 25% loads resulted in LBDs that were significantly higher than the LBD for the 5% load. The belt factor resulted in a significantly positive differential for LBD for the heavier weights of lift for both subjects, which may be indicative of greater work intensity for the LBD, or higher IMP for the lower left back muscles.

4.5.5 Lower Right Back Discomfort

The main factors of belt wearing, weight and period did not have a significant effect on lower right back discomfort (RBD), although many of the subject interactions were significant. The mean lower RBD ratings were lower than 1.0 for each of the belt-weight conditions, and therefore were not examined further.

4.5.6 Rating of Perceived Exertion

The weight x belt x subject interaction significantly affected RPE ($F(2,20) = 37.74, p = 0.0001$). The perceived exertion ratings for Subject 2 for the 15% (14.8) and 25% loads (14.6) with the belt were significantly higher than the RPEs for all other belt-weight-subject conditions. The RPE for Subject 1 for the 25% load (13.3) with belt wearing followed, and was significantly higher than without belt wearing. Subject 2 had a significantly higher RPE at the 5% load without the belt than with the belt. All other belt effects were not significant. In general, the RPE was higher with belt wearing at the 35% weight, but at the lower weights the pattern was not clear. The belt x period x subject effect was also significant ($F(5,20) = 2.88$, $p = 0.041$).

4.7 Conclusions and Recommendations

The following conclusions were reached from the analyses of the Experiment 1 data:

1. Linear regression equations explained 99% of the variability in actual force data for each belt used. Low standard errors existed for the intercepts and slopes for each prediction equation. Linear regression equations were sufficient for predicting belt force from the belt strap displacement measures.

2. The effect of rest time on pulse rate and systolic blood pressure was not significant at the 0.05 level. The effect of rest time on diastolic blood pressure was significant ($F(3,3) = 13.08$, $p = 0.031$). The DBP for the 5th minute was significantly higher than the DBP for the later periods of rest. These results showed that a rest duration of 10 minutes would be a sufficient period of rest prior to work.

3. The workload of 12 lifts per minute at 25% of static lift strength resulted in a mean work pulse of 36.5 bpm without belt wearing. The highest WP was 47 bpm at a pulse rate of 119 bpm. Since the sitting, resting pulse rate is lower than the standing, resting pulse rate, the mean work pulse exceeded the work pulse limit of 35 bpm for avoiding fatigue in continuous work (Grandjean, 1988). The mean lower left and right back discomfort was 3.5 and 0.25, respectively. The lower left back experienced slightly

higher than moderate discomfort, and almost no discomfort existed in the lower right back. The task resulted in a mean perceived discomfort rating of 12.3. The perceived exertion rating ranged from fairly light to somewhat hard. The subjects were able to complete all sessions without work cessation due to discomfort or fatigue. The subjects had some residual discomfort after 24 hours of recovery but none existed after 48 hours. The task was judged acceptable, but slightly fatiguing to the average, young male subject. Some low back muscle fatigue was expected.

4. The mean differential WP (belt – no-belt) was significantly lower (negative) at the heaviest load (25% SLS). The 25% load without the belt resulted in an average work pulse that was significantly higher than the work pulse for all other weight-belt conditions. The mean differential ΔSBP was significantly highest at the 15% load. The 25% load for Subject 2 for the belt factor resulted in a significant increase in differential ΔSBP. The ΔSBP for this belt-weight-subject condition was significantly higher than all other ΔSBPs. The highest ΔSBP for Subject 1 occurred at the 15% load with belt wearing. However, Subject 1 had a significant negative differential ΔSBP for the belt factor at the 5% and 25% loads. The weight factor did not significantly affect differential ΔDBP. There was not a consistent ΔDBP recovery pattern for either subject. Measurement variation and artifacts occurred due to the subjects not wearing the back belt during the work periods, and because the blood pressure cuff position was not marked to ensure that is was properly positioned across the periods.

5. A maximum lift duration of two hours was initially selected because it is representative of the work-rest schedule predominant in the U.S. industrial

environment. A two-hour work period allowed physiological and subjective measures to be evaluated across the NIOSH (1992) defined "moderate duration" of work. A two-hour work session allowed physiological strain and subjective response to be evaluated in the periods less than two hours.

6. The procedure did not require the subjects to wear the blood pressure cuff during work. The cuff and hose contour was not marked prior to the work sessions. This might have caused inconsistencies in the positioning of the cuff. Blood pressure measurement was delayed 15 seconds from the final lift of each period to place the cuff on the arm and adjust the cuff. It was recommended that the position of the cuff be marked with indelible ink and that the cuff be loosely worn during the work periods.

7. Empirical observation revealed that at least 48 hours was required between lift sessions in order to avoid residual low back discomfort carry-over effects. Each of the subjects experienced some discomfort after 24 hours of recovery, and were not allowed to lift. The subjects returned 24 hours later and the discomfort had dissipated. A minimum recovery period of 48 hours between work sessions was recommended.

CHAPTER 5

EXPERIMENT 2 RESULTS AND ANALYSES

5.1 Experiment 2 Overview

The main goal of Experiment 2 was to provide the researcher with a better understanding of the effect of belt wearing on physiological strain during an asymmetric stoop lift task performed at a frequency of lift of 12 times per minute, at a load weight of 25% MVC for a duration of two hours. In addition, Experiment 2 further aided the researcher in identifying and clarifying procedural problems and concerns, and rectifying these issues. Experiment 2 was conducted to:

1. determine the reliability of belt tension setting from day-to-day for the different weight levels,
2. determine if belt tension varied with the weight of lift,
3. determine if the tension set for the 25% MVC weight of lift significantly differed from the back belt tensions set in the Bowen et al. (1995) back belt study, and in the Madala (1996) back belt study,
4. evaluate the effect of rest time on pulse rate, systolic blood pressure and diastolic blood pressure with and without belt wearing
5. evaluate the effect of belt wearing and lift period on work pulse, blood pressure, low back discomfort, and rating of perceived exertion during a continuous

asymmetric stoop lift task with a load of 25% of the static lift strength lifted at a frequency of 12 lifts per minute,

6. evaluate the effect of belt wearing on pre and post asymmetric stoop lift strength,

7. evaluate the relationship between static lift strength and other subject and task characteristics, and the physiological measures, and

8. use the belt effect sizes and estimates of variability to compute the number of subjects required for different powers of the test.

5.2 Experimental Methodology

The facilities and equipment used in Experiment 2 were discussed in Section 3.2. Four healthy male subjects between the ages of 21 and 39 were recruited from the School of Industrial Engineering at the University of Oklahoma to participate in Experiment 2. One of the subjects participating in Experiment 2 (Subject 1) also participated in Experiment 1 (Subject 2). This subject was the only subject to perform some form of regular exercise at least two times per week, and was the most "fit". The remainder of the subjects did not participate in a regular exercise program. Table 5.1 provides the subject characteristics and task settings.

Table 5.1. Subject and Task Characteristics for Experiment 2.

SUBJECT CHARACTERISTICS	SUB. 1	SUB. 2	SUB. 3	SUB. 4	MEAN	S.D.	MIN.	MAX.
AGE	21	35	21	39	29	9.4	21	39
BODY WEIGHT (KG)	66.9	80.4	84.8	98.2	82.6	12.9	66.9	98.2
STATURE (CM)	177.8	171	177.8	180.4	176.8	4.0	171.0	180.4
ACROMION HEIGHT (CM)	144.8	139.7	152.2	144.8	145.4	5.2	139.7	152.4
KNUCKLE HEIGHT (CM)	76.2	78.7	81.3	68.5	6.2	5.5	68.5	81.3
KNEE HEIGHT (CM)	48.3	50.8	55.9	55.3	52.1	3.3	48.3	55.9
UPPER ARM GIRTH (CM)	31.8	31.8	34.3	36.2	33.5	2.2	31.8	36.2
CHEST WIDTH (CM)	24.3	32.3	33.0	33.25	32.8	0.47	32.3	33.3
CHEST DEPTH (CM)	21.3	23.3	29.0	26.25	24.9	3.3	21.3	29.0
ABDOMINAL GIRTH (CM)	80.0	97.5	95.0	105.0	91.4	6.9	81.3	96.5
ABDOMINAL DEPTH (CM)	20.0	28.2	27.0	33.3	24.3	4.9	17.5	29.3
HIP GIRTH (CM)	94.0	104.1	104.1	116.8	104.7	9.3	94.0	117
HIP BREADTH (CM)	24.5	33.2	38.1	37.3	33.3	6.2	24.5	38.1
PREDICTED PERCENT MUSCLE MASS	49.5	53.8	57.6	74.2	23.8	4.5	17.4	27.2
TASK CONTROL VARIABLES								
SAGITTAL HORIZONTAL DISTANCE (CM)	50.8	50.8	55.8	53.4	52.7	2.4	50.8	55.8
NON-SAGITTAL HORIZONTAL DISTANCE (CM)	43.2	43.2	45.7	40.6	43.2	2.1	40.6	45.7
SAGGITAL PLANE VERTICAL DISTANCE (CM)	91.5	91.5	100.3	100.3	95.9	5.1	91.5	100.3
NON-SAGITTAL PLANE VERTICAL DISTANCE (CM)	27.9	33.1	27.9	27.9	29.2	2.6	27.9	33.0
STATIC STRENGTH TEST								
STATIC STRENGTH IN ASYMMETRIC STOOP LIFT POSTURE (KG)	45.9	40.5	58.2	81.8	56.6	18.3	40.5	81.8
25% OF STATIC STRENGTH	11.5	10.1	14.5	20.5	14.15	4.64	10.1	20.5
BELT TENSION								
BELT TENSION SETTING (KG)	4.45	4.45	4.45	4.45	4.45	0	4.45	4.45

The independent variables, criterion measures, and control variables used in Experiment 2 were defined in Sections 3.4 through 3.6.

5.3 Experimental Procedure

The experiment was conducted in Room S-23 of the Carson Engineering Center. Task familiarization and subject characteristics data collection were performed in the first session, static lift strength and belt tension adjustment were performed in the second session, followed by belt tension adjustment in the third session. The experimental work sessions were completed across the next two sessions.

Four static lift strength trials were performed in the first belt tension adjustment session. The subject rested in a seated position for 2 minutes after each trial. The average of the last three strength trials defined the subject's static lift strength. Two 2-hour belt tension adjustment sessions were performed by each subject (see Section 3.8.2 for procedures). Each session consisted of six belt tension adjustment trials of 20 minutes each. The interval between sessions ranged from 24 to 48 hours.

Belt tensioning instructions were provided. The subjects were asked to tighten the belt to a tension that was tight but comfortable for a period of 2 hours. Two 20-minute belt tension adjustment trials were performed for each weight of lift (5%, 15% and 25% of static lift strength). The average of the tensions determined in the two trials was defined as the acceptable belt tension for the weight of lift. The belt tension data for the four subjects are provided in Appendix J.

After the belt tension adjustment trials were completed, the subjects participated in two experimental lifting sessions (25% of static lift strength for two belt conditions). At least 48 hours of rest were provided between sessions. The subjects performed lifting sessions within 96 hours of the previous lift session. The initial rest period was 22 minutes long. When the subject arrived at the lab, the pre-session static lift strength measurement was conducted. The subject rested for 2 minutes in a seated position between the trials. The average of the 4 trials was the subject's static lift strength. Table 5.2 provides the lifting schedule for the two subjects.

Table 5.2. Experiment 2 Lifting Schedule.

	SESSION			
SUBJECT	**1**	**2**	**3**	**4**
1	**No Belt (25% MVC)**		**Belt (25% MVC)**	
2	**Belt (25% MVC)**		**No Belt (25% MVC)**	
3		**No Belt (25% MVC)**		**Belt (25% MVC)**
4		**Belt (25% MVC)**		**No Belt (25% MVC)**

After completion of the static lift strength test, the subject began the initial rest period. If the belt was not worn during the work period, then the belt was not worn during the initial rest period. If the belt was worn during the lift session, then the belt was placed on the subject at the 10th minute of the initial rest period and was worn by the subject for the remainder of the session.

The experimenter aided the subject in adjusting the overlap of the outer belts to attain a belt tension of 4.5 kg. The experimenter marked the required left belt strap overlap distance on the right belt strap with duct tape. The subject pulled the left belt strap to the proximal edge of the tape, and secured the left belt strap on the velcro on the right belt strap. The subject rested in a normal standing posture.

The schedule for measuring pulse rate, blood pressure, LBD, RBD and RPE is displayed in Table 5.3. Pulse rate was measured continuously during the rest period. Baseline pulse rate measures were obtained by averaging the pulse rate from the 15th to the 20th minutes of the rest period. Blood pressure was measured at the 5th, 10th, 15th and 20th minutes of rest. The baseline blood pressure measure was obtained at the 20th minute of the initial rest period.

Table 5.3. Pulse Rate and Blood Pressure Measurement Schedule.

Elapsed Time (min)	Belt Wearing Condition	Measurement
0 – 4	No Belt	PR
4 – 5	No Belt	PR
5 – 9	No Belt	PR
9 – 10	No Belt	PR/SBP/DBP
10 – 11	(Belt Installation)	PR
11 – 14	Belt	PR
14 – 15	Belt	PR/SBP/DBP
15 – 18	Belt	PR
18 – 19		PR/LBD/RBD/RPE
19 – 20		SBP/DBP
20 – 22	Belt	Pulse Download/ Determination of 135% of Resting Pulse

Legend: PR = pulse rate, SBP = systolic blood pressure, DBP = diastolic blood pressure, RBD = low right back discomfort, LBD = low left back discomfort, RPE = rating of perceived exertion

The perceived exertion rating and LBD and RBD measures were elicited at the 18th minute. At the completion of 20 minutes of rest, the Polar watch was removed from the subject, the pulse data were downloaded, the lower pulse rate limit was set in the watch, and the watch was repositioned on the subject's wrist. At the completion of the 22nd minute of rest, the subject began the first of six 20-minute work periods. During the work periods, the subject positioned his heels over duct tape marks on the floor. This aided the subject in maintaining approximately the same foot position across the work session. The subject lifted or lowered the tote box every 5 seconds at the sound of a computer-generated tone. Each subject performed 120 cycles of lifting and lowering.

The blood pressure cuff was worn by the subjects during the work periods, and the contour of the cuff and hose were marked to ensure a consistent cuff position across measurements. At the 18th minute of each period the LBD, RBD and RPE were elicited from the subject. Blood pressure measurement was begun 5 seconds after the final lift of each period. The cycle time for blood pressure measurement was 45 seconds. The subject rested for the longer duration of either pulse rate recovery to within 135% of the resting pulse rate or completion of blood pressure measurement (approximately 50 seconds). When recovery pulse rate and/or blood pressure measurement were complete, the subject began the next period. This cycle of lifting, blood pressure measurement, and rest was performed by each subject six times for each work session. At the completion of the six work periods, the Polar Vantage transmitter, watch receiver, and back belt were removed and the subject performed the post-lift static lift strength test. The procedures used in measuring SLS in the post-lift static strength test were the same as those documented in Section 3.7.4.

5.4 Results and Analyses

5.4.1 Belt Tension Setting Repeatability

The PROC CORR procedure in the SAS 6.12 programming language was used to compute the Pearson correlation coefficients between the subject's belt tension measures for the two sessions. The belt tension setting and belt length displacement were significantly correlated with the weight of lift. As the weight of lift increased, the belt tension increased. Across the 5%, 15% and 25% MVC loads the belt tension in Session 1 was significantly related to the belt tension in Session 2 ($r = 0.88$, $p = 0.0001$). The subjects were highly reliable in setting belt tension between the two sessions. Table 5.4 shows the significant correlations.

Table 5.4. Belt Tension Setting Correlations.

	Weight Of Lift	**Session 1 Tension**	**Session 2 Tension**	**Waist Size**
Weight of Lift	1.0 (0.0)	0.59 (0.043)	0.61 (0.035)	N.S.
Session 1 Tension		1.0 (0.0)	0.88 (0.0001)	0.82 (0.0002)
Session 2 Tension			1.0 (0.0)	0.87 (0.0002)

For the individual weight levels, the relationship between the tensions for Session 1 and Session 2 for the 5% load ($r = 0.95$, $p = 0.04$), and the 25% load ($r = 0.95$, $p = 0.04$) were highly positive and significant. The correlation for the 15% load ($r = 0.54$, $p = 0.45$) was positive but not significant. In addition, the waist size was significantly correlated to belt tension for the 5% MVC condition.

To further evaluate the effect of the weight of lift on belt tension, an ANOVA was performed on the belt tension data for the 5, 15 and 25% MVC loads for the two belt tension adjustment sessions. The session did not have a significant effect on the belt tension level. However, the weight of lift significantly increased the belt tension ($F(2,6) = 6.69$, $p = 0.029$). Comparison of the means using the Newman-Keuls means comparison test revealed that the tension for the 25% MVC load was significantly higher than the tension set for the 5% MVC load (9.8 lb (± 1.7 lb) versus 7.3 lb (± 1.3 lb). The tension set for the 25% MVC load was not significantly different from the tension set for the 15% MVC load (7.6 lb (1.4 lb)), and the tension set for the 5% MVC load was not significantly different from the tension set for the 15% MVC load.

The belt tension set for the 25% MVC load in Experiments 1 and 2 of the current study (the average weight of lift was equal to 34.3 lbs (15.6 kg)), was compared to the belt tension set in the Bowen et al. (1995) floor-to-knuckle, and Madala (1996) knuckle-to-shoulder studies using the Cochran t test. The appropriate degrees of freedom for the t test was the number of subjects – 2 degrees of freedom. Table 5.5 provides the experimental conditions for each of the studies, and the statistical results. In the Bowen et al. (1995) study, the subjects were instructed to set the belt tension to a level that would be comfortable for 8 hours. In Experiments 1 and 2 of the current study, the subjects were instructed to set the belt tension to a level that would be comfortable for 2 hours of lifting. In the Madala (1996) study, the subjects were instructed to set the belt tension to a level that would aid in the lift and that would be comfortable for extended periods. The method of tension measurement in the three studies was different. In the Bowen et al. (1995) and Madala (1996) studies, tension was measured with the belt on the subject. A velcro strap attached to a load cell was used to measure the tension in each belt strap. In the current study, force-displacement regression equations were developed for each belt. During belt tension adjustment, the subject set the tension in the belt and the resulting overlap of the belt straps was measured and input into the appropriate regression equation to determine the tension. The mean belt tension set in the Bowen et al. (1995) was significantly larger (1.45 kg) than the mean tension set in Experiments 1 and 2 of this study. The mean tension set in the Madala (1995) study was significantly larger (4.04 kg) than the tension set in the current study. The reason for the difference in the tension settings between the current study and the two previous studies could be attributable to the instructions, task conditions or method of tension measurement. The mean tension in the Madala (1996) study, was significantly larger ($t(13) = 3.41$, Prob > $|t| = 0.012$) than the tension set in the Bowen et al. (1995) study.

Table 5.5. Belt Tension Comparisons with Prior Studies.

Study	Bowen et al. (1995) (a)	Bowen et. al. (1995) (b)	Madala (1996)	Whitney (1997)	Comparison of Studies	Bowen et al. (1995) (a) vs. Whitney (1997)	Madala (1996) vs. Whitney (1997)
Study Parameters							
Lift Type	Floor-to-knuckle (Lift and Lower)	Knuckle-to-shoulder (Lift and Lower)	Knuckle-to-Shoulder (Lift and Lower)	Floor-to-Knuckle (Lift and Lower)	Average Difference (kg)	1.45 kg	4.04 kg
Lift Plane	Sagittal Plane	Sagittal Plane	Sagittal Plane	90 degree Lateral Plane to Mid-sagittal Plane	t-Value	1.09	6.2
Number of Subjects	13	6	8	6	Df	17	12
Gender of Subjects	Male/ Female	Male	Male	Male	Prob (t) > 0	0.0429	0.0001
Frequency	2 lifts and 2 lowers per min	2 lifts and 2 lowers per min	3 lifts and 3 lowers per min	6 lifts and 6 lowers per min			
Weight (kg) (S.D.)	13.6 (2.2)	13.6 (2.2)	10.8 (2.1)	15.6 (3.8)			
Lift Duration	2 (20-min) periods	2 (20-min) periods	5 (4-minute) periods	2 hours			
Tension Measurement Method	Measured strap tension with belt on subject	Measured strap tension with belt on subject	Measured Strap tension with belt on subject	Measured strap Tension with belt on a fixture			
Tension (kg) (S.D.)	6.24 (1.3)	6.95 (1.1)	8.8 (1.0)	4.7 (1.4)			

The primary difference that would affect belt tension in these two studies was associated with the lift frequency and weight of lift. In the Bowen study, subjects lifted at a frequency of 2 lifts and 2 lowers per minute and the weight of lift was 13.6 kg (± 2.2), and in the Madala (1996) study subjects lifted at a frequency of 3 lifts and 3 lowers per minute with a weight of lift of 10.8 kg (± 2.1).

5.4.2 Belt Wearing Effect on Physiological Measures During Rest

An ANOVA was performed on the pre-session rest data to determine if the belt/rest period conditions had an effect on the physiological measures. Two belt levels and four time levels (no belt at 5 min, no belt at 10 min, no belt at 15 min, no belt at 20 min, belt at 15 min and belt at 20 min) comprised six belt x rest period conditions. The resting heart rate, SBP, and DBP data for Experiment 2 are presented in Appendix K. The ANOVA summary results are provided in Table 5.6.

Table 5.6. ANOVA Summary for Rest Time and Belt Condition Effect.

CRITERION MEASURE	FACTOR	DF	F	P>F
Pulse Rate	Subject	3	44.2	0.0001
	Condition	5	1.3	0.3000
	Condition x Subject	15	0.5	0.9000
Systolic Blood Pressure	Subject	3	13.7	0.0020
	Condition	5	1.9	0.9000
	Condition x Subject	15	1.8	0.1900
Diastolic Blood Pressure	Subject	3	24.3	0.0002
	Condition	5	2.3	0.0990
	Condition x Subject	15	0.8	0.6750

The belt x rest period conditions did not have a significant effect on pulse rate, systolic blood pressure or diastolic blood pressure at the 0.05 level. The subject factor was significant for the three criterion measures. Subjects 2 and 4 had significantly higher pulse rates and systolic and diastolic blood pressure measures than subjects 1 and 3. Subjects rested on a separate day with belt wearing than they rested without belt wearing. Therefore, the day-to-day variability in physiological response was confounded with the variability due to belt wearing. Therefore, an ANOVA was performed on the rest time data for the no-belt wearing condition only. The ANOVA summary and mean comparison test results are provided in Table 5.7. Pre-lift rest time did not significantly effect the physiological measures. However, the rest time of 10 minutes consistently resulted in the lowest or the next to the lowest blood pressure measure. Pulse rate was lower with a rest time of 15 and 20 minutes. However, the pulse rate difference between a rest time of 10 minutes versus 20 minutes was only 2 bpm. It was concluded that a rest time of 10 minutes was adequate for a meaningful decrease in the physiological responses.

Table 5.7. Mean Comparison Tests on Physiological Measures Across Rest Periods.

Criterion Measure	Factor	Means Comparison Ranking		DF	F	P>F
		Min.	BPM			
Pulse Rate (bpm)	Time	20	88	3,9	0.83	0.51
		15	89.2			
		10	90			
		5	91.2			
Systolic Blood Pressure (mmHg)	Time	20	122	3,9	0.74	0.55
		10	122.7			
		5	124.7			
		15	128.5			
Diastolic Blood Pressure (mmHg)	Time	5	80.7	3,9	1.08	0.41
		10	83			
		15	86			
		20	87.7			

5.5 Physiological Strain Data Analyses

The descriptive statistics for the criterion measures across the belt levels for each period and across the periods for the belt and no belt wearing levels are provided in Table 5.8.

Table 5.8. Descriptive Statistics for the Criterion Measures.

Measure / Belt Condition	Overall Mean (S.D.)	Lift Periods Mean (S.D.)					
		1	2	3	4	5	6
WP(bpm) Belt	30.5 (12.5)	29.0 (15.7)	30.5 (12.9)	29.8 (13.9)	29.3 (11.8)	30.8 (14.4)	33.5 (15.1)
No Belt	30.8 (8.8)	28.3 (10.0)	28.5 (7.7)	30.3 (8.3)	31.5 (10.6)	32.5 (10.5)	34.0 (10.2)
Δ SBP (mmHg) Belt	13.0 (9.9)	10.7 (5.7)	13.7 (10.4)	21.7 (13.7)	8.3 (2.9)	18.5 (6.8)	5.0 (10.2)
No Belt	4.7 (11.65)	11.7 (4.5)	12.8 (3.2)	3.3 (6.2)	0.0 (5.6)	-1.0 (19.3)	1.3 (18.0)
ΔDBP (mmHg) Belt	7.6 (15.1)	3.5 (4.5)	8 (11.4)	16.2 (20.5)	1.2 (13.5)	16.5 (16.7)	0.3 (9.22)
No Belt	-2.6 (16.0)	-6.7 (11.0)	-0.3 (6.8)	-5.5 (13.2)	5.5 (15.5)	5.8 (25.2)	-3.5 (24.6)
LBD Belt	1.9 (1.4)	1.0 (1.35)	1.3 (1.2)	1.6 (1.6)	2.1 (1.4)	2.5 (1.3)	3.3 (0.9)
No Belt	2.0 (1.6)	0.6 (0.9)	1.1 (1.0)	1.9 (1.3)	2.4 (1.5)	2.8 (1.7)	3.3 (2.1)
RBD Belt	1.6 (1.8)	0.6 (0.9)	0.9 (0.9)	1.6 (1.8)	1.9 (1.9)	2.4 (2.5)	2.5 (2.4)
No Belt	1.5 (1.9)	0.5 (0.6)	1.3 (1.5)	1.5 (1.9)	1.8 (2.4)	2.0 (2.8)	2.0 (2.8)
RPE Belt	12.8 (2.2)	11.5 (2.4)	11.8 (2.2)	12.3 (2.8)	13.3 (1.5)	13.8 (1.5)	14.8 (1.7)
No Belt	13.1 (1.9)	11.0 (2.2)	12.3 (1.5)	13.0 (1.6)	13.5 (1.3)	14.0 (1.4)	14.8 (1.5)

The physiological strain data were analyzed using a repeated measures design with belt wearing, weight of lift, and lift period as within-subjects factors. The trial factor served as a blocking factor for the sequence of belt wearing. The experimental model can be stated as follows:

$$y_{ijk} = \mu + B_i + P_j + S_k + T_l + BP_{ij} + BS_{il} + PS_{jl} + e_{ijkl}$$

where,

y_{ijkl} = criterion measure under consideration

μ = overall main effect

B_i = effect due to belt level, i = 1,2

P_j = effect due to work period, j = 1,......6

S_k = effect due to subject, k = 1,....4

T_l = effect due to order of belt wearing, l = 1, 2.

The ANOVA summary results for the criterion measures are presented in Table 5.9.

Table 5.9. ANOVA Summary for the Criterion Measures.

FACTOR		WORK PULSE		Δ SBP		Δ DBP		LBD		RBD		RPE	
SOURCE	DF	F	P	F	P	F	P	F	P	F	P	F	P
BELT	1	0.01	0.940	4.6	0.16	20.2	0.05 **	0.0	0.950	0.03	0.880	0.10	0.7800
PERIOD	5	3.4	0.030 **	1.3	0.33	0.6	0.68	6.0	0.007 ***	2.4	0.080	8.3	0.0006 ***
SUBJECT	3	15	.0001 ***	1.8	0.19	9.6	.0009 ***	16	.0001 ***	166.7	.0001 ***	55	0.0001 ***
BELT X PERIOD	5	0.6	0.720	2.2	0.11	0.5	0.77	1.3	0.300	0.9	0.530	0.5	0.740
BELT X SUBJECT	3	27.3	.0001 ***	2.6	0.11	0.5	0.59	47.7	.0001 ***	38.9	.0001 ***	16.4	0.0002 ***
PERIOD X SUBJECT	15	0.9	0.580	1.7	0.16	1.9	0.12	8.0	.0001 ***	1.9	0.300 ***	3.6	0.0009 ***
TRIAL	1	62.9	.0001 ***	3.9	0.07	1.7	0.22	5.2	.0380 **	0.6	0.44	0.00	1.0000
LEGEND: * p<0.1 ** p<0.05 ***p<0.005	Factors: O = order of belt wearing, B = belt, P = lift period, S = subject. Criterion Variables: Δ SBP = change in systolic blood pressure, Δ DBP = change in diastolic blood pressure, LBD = left back discomfort, RBD = right back discomfort, and RPE = rating of perceived exertion												

Table 5.9 shows that the belt had a significant effect on ΔDBP. The period had a significant effect on LBD and RPE. Belt x subject interaction had a significant effect on WP, LBD, RBD and RPE, and the period x subject interaction had a significant effect on LBD, RBD and RPE. The descriptive statistics for the criterion measures across the lift periods between the belt levels for each subject are provided in Table 5.10.

Table 5.10. Subject Descriptive Statistics.

Subject	WP Mean (S.D.)		ΔSBP Mean (S.D.)		ΔDBP Mean (S.D.)		LBD Mean (S.D.)		RBD Mean (S.D.)		RPE Mean (S.D.)	
	Belt	No Belt	Belt	No Belt	Belt	No Belt	Belt	No Belt	Belt	No Belt	Belt	No Belt
1	16.3 (3.3)	27.2 (3.0)	9.5 (5.0)	0.5 (10.1)	-6.7 (5.5)	-17.3 (6.5)	1.4 (1.1)	1.4 (1.1)	0 (0)	0 (0)	14.5 (0.8)	12.6 (2.8)
	NB (s.)											
2	21 (3.2)	22.6 (3.2)	16.6 (16.0)	-2.0 (14.5)	15.3 (14.2)	-0.67 (14.2)	1.9 (1.4)	3.41 (2.01)	2.5 (1.7)	4.1 (1.9)	10.8 (2.4)	12.6 (2.8)
					B (s.)		NB (s.)		NB (s.)		B (s.)	
3	40.8 (1.9)	44.2 (4.4)	10.6 (3.7)	12.5 (11.3)	8.0 (7.2)	6.0 (22.9)	0.8 (0.6)	0.5 (0.4)	0.5 (0.3)	0.0 (0.0)	11.6 (0.8)	11.8 (0.9)
4	43.6 (3.4)	29.3 (1.9)	15.2 (10.6)	7.6 (5.1)	13.8 (11.3)	1.5 (8.01)	3.6 (0.5)	2.7 (0.5)	3.5 (1.2)	1.8 (0.4)	14.3 (1.5)	13 (0.6)
	B (s.)				B (s.)		B (s.)		B (s.)		B(s.)	
LEGEND:	NB – not wearing a belt resulted in a higher criterion response than wearing a belt. B – wearing a belt resulted in a higher criterion response than not wearing a belt. s. – significant at the 0.05 level.											

The back belt factor had a significantly negative effect on WP for subject 1 and a significantly positive effect on WP for subject 4. Subjects 2 and 4 experienced a significant positive differential ΔDBP with back belt wearing. A positive differential ΔDBP might be indicative of a higher muscle relaxation pressure or ischemia.

5.5.1 Work Pulse

The ANOVA results demonstrated that period had a significant effect on work pulse for the combined belt treatments (*F*(5,15) = 3.39, p = 0.030). The Newman-Keuls means comparison test revealed that work period 6 resulted in a significantly higher work pulse than work periods 1 through 5 for the combined belt treatments. Evaluation of the period effect at each belt level revealed that the period did not have a significant effect on work pulse. The belt x subject interaction was also significant (*F*(2,15) = 27.3, p = 0.0001). A separate ANOVA with 8 conditions (4 subjects x 2 belt conditions) and a multiple comparison test was performed to examine the interaction. Subject 1 had a significantly lower work pulse with back belt wearing than without, and Subject 4 had a significantly higher work pulse with the back belt than without The trial factor (sequence of back belt wearing) had a significant effect on work pulse (*F*(1,15) = 62.9, p = 0.0001). Subjects 2 and 4 wore the belt in the first trial. Subject 2 had a smaller decrease in the differential work pulse than subjects 1 and 3. Subject 4 had a significantly positive differential work pulse. These results may suggest that wearing the back belt in the first trial tended to decrease or reverse the negative differential effect of the belt factor on work pulse. Subject 4, the oldest and least fit subject, had the largest static lift strength and abdominal girth in comparison with the other subject. Subject 4 also experienced the highest average pulse rate (155.6 bpm), which occurred with back belt wearing. Subject 1 was the most "fit" subject and was task conditioned, having participated in six 2-hour work sessions in Experiment 1 as Subject 2. These aspects may have contributed to the significant positive work pulse differential for Subject 4 and the significant negative work pulse differential for Subject 1. All subjects experienced an increase in WP across the work periods indicating that the task was fatiguing.

5.5.2 Change in Systolic Blood Pressure

The subjects were not instructed to breath normally prior to the work sessions. Holding the breath during lifting might have affected the blood pressure responses. None of the independent factors had a significant effect on ΔSBP. Observation of the subject x belt interaction trend lines displayed in Figure 5.1 shows that Subjects 1, 2, and 4 experienced higher mean ΔSBP with belt wearing than without belt wearing. Subject 3 had a lower ΔSBP with belt wearing than without belt wearing. In summary, belt wearing produced a meaningful increase in the average differential ΔSBP across the periods (13.0 mmHg with the belt versus 4.7 mmHg without the belt). The ΔSBP tended to increase for each subject across the periods. This might be representative of a higher physiological workload. However, there was a tendency for the ΔSBP to

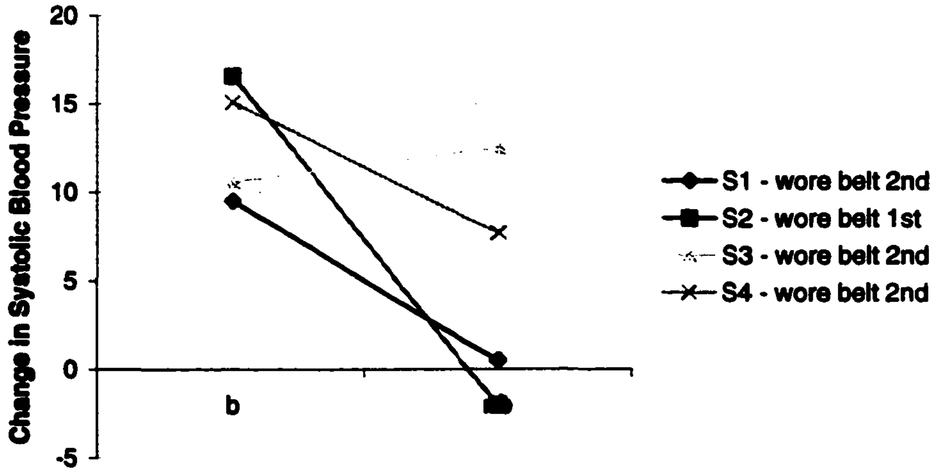

Figure 5.1. Subject x Belt Effect on Change in Systolic Blood Pressure.

decrease in the latter two periods. This might have been due to the recruitment of additional secondary muscles across the work periods due to fatigue, and the potential for a greater vasodilative effect upon load release. The increase in ΔSBP was not significant due to the high variability in ΔSBP between the subjects and across the lift periods. The high variability may have been the result of measurement artifacts or variation in subject breathing patterns, since the subjects were not instructed to breath normally prior to the sessions.

5.5.3 Change in Diastolic Blood Pressure

The differential main effect of the belt factor on ΔDBP was significantly positive ($F(1,2) = 20.2$, $p = 0.046$). The belt x subject interaction was also significant ($F(2,15) = 27.3$, $p = 0.0001$). A separate ANOVA with 8 conditions (4 subjects x 2 belt conditions) and a multiple comparison test was performed to examine the interaction. Examination of the results revealed that Subjects 2 and 4 experienced a significant higher positive ΔDBP with belt wearing than without. Subject 4 had the highest static lift strength, and the largest predicted muscle mass. Subjects 2 and 4 also had the largest abdominal girths of the four subjects, and were the oldest and least fit. Subject 1's responses were unique in that with belt wearing the ΔDBP was slightly negative, and without belt wearing it was more negative. This may be due to a vasodilative triggered blood pressure undershoot from the release of the load. Subject 3 had the smallest positive differential ΔDBP. Negative ΔDBPs and negative or low ΔSBPs are common recovery blood pressure responses after non-fatiguing dynamic or resistance work.

Figure 5.2 displays the mean ΔDBP response for each back belt treatment for each period. With belt wearing, mean ΔDBP had a high of 14 mmHg above baseline in period 3, and a low of 0.25 mmHg above resting in period 6. Without the belt, the highest ΔDBP was 5.75 mmHg in period 5, and the lowest was -6.75 mmHg in period 1. The ΔDBP increased in the beginning lift periods with belt wearing, and then tended to decrease in lift periods 5 and 6. The mean ΔDBP without the belt, was negative for the first 4 lift periods, and then increased slightly, and then decreased below resting in lift period 6. The ΔDBP without back belt wearing is a typical hypotensive response demonstrated in recovery from non-fatiguing dynamic or resistance work.

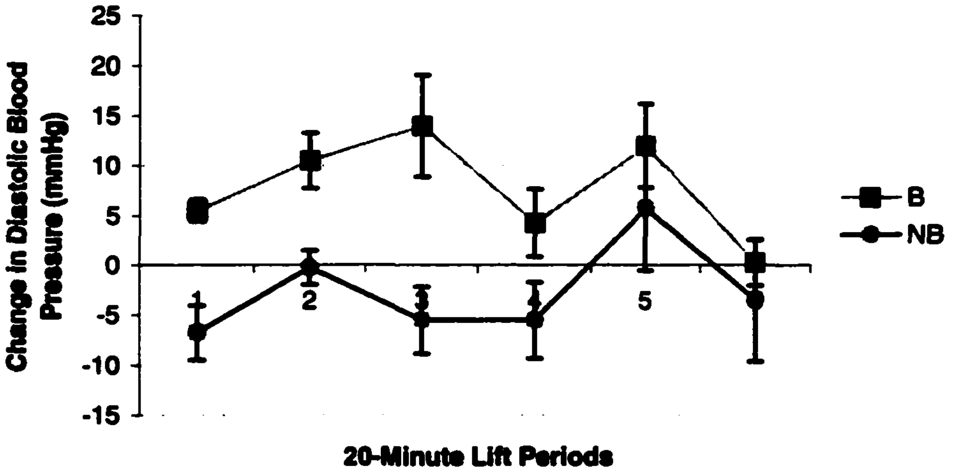

Figure 5.2. Belt x Period Effect on Change in Diastolic Blood Pressure.

The intrasubject variability in ΔDBP was high. This might be indicative of the use of the Valsalva maneuver. Kirkendall et al. (1980) demonstrated that recovery systolic blood pressure measured immediately after arm curls and leg presses underestimated peak systolic blood pressure during exercise by approximately 30%. Indirect measurement (auscultatory technique) of recovery systolic blood pressure was 12% less than direct measurement (intra-arterial) in work and in recovery. An analysis of the average of the maximum SBP and DBP during recovery and estimates of the peak SBP and an estimate of the intra-arterial DBP during recovery occurring across all the subjects is provided in Table 5.11. The blood pressures for the two subjects that had significant increases in blood pressure, are also provided in Table 5.11.

Table 5.11. Comparison of Highest Blood Pressures.

Subjects	**Belt**		**No Belt**	
	SBP (Est. SBP) MmHg	**DBP (Est. DBP) mmHg**	**SBP (Est. SBP) MmHg**	**DBP (Est. DBP) MmHg**
All subjects	143±18.6 (186)	114±18.4 (127)	137±5.6 (178)	100±18.5 (112)
Subjects with Significant Differential Blood Pressure	153 (198)	128 (143)	133 (173)	99 (110)

Legend: SBP = Measured recovery SBP, SBP Est. = Estimated Peak intra-arterial SBP, DB*P* = Measured recovery DBP, DBP Est. = Estimated Intra-arterial DBP in recovery..

The estimated peak intra-arterial SBP, and average recovery systolic blood pressure with the back belt exceeded the estimated peak and average recovery SBP without the back belt for the two subjects that experienced a positive significant differential ΔSBP by 25 mmHg and 20 mmHg, respectively.

5.5.4 Subjective Responses

The lift period had a significant effect on LBD with the belt ($F(5,15) = 9.39$, $p = 0.0003$) and without the belt ($F(5,15) = 6.58$, $p = 0.0002$). The period x subject interaction was also significant ($F(15,15) = 8.0, p = 0.0001$. The trial (sequence of belt wearing) effect was significant ($F(1,15) = 5.21, p = 0.0375$), although a pattern of LBD response due to the trial factor is difficult to discern. Subject 4's LBD increased dramatically in the first period and then was steady rate for the remainder of the session. Subject 4's LBD response across all of the lift periods was higher with the belt than without. The LBD response for the other subjects increased monotonically across the periods both with and without the belt. The belt x subject interaction had a significant effect on LBD ($F(3,15) = 47.7, p = 0.0001$). The Newman-Keuls means comparison test was used to test the significance of the belt versus no belt wearing conditions for the individual subjects. Subject 2 had a significantly lower LBD with belt wearing than without belt wearing, and Subject 4 had a significantly higher LBD with belt wearing than without belt wearing. Both of these subjects lifted with the belt during their first trial. The positive differential LBD of Subject 4 may be related to the increase in ΔDBP that he experienced with belt wearing. However, Subject 2 also experienced a positive differential ΔDBP, and had a negative differential LBD. This suggests that different physiological processes may have resulted in the positive differential ΔDBP for these two subjects, or belt wearing tended to alter the perception of discomfort for Subject 2.

The belt x subject interaction had a significant effect on the RBD ($F(3,15) = 38.9, p = 0.0001$). The Newman-Keuls multiple comparison test was used to test the significance of the belt versus no belt wearing conditions for the individual subjects. Subject 2 had a significantly lower RBD with belt wearing than without belt wearing, and Subject 4 had a significantly higher RBD with belt wearing than without belt wearing. Subjects 2 and 4 lifted with the belt during their first trial. The trial effect was not significant. Subjects 2 and 4 displayed significantly higher RBDs than Subjects 3 and 1 with and without the belt. Also, the RBD for Subject 2 without the belt was significantly higher than Subject 4's RBD with the belt.

Subjects 1 and 3 had the two lowest LBD and RBD measures of all the subjects for both belt conditions. These same two subjects did not experience a positive differential blood pressure effect. On the other hand, Subjects 2 and 4 had positive and significant differential ΔDBP, and experienced differential discomfort effects.

The lift period had a significant effect on RPE with the belt ($F(5,15) = 7.38$, $p = 0.0011$), and without the belt ($F(5,15) = 6.0$, $p = 0.003$). For the belt wearing condition, means comparison tests showed that lift period 6 resulted in an RPE that was significantly larger than the RPEs for lift periods 1, 2 and 3. Lift period 5 and period 4 were significantly different than lift period 1. For the no belt wearing condition, the RPE for lift period 1 was significantly lower than the RPE for lift periods 2 through 6. However, the lift period x subject factor was significant ($F(15,20) = 4.7$, $p = 0.0021$). The significant interaction resulted from the non-parallel pattern of RPE responses displayed by Subjects 2 and 3. Subject 2 began period 2 with a RPE rating lower than the RPE rating of Subject 3. In period 3, Subject 2's RPE increased to a level higher than the RPE of Subject 3 and remained higher throughout the next three lift periods. The belt x subject interaction had a significant effect on RPE ($F(1,2) = 12.3$, $p = 0.0001$). The Newman-Keuls means comparison test was used to test the significance of the belt versus no belt wearing conditions for the individual subjects.

Subject 2 had a significantly lower RPE with belt wearing than without belt wearing, and Subject 4 had a significantly higher RPE with belt wearing than without belt wearing. In a dynamic task, RPE is linearly related to pulse rate. In a combined static and dynamic lifting task, RPE increases and disassociates from pulse rate to reflect the static component or an elevated IMP. The LBD, RBD and RPE responses of Subject 2 are in agreement but do not reflect the positive, significant differential ΔDBP for this subject. These results may suggest that the comfort and support provided by belt wearing masked the discomfort of the low back muscles for Subject 2 or that the higher physiological strain measures with belt wearing were due to some other physiological event not related to muscle discomfort.

5.6 Belt Effect on Static Lift Strength in the Asymmetric Stoop Posture

Static strength measurements in the 90 degree lateral plane (without belt wearing) were conducted prior to (pre) and immediately after each lifting session (post). Table 5.12 shows the pre and post static strength data for each of the four subjects. The coefficient of variation ranged from 4% to 13% for the static strength measurement sessions. The repeatability of the strength trials was within the expected ranges, indicating high consistency between trials. The strength data were analyzed using a repeated measures design with belt wearing and trial (pre-session strength and post-session strength) as the within-subjects trial factor.

Table 5.12. Pre-Lift and Post-Lift Static Strength Data.

	Belt Wearing Mean (S.D.)					No Belt Wearing Mean (S.D.)				
Trial	Pre-Lift	CoV	Post-Lift	CoV	% Diff.	Pre-Lift	CoV	Post-Lift	CoV	% Diff.
Subject										
1	55.1 (6.2)	0.11	46.9 (2.8)	0.06	14.8	43.7 (0.8)	0.02	38.2 (1.7)	0.04	12.5
2	42.3 (1.9)	0.04	35.4 (4.4)	0.13	16.3	39.0 (3.4)	0.08	36.2 (1.8)	0.05	7.1
3	55.6 (3.5)	0.06	47.4 (2.4)	0.05	14.7	44.6 (2.9)	0.06	41.2 (4.0)	0.10	7.6
4	86.6 (3.9)	0.05	63.2 (0.9)	0.01	27.0	85.0 (6.4)	0.07	75.4 (5.9)	0.07	11.2

The ANOVA summary results displayed in Table 5.13 revealed that the effect of the belt x trial interaction on static strength was not significant at the 0.05 level ($F(1,3) = 6.06$, $p = 0.0908$), but was significant at $\alpha = 0.1$.

Table 5.13. ANOVA Summary Results for the Strength Measures.

	STATIC LIFT STRENGTH		
SOURCE	DEGREES OF FREEDOM	F	P
BELT	1	1.07	0.3760
TRIAL	1	9.69	0.0528
BELT X TRIAL	1	6.06	0.0908
SUBJECT	3	177.96	0.0007
SUBJECT X BELT	3	7.44	0.0670
SUBJECT X TRIAL	1	0.91	0.5750

5.7 Analyses of the Relationships Among the Criterion Measures

Numerous correlation analyses were performed to better understand the relationship of the criterion measures. Correlations were performed as follows:

1. Across all subjects and belts between response variables. Correlation between the observations (4 subjects x 6 lift periods x 2 belt conditions = 48 observations) collected on one criterion measure with the observations collected on another criterion measure or subject or task measure.
2. Across all subjects between response variables. Correlation between the observations (4 subjects x 6 lift periods = 24 observations for the belt level and 24 observations for the no belt level) for two different criterion measures or one criterion measure and one subject or task measure for a belt level.
3. Across all subjects between belts. Correlation between the observations (4 subjects x 6 lift periods = 24 observations) for a criterion measure between the belt and no belt wearing levels.
4. For each subject between belt levels for each criterion measure. Correlation between the observations (1 subject x 6 observations = 6 observations for each belt level) for each subject and each criterion measure.
5. For each subject across belt levels, between criterion measures. Correlation between observations (6 lift periods x 2 belt levels = 12 observations for each correlation) obtained on one criterion measure with another criterion measure or subject or task measure.

All of the criterion measures were evaluated pair-wise in the correlation analyses. The subject factors of weight of lift and abdominal circumference were included. The subject specific task factors of horizontal distance of lift in the lateral plane and vertical distance of lift (difference between the tote box height in the lateral plane and the tote box height in the sagittal plane) were also incorporated. Table 5.14 provides the results of the correlation analyses across the subjects for the criterion measures. Table 5.15 provides the correlation analyses for each subject between belt levels for each of the criterion measures, and the correlations for each subject across the belt levels for each criterion measure. Table 5.16 provides the correlation analyses across the subjects for each subject and task measure. Table 5.17 provides the regression analyses for the criterion measures with respect to the subject and task parameters.

Several speculations can be developed from the results displayed in Table 5.14. First, the negative relationship between RPE and work pulse is indicative of a task that has a static component both with and without belt wearing. The higher correlation between ΔSBP and ΔDBP with belt wearing may be indicative of greater physiological work, intramuscular relaxation pressure, ischemia or different breathing patterns with belt wearing, as all of these will cause recovery blood pressure to be elevated. The positive significant correlation between ΔDBP and RBD with belt wearing, but not without belt wearing, may reflect a higher workload for the ipsilateral rotators and higher intra-muscular pressures during lateroflexion. The higher significant correlation between RPE and LBD with belt wearing may suggest that greater intra-muscular pressure occurs with the belt than without the belt. Finally, all criterion measures were significantly correlated between the belt conditions, which suggests that the pattern of the responses were similar in the belt and no belt wearing conditions.

Table 5.14. Correlation Analyses Results Across Subjects Between Criterion Measures.

CRITERION MEASURES	ACROSS ALL SUBJECTS & BELTS BETWEEN CRITERION MEASURES	ACROSS ALL SUBJECTS BETWEEN CRITERION MEASURES		ACROSS ALL SUBJECTS BETWEEN BELT LEVELS	
		Belt	No Belt	Criterion Measure	
WP & SBP	0.1585 (0.281)	0.0457 (0.8317)	0.3499 (0.093)	WP	0.6049 (0.0017) ***
WP & DBP	0.2859 (0.0488) *	0.3112 (0.1388)	0.3362 (0.1081)	SBP	0.3895 (0.0599) *
WP & LBD	-0.0004 (0.9975)	0.3112 (0.1388)	-0.3962 (0.0538)	DBP	0.5239 (0.0086) ***
WP & RBD	-0.0343 (0.8166)	0.3318 (0.1379)	-0.4800 (0.0176)	RBD	0.7544 (0.0001) ***
WP & RPE	-0.0226 (0.8785)	-0.0145 (0.9461)	-0.0297 (0.8904)	RPE	0.7682 (0.0001) ***
SBP & DBP	0.687 (0.0001) ***	0.7322 (0.0001) ***	0.5809 (0.0029) ***		
DBP & RBD	0.2488 (0.0880)	0.4403 (0.0313) **	0.1117 (0.6030)		
DBP & RPE	-0.3384 (0.0186) **	-0.3951 (0.0560)	-0.2945 (0.1624)		
LBD & RBD	0.8383 (0.0001) ***	0.4403 (0.0313) *	0.8576 (0.0001) ***		
RPE & LBD	0.5687 (0.0001) ***	0.6091 (0.0016) **	0.5396 (0.0065) **		
Legend:	W*P* = Work Pulse, SB*P* = Systolic Blood Pressure, DB*P* = Diastolic Blood Pressure, LBD = Lower Left Back Discomfort, RBD = Lower Right Back Discomfort and RPE = Rating of Perceived Exertion				

Examination of Table 5.15 shows that Subjects 2 and 4, the two oldest and least "fit" subjects, were the only subjects to demonstrate positive, significant differential blood pressures with belt wearing. Subjects 2 and 4 also had the two highest abdominal girths, and the largest differential static lift strength decreases with back

Table 5.15. Correlation Analyses Results for Each Subject.

FOR EACH SUBJECT BETWEEN CRITERION MEASURES								
	SUBJECT							
	1		2		3		4	
CRITERION MEASURES	BELT TREATMENT		BELT TREATMENT		BELT TREATMENT		BELT TREATMENT	
	BELT	NO BELT	BELT	NO BELT	BELT	NO BELT	BELT	NO BELT
WP & SBP	0.7560 (0.082)	-0.772 (0.072)	-0.0077 (0.988)	-0.831 (0.040) *	0.1000 (0.850)	0.3395 (0.510)	-0.265 (0.611)	0.6732 (0.142)
WP & LBD	0.8452 (0.034) *	0.9725 (0.001) **	-0.297 (0.567)	0.9728 (0.001) **	0.737 (0.09) *	0.905 (0.013) *	0.1499 (0.776)	-0.656 (0.156)
WP & RBD	N/A	N/A	-0.266 (0.609)	0.9755 (.0009) ***	0.3258 (0.528)	N/A	0.2370 (0.651)	-0.415 (0.413)
WP & RPE	0.5748 (0.237)	0.959 (0.002) ***	-0.224 (0.668)	0.9421 (0.004) **	0.4627 (0.355)	0.9227 (0.008) **	0.758 (0.080)	-0.160 (0.760)
SBP & DBP	-.2650 (0.611)	0.488 (0.325)	0.9523 (0.003) **	0.329 (0.523)	-0.0881 (0.868)	0.9359 (0.006) **	0.984 (.0004) ***	0.205 (0.695)
DBP & RPE	-0.814 (0.048) *	-0.1389 (0.793)	-0.3718 (0.467)	-0.262 (0.615)	0.5095 (0.301)	0.766 (0.075)	-0.160 (0.761)	-0.1971 (0.708)
LBD & RBD	N/A	N/A	0.9753 (.0009) ***	0.9781 (.0007) ***	0.7833 (0.065)	N/A	0.9486 (0.003) **	0.6324 (0.177)
RPE & LBD	0.804 (0.053)	0.908 (0.012) *	0.974 (0.001) **	0.9695 (.0014)	0.8764 (0.022) *	0.9097 (0.011)	0.685 (0.132)	0.6123 (0.196)
RPE & RBD	N/A	N/A	0.9736 (0.001) **	0.9675 (.0016) **	0.774 (0.070)	N/A	0.650 (0.161)	0.7746 (0.070)

FOR EACH SUBJECT BETWEEN BELTS				
	1	2	3	4
WP	0.9167 (0.0100) *	-0.2322 (0.6579)	0.3283 (0.5252)	-0.3937 (0.9410)
SBP	-0.7321 (0.0980)	0.5866 (0.2221)	-0.201 (0.702)	-0.3791 (0.458)
DBP	-0.4154 (0.4127)	1.0000 (0.0001) ***	0.1306 (0.8052)	-0.1257 (0.8124)
LBP	1.0000 (0.0001) ***	0.9499 (0.0037) ***	0.7385 (0.0936)	1.0000 (0.0001) ***
RBP	N/A	0.9404 (0.0052) **	N/A	0.6000 (0.2080)
RPE	0.9201 (0.0093) **	0.8805 (0.020) *	0.9135 (0.0100) *	0.8401 (0.0363) **

belt wearing. Subject 4 had the highest static lift strength and predicted muscle mass, and Subject 2 had the lowest static lift strength. Subject 2 was the only subject to demonstrate a significant ΔDBP correlation between the belt conditions.

Table 5.16 provides the correlation analysis results across all subjects for the subject, task and criterion measures. The significant correlation for weight of lift and work pulse, weight and discomfort, abdominal girth and work pulse, and abdominal girth and discomfort for the belt wearing treatment, but not for the no-belt wearing treatment suggests that these factors explain some of the variability in the differential criterion responses.

Table 5.16. Correlation Analyses Results Across Subjects Between Response Measures.

CRITERION MEASURES	ACROSS ALL SUBJECTS & BELTS BETWEEN CRITERION MEASURES	ACROSS ALL SUBJECTS BETWEEN CRITERION MEASURES	
		Belt	No Belt
WT & WP	0.6029 (0.0001) ***	0.8398 (0.0001) ***	0.2877 (0.1728)
WT & LBD	0.2392 (0.1014)	0.5418 (0.0062) **	-0.0252 (0.9069)
WT & RBD	0.1105 (0.454)	0.4242 (0.0388) **	-0.1720 (0.4213)
AG & WP	0.4415 (0.0017)	0.719 (0.0001) ***	0.0626 (0.7711)
AG & DBP	0.5137 (0.0002) ***	0.6487 (0.0006) ***	0.4683 (0.0210) *
AG & LBD	0.4112 (0.0037) **	0.50230 (0.0124) **	0.3329 (0.1119)
AG & RBD	0.5824 (0.0001) ***	0.7183 (0.0001) ***	0.4621 (0.0230)
AG & RPE	-0.2954 (0.0415) **	-0.1917 (.3693)	-0.4194 (0.041) *
VERTD & WP	0.8085 (0.0001) ***	0.8976 (0.0001) ***	0.7119 (0.0001) ***
Legend:	WT = Weight of Lift, AG = Abdominal Girth, VERTD = Vertical Distance of Lift, LATD =Lateral Distance of Lift , LBD = lower left back discomfort, RBD = lower right back discomfort		

The regression of the difference in the criterion measures (belt – no belt) on the task and subject measures was performed to better understand the nature of these relationships. Table 5.17 provides the results of the regression analyses.

Table 5.17. Regression Analyses on Subject and Task Measures.

Criterion Measure	**Variable(s)**	**Partial R^2**	**Model R^2**	**F**	**Prob > F**
WP	BODWT WT/25%SLS	0.8217 0.0462	0.8217 0.8679	101.39 7.33	0.0001 0.0131
Regression Equation	WP = -71.8 + 1.61*BODWT – 1.69*WT				
LBD	VERTD	0.6564	0.6564	42.03	0.0001
	LBD = -8.93 + 0.1337*VERTD				
RBD	WT/25%SLS LBM	0.6801 0.1192	0.6801 0.7992	46.76 12.46	0.0001 0.0020
Regression Equation	RBD = 0.53 + 0.610*WT – 0.15*LBM				
RPE	WT/SLS AG	0.5624 0.0861	0.5624 0.6485	28.27 5.142	0.0001 0.0340
	RPE = 0.446 + 0.34*WT – 0.058*AG				
Legend:	Criterion Measures: WP = work pulse, SBP = systolic blood pressure, DBP = diastolic blood pressure, LBD = lower left back discomfort, RBD = lower right back discomfort, RPE = rating of perceived exertion. Subject Measures: LBM = lean body mass, SLS = static lift strength, BODWT = Body Weight. Task Measures: WT = weight of lift, LATD = lateral distance in nonsagittal plane, VERTD = vertical distance of lift				

The prediction equation that explained the highest percentage of variability in the difference between WP with and without belt wearing included weight of lift (static lift strength) and body weight. The model explained 86.7% of the variability in the differential WP for the belt factor. An increase in the weight of lift would increase differential muscle pump and stroke volume and decrease pulse rate. An increase in the body weight combined with back belt wearing would potentially increase IAP and

IMP, the pressor response, and/or the valsalva. None of the factors significantly predicted ΔDBP or ΔSBP at the 0.10 level. The best linear fit for the differential LBD was provided by the vertical distance of lift with an associated R^2 value of 65.5%. A larger distance of lift increases work intensity and intramuscular pressure, which is augmented with back belt wearing. A high percentage of the variability (79.9%) in the differential RBD was explained by the weight of lift, and the lean body mass. A stronger individual develops higher intramuscular pressures, and has a lower occlusion level than a weaker individual (Heyward, 1975). A larger muscle mass allows the load to be distributed across a larger active muscle mass. The differential RPE was best predicted by the weight of lift, and abdominal girth. The model explained 64.8% of the variability in RPE. As the weight of lift increased, the difference in the RPE with belt wearing versus not wearing a belt became larger. This suggests that lifting heavier weights with belt wearing is associated with a positive differential perceived exertion rating. The lifting of heavy weights increases IMP and torso stiffness. The wearing of a back belt increases external muscle pressure and provides resistance to trunk movement. A larger abdominal girth appears to reduce the positive differential RPE. This may suggest that individuals with larger abdominal girths perceive more comfort and support with back belt wearing than individuals with smaller abdominal girths.

5.8 Sample Size Requirements

Standardized power tables for the repeated measures design, the correlation between levels of the repeated factor, the anticipated effect size, and the following relation,

$$d = \frac{\mu_{max} - \mu_{min}}{\sigma}$$

were used to evaluate the power of the test (Maxwell and Delaney, 1990). The μ_{max} - μ_{min} corresponds to the difference between the largest and smallest means (across the belt levels) found, and σ = the overall model standard deviation. The D corresponds to the percentage of the standard deviation that is to be detected. For example, if it was desired to detect a true effect for d = 0.75, then we would want to detect an effect that is three-quarters standard deviation difference between the largest and smallest belt level means for the criterion measure.

Back belt wearing resulted in an upper mean SBP of 13.0 mmHg and a lower mean of 4.66 mmHg occurred without belt wearing. The standard error for the belt factor was of 9.6 mmHg. The correlation between the overall population ΔSBP with belt wearing and without belt wearing was found to be 0.389. The difference between the mean ΔSBP with the belt and the mean ΔSBP without the belt in the experiment was 8.34 mmHg. For diastolic blood pressure the difference between the upper mean and a lower mean was 5.15 mmHg. The correlation between the overall population mean ΔDBP with belt wearing and without belt wearing was 0.523. The standard error was 8.0 mmHg. The number of subjects required to detect 0.25, 0.5, 0.75, 1.00, 1.25 and 1.5 of $\sigma = 9.6$ mmHg (e.g., 2 mmHg to 15 mmHg) for ΔSBP and ΔDBP (e.g., 2 mmHg to 14 mmHg) with a power of 0.5, 0.8 and 0.95 at $\alpha = 0.05$ are provided in Table 5.18. The effect sizes for ΔSBP and ΔDBP resulted in a power of the test for the criterion measures that was less than 0.5. However, to detect a ΔSBP effect size of at least 8 mmHg in Experiment 3 with a power of at least 0.5, twelve subjects would be required. Thirty-five subjects would be required to attain a power of 0.95. At least 24 subjects would be required to detect a ΔDBP effect size of at least 5 mmHg with a power of 0.5. To attain a power of 0.95 would require at least 75 subjects. The number of subjects required to detect a meaningful ΔDBP effect with a power of 0.50 was in excess of the available experimentation time. Therefore, no further power computations were performed.

Table 5.18. Minimum Sample Size Requirements.

	Power For ΔSBP ($\rho = 0.389$)			**Power For ΔDBP ($\rho = 0.523$)**		
D	0.5	0.8	0.95	0.5	0.8	0.95
0.25	88	178	294	64	128	210
0.5	24	46	75	18	34	54
0.75	12	22	35	9	16	26
1.00	8	14	21	6	10	16
1.25	6	10	14	5	8	11
1.50	5	8	11	4	6	8

5.9 Conclusions

The following conclusions were reached from the analyses of the Experiment 2 data:

1. Significant agreement existed between the acceptable belt tensions determined in the two belt tension adjustment sessions for the 5% ($r = 0.95$, $p = 0.04$) and 25% loads ($r = 0.95$, $p = 0.041$). Waist size was significantly correlated to the acceptable belt tension for the 5% load ($r = 0.87$, $p = 0.0002$).

2. The weight of lift significantly increased the belt tension (*F*(2,6) = 6.69, *p* = 0.029). The tension set for the 25% load was significantly tighter than the tension set for the 5% load. The tension set for the 15% SLS load was not significantly different than the tension set for the 25% SLS and 15% SLS loads.

3. The average belt tensions set for the 25% SLS load in Experiments 1 and 2 of the current study were significantly lower than the mean belt tension set in the Bowen et al. (1995) study (t(17) = 0.0429, *p* = 0.042) and the belt tension set in the Madala (1996) study (t(12) = 6.2, *p* = 0.0001). The reason for the significant differences in the tension settings between the current study and the two previous studies could be attributable to the instructions provided, the task conditions, or the method of tension measurement.

4. The six belt x rest period conditions (no belt at 5 min, no belt at 10 min, no belt at 15 min, no belt at 20 min, belt at 15 min, and belt at 20 min) did not result in significant differences in pulse rate, systolic blood pressure or diastolic blood pressure. Pre-session rest time and belt wearing did not significantly affect the physiological measures.

5. Wearing the belt resulted in a significantly higher mean diastolic blood pressure than not wearing the belt (*F* (1, 3)= 20.2, *p* = 0.046). Subject 1 was the most "fit" of the subjects (Subject 2 from Experiment 1), had the smallest body weight and abdominal girth, and had the next to lowest static lift strength. Subject 1 had a significantly lower work pulse with belt wearing than without, and had the lowest

(negative) ΔSBP and ΔDBP measures of the four subjects. The belt factor did not have a significant effect on differential blood pressure for Subject 1. Subject 4 was the least "fit", had the highest body weight, and highest static lift strength. Subject 4 had a significantly positive differential work pulse.

It is speculated that the increase in workload with back belt wearing elevated sympathetic activity and decreased parasympathetic activity to increase cardiac output and blood pressure, and the increased cardiac output and pulse rate masked the augmented preload. Subjects 2 and 4 were the oldest, the least "fit", had the largest abdominal girths, and experienced a significantly higher ΔDBP with belt wearing than without. The high variability in ΔSBP may have been the result of an inadequate procedure to control foot position during and between work sessions. However, belt wearing produced a meaningful increase in the average differential ΔSBP across the work periods (13.0 mmHg with the belt versus 4.7 mmHg without the belt), and Subjects 2 and 4 had the largest positive differential ΔSBP. The larger SBP with back belt wearing provides mitigating support that differential workload was increased with belt wearing.

6. The two subjects (Subjects 2 and 4) that experienced a significant positive differential blood pressure effect had an estimated peak intra-arterial systolic blood pressure of 198 mmHg, and an estimated intra-arterial recovery diastolic blood pressure of 143 mmHg with back belt wearing. This compared to 173 mmHg and 110 mmHg without the back belt. Measurement of SBP and a DBP during recovery using the ausculatory technique revealed an average SBP reading of 153

mmHg, and DBP of 114 mmHg with the back belt, vs. 133 mmHg and 99 mmHg without the belt for these two subjects.

7. Subject 1 was the most "fit" subject, had the lowest body weight and smallest abdominal girth, lifted the next to the lowest absolute load, and experienced the smallest decrease in differential static lift strength. Subjects 2 and 4 were the least "fit", had the largest abdominal girths, and Subject 4 lifted the highest absolute load. Subject 4 had the most positive difference between the loss in static lift strength with belt wearing and the loss in static lift strength without belt wearing. Subject 2 had the next to the largest positive difference.

8. The negative, significant relationship between RPE and work pulse is indicative of a task that has a static component both with and without belt wearing. The positive significant correlation between ΔSBP and ΔDBP with belt wearing for Subjects 2 and 4, along with the lack of a correlation without belt wearing may be indicative of higher intra-muscular pressure or metabolite accumulation within the low back muscles or increased dependence on breath-holding for these two subjects. The positive significant correlation between ΔDBP and RBD with back belt wearing, but not without may reflect higher intra-muscular pressures during lateroflexion with the back belt. The body weight and weight of lift explained 86.7% of the variability in WP. The weight of lift explained 68% of the variability in lower right back discomfort, and 56.2% of the variability in RPE. A heavier weight of lift will increase trunk muscle activity, and intra-muscular pressure. These events may increase work pulse, lower back discomfort and RPE.

9. The power of the test for the criterion measures was less than 0.5. To detect a ΔSBP effect size of at least 8 mmHg in Experiment 3 with a power of at least 0.5, twelve subjects would be required. Thirty-five subjects would be required to attain a power of 0.95. At least 24 subjects would be required to detect a ΔDBP effect size of at least 5 mmHg with a power of 0.5. To attain a power of 0.95 would require at least 75 subjects. The number of subjects required to detect a meaningful ΔDBP effect with a power of 0.50 was in excess of the available experimentation time.

CHAPTER 6

EXPERIMENT 3 RESULTS AND ANALYSES

6.1 Experiment 3 Overview

The main objective of Experiment 3 was to evaluate the effect of belt wearing, work period, and order of belt wearing on work pulse, ΔSBP, ΔDBP, LBD, RBD, RPE and SLS for the well-conditioned subject. The asymmetric stoop lift was performed at a frequency of lift of 12 times per minute, at a load weight of 25% MVC for a duration of 2 hours. The relationship of the criterion measures, and subject and task factors between and across the belt conditions was also investigated. The relationship between measures of belt effectiveness (support, help and compliance) and the sensory dimensions of temperature, restriction, circulation, pressure and comfort were examined. The effect of belt wearing and rest was also studied, as was the repeatability of belt tension setting from trial to trial in the same session

6.2 Experimental Methodology

The facilities and equipment used in Experiment 3 were delineated in Section 3.2. Eight healthy male subjects between the ages of 21 and 29 were recruited from the University of Oklahoma and surrounding area. The desired qualifications for the participants were that they regularly perform resistance exercise or work, as well as, some form of dynamic exercise. Subject 1 performed weight lifting at least 3 times per week and either played tennis or basketball at least 1 time per week. Subject 2 was task conditioned, as one month earlier he had performed eight two-hour work sessions in Experiment 1 (subject 1). Subject 2 was also active in Judo at least 3 times per week. Subject 3 was an avid body-builder, and lifted free-weights at least 5 times per week, and ran 3 miles at least 2 times per week. Subject 4 was the least conditioned, performing some form of exercise one time per week. Subject 5 was a construction laborer and lifted frequently in his job. He also ran 5 miles at least 2 times per week. Subject 6 was an active all-round exercise enthusiast, enjoying basketball, weight-lifting, tennis or bicycling at least 4 times per week. Subject 7 was a brick layer, and also ran 5 miles at least 3 times per week. Subject 8 was an Army ROTC student, and enjoyed weight-lifting at least 3 times per week, and ran 3 miles at least 2 times per week. Table 6.1 displays the subject characteristics, and task settings.

Table 6.1. Subject and Task Characteristics for Experiment 3.

Subject Characteristic	Mean	Stdev	Min.	Max.
Age	22.8	4.3	19	29
Body Weight (kg)	78.4	11	65.9	95.5
Stature (cm)	173.5	5.5	167.0	185.0
Acromion Height (cm)	141.4	3.8	137.0	147.0
Knuckle Height (cm)	74.8	3.6	70.0	80.0
Upper Arm Girth (cm)	30.6	2.9	26.9	36.3
Chest Width (cm)	16.9	1.2	15.0	18.8
Chest Depth (cm)	29.2	2.9	23.1	31.3
Abdominal Girth (cm)	21.2	3.4	14.2	25
Abdominal Depth (cm)	86.5	9.9	75.1	103
Abdominal Breadth (cm)	20.4	3.7	15.3	26.3
Hip Girth (cm)	98.2	9.2	85.6	111.0
Hip Breadth (cm)	29.8	4.6	22.3	35.5
Thigh Girth (cm)	52.2	4.9	45.4	60.6
Abdominal Girth/Hip Girth Ratio	0.87	0.07	0.78	0.9
Predicted Lean Body Mass (kg)	61.1	9.1	46.4	73.5

Table 6.1. Subject and Task Characteristics for Experiment 3 (cont.).

Task Characteristics				
Sagittal Horizontal Distance (cm)	56.2	3.5	52.5	62.5
Non-sagittal Horiz. Distance (cm)	40.3	3.5	36.3	45
Sagittal Vertical Distance (cm)	97.0	4.2	92.5	105
Non-sagittal Vert. Distance (cm)	38.6	5.1	32.5	47.5
Static Strength Test				
Static strength in asymmetric Stoop lift posture (kg)				
25% of static strength	18.1	3.6	12.7	22.7
Belt Tension				
belt tension setting (kg)	17.3	2.3	17.3	17.3

The independent criterion variables and control variables used in Experiment 1 were delineated in Sections 3.4 through 3.6.

6.3 Experimental Procedure

The experiment was conducted in Room S-23 of the Carson Engineering Center. Task familiarization and subject characteristics data collection were performed in the first session, and static lift strength and belt tension adjustment were performed in the second session. The practice and two experimental sessions (belt and no belt wearing) were completed across the next three sessions. Four static lift strength trials were performed in the belt tension adjustment session. The subject rested in a seated position for 2 minutes after each trial (see Section 3.7.4 for procedures). The average of the last three strength trials was the subject's static lift strength. A one-half hour belt tension adjustment session was performed by each subject (Section 3.7.2). The subjects were told to cinch the belt to a tension that was tight but that would not restrict breathing for a work period of 2 hours. The session consisted of two belt tension adjustment trials of 15 minutes each. The subjects determined the acceptable tension for the 25% SLS load. The average of the tensions determined in the two trials was defined as the acceptable belt tension for the weight of lift. The belt tension data for the eight subjects is provided in Appendix J. After the belt tension adjustment trials were completed, the subjects participated in a 2 hour practice session, followed by two experimental sessions. The practice session and experimental sessions were conducted on separate days. A minimum recovery period of 48 hours and a maximum of 96 hours separated sessions. Table 6.2 provides the schedule for the practice and experimental sessions for the eight subjects.

Table 6.2. Experiment 3 Lifting Schedule.

SUBJECT/ DAY	DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY 7	DAY8	DAY9
1	PR		B		NB				
2	PR		B		NB				
3		PR			NB			B	
4		PR		NB			B		
5			PR			B		NB	
6	PR			B				NB	
7			PR			NB			B
8				PR		NB			B

Upon the subject's arrival to the lab, the pre-session SLS measurement was conducted. After completion of the static lift strength test, the subject began the initial rest period. The initial rest period was 12 minutes long. If the belt was not worn during the periods than the belt was not worn during the initial rest period. If the belt was worn during the lift session, then the belt was worn during the final 5 minutes of the rest period. The experimenter aided the subject in adjusting the overlap of the outer belts to attain a belt tension of 7.9 kg. The experimenter marked the required left belt strap overlap distance on the right belt strap with duct tape. The subject pulled the left belt strap to the proximal edge of the tape, and secured the left belt strap on the velcro of the right belt strap. The subject rested in a normal standing posture. The schedule for measuring pulse rate, blood pressure, LBD, RBD and RPE is displayed in Table 6.3. Pulse rate was measured continuously during the rest period. Baseline pulse rate measures were obtained from averaging the pulse rate from the 5th to 10th minutes of the initial rest period. Blood pressure was measured at the 5th and 10th minutes of rest. A baseline blood pressure measure was obtained at the 10th minute of the initial rest period

Table 6.3. Measurement Schedule.

Rest Period Time	**Belt Wearing Condition**	**Measurement**
0 – 4	No Belt	PR/SBP/DBP
4 – 5	No Belt	PR
5 – 6	Belt Installation	PR
6 – 8	Belt	PR
8 – 9	Belt	PR/LBD/RBD/RPE
9 – 10	Belt	PR/SBP/DBP
10 – 12	Belt	Pulse Download/ Determination of 135% of Resting Pulse
Legend: PR =pulse rate, SBP = systolic blood pressure, DBP = diastolic blood pressure, RBD = low right back discomfort, LBD = low left back discomfort, RPE = rating of perceived exertion		

The perceived exertion rating and LBD and RBD measures were elicited at the 8th minute. After the completion of 10 minutes of rest, the Polar watch was removed, the pulse rate data was downloaded, the lower pulse rate limit of 135% of resting pulse rate was set in the watch, and the watch was repositioned on the subject's wrist. At approximately the 12th minute of rest the subject began the first of six 20-minute work periods. Prior to beginning the work periods, the subject was instructed to breathe normally. During the periods, the subject positioned his feet over cardboard patterns that were taped to the floor. This aided the subject to maintain the same foot position across and between work sessions. The subject either lifted or lowered the tote box every 5 seconds at the sound of a computer-generated tone. Each subject performed 120 cycles of lifting and lowering. The subjects wore the blood pressure cuff during the work periods and the contour of the cuff and hose were marked to ensure a constant cuff position across measurements. At the 18th minute of each period the LBD, RBD and RPE were elicited from the subject. Immediately after the last lift of each period, the blood pressure cuff and hose were adjusted as necessary to align with the ink contours. Blood pressure measurement was begun 5 seconds after the final lift of each period. The cycle time for blood pressure measurement was 45 seconds. The subject rested for the longer duration of either pulse rate recovery to within 135% of the resting pulse rate or completion of blood pressure measurement (approximately 50 seconds). When rest and/or blood pressure measurement was complete, the subject began the next period. Each subject performed the cycle of lifting, blood pressure measurement, and recovery six times for each session. At the completion of the six periods, the Polar Vantage transmitter, watch receiver, and back belt were removed and the subject performed the post-session static lift strength test. The procedures used in measuring static strength in the post-lift static strength test were the same as those documented in Section 3.7.4.

6.4 Results and Analyses

6.4.1 Belt Wearing and Physiological Measures During Rest

An ANOVA was performed on the pre-lift rest data to determine if rest period and belt wearing had an effect on the physiological measures. Two belt conditions and three time factors (no belt at 5 min, no belt at 10 min, and belt at 10 min) comprised six belt x rest period conditions. The resting heart rate, SBP, and DBP data for Experiment 3 are presented in Appendix K. The ANOVA summary results are provided in Table 6.4.

Table 6.4. ANOVA Summary for Rest Time and Belt Condition Effect.

CRITERION MEASURE	FACTOR	DF	F	P
Pulse Rate	Subject	7	16.68	0.0003
	Condition	2	0.208	0.5254
	Condition x Subject	14	0.40	0.9371
Systolic Blood Pressure	Subject	7	6.73	0.007
	Condition	2	3.31	0.066
	Condition x Subject	14	1.38	0.329
Diastolic Blood Pressure	Subject	7	5.31	0.015
	Condition	2	3.56	0.073
	Condition x Subject	14	0.95	0.952

The belt-period conditions did not have a significant effect on pulse rate, systolic blood pressure or diastolic blood pressure during rest at the 0.05 level. A belt tension of 7.9 kg does not appear to sufficiently compress the abdominal volume or increase the intra-muscular pressure of the lower back muscles during rest to affect blood pressure. Subjects rested on a separate day with belt wearing than they rested without belt wearing. Therefore, the day to day variability in physiological response was confounded with the variability due to belt wearing.

6.4.2 Belt Tension Setting Repeatability

Belt tension adjustment setting was performed for each of the subjects using the psychophysical method of adjustments across two 15-minute lifting trials. Appendix J displays the results of these sessions. The tensile force in the belt was 7.8 kg (± 1 kg). The tension was not significantly correlated with weight of lift. This was due to the instructions provided to the subjects to "Tension the belt to a level that does not restrict breathing". The pair-wise relationships of trial 1, trial 2 (repeatability), the weight of lift, abdominal girth, predicted fat mass, and hip girth of the subjects were examined using the Pearson correlation coefficient. The significant results of the correlation analysis are displayed in Table 6.5.

Table 6.5. Pearson Correlation Coefficients (P > |R| under H0: Rho = 0) for Belt Tension and Anthropometric Measures.

	Trial 1 Tension	Trial 2 Tension	Abdominal Girth	Fat Mass
Trial 1 Tension	1.00 (0.000)	0.84 (0.008)	0.61 (0.107)	0.69 (0.0580)
Trial 2 Tension		1.0 (0.000)	0.84 (0.077)	0.69 (0.053)
Abdominal Girth			1.0 (0.000)	0.80 (0.016)

The tensions obtained in trial 1 were significantly correlated to the tensions found in trial 2. The tensions selected in trials 1 and 2 were significantly correlated to the abdominal girth and fat mass at the 0.10 level of significance.

6.5 Physiological Strain Data Analyses

The descriptive statistics for the criterion measures averaged across the periods between belt and no belt wearing and averaged across the subjects for each period between belt levels are provided in Table 6.6.

Table 6.6. Descriptive Statistics for the Criterion Variables.

Measure / Belt Condition	Overall Mean (S.D.)	Lift Periods Mean (S.D.)					
		1	2	3	4	5	6
WP(bpm) Belt	32.7 (11.5)	29.5 (9.7)	31.1 (11.5)	31.3 (11.5)	31.4 (11.9)	34.9 (12.7)	37.6 (13.0)
No Belt	32.2 (11.9)	31.6 (13.9)	31.3 (13.72)	30.1 (11.9)	31.8 (11.8)	32.4 (11.10)	35.9 (11.6)
Δ SBP (mmHg) Belt	14.3 (13.54)	12.9 (15.14)	10.9 (10.9)	9.3 (8.3)	12.5 (12.8)	16.9 (14.90)	23.1 (16.9)
No Belt	2.8 (8.5)	4.6 (5.9)	6.3 (6.1)	3.6 (3.6)	3.9 (6.4)	0.1 (7.8)	-1.6 (15.7)
ΔDBP (mmHg) Belt	7.3 (15.4)	6.8 (15.6)	7.8 (18.9)	9.4 (12.7)	8.9 (13.1)	5.9 (11.3)	4.9 (22.7)
No Belt	-0.9 (10.7)	-2.8 (7.7)	-2.4 (9.7)	0.6 (12.5)	1.6 (11.4)	1.8 (13.9)	-4.1 (9.5)
LBD Belt	2.8 (1.1)	2.7 (1.3)	2.8 (1.03)	2.4 (0.7)	2.6 (1.2)	3.0 (1.1)	3.3 (1.4)
No Belt	3.7 (1.5)	3.3 (1.8)	3.6 (1.4)	3.4 (1.3)	3.8 (1.5)	3.9 (1.5)	4.5 (1.7)
RBD Belt	2.9 (1.5)	2.4 (1.6)	2.7 (1.8)	2.8 (1.4)	2.7 (1.4)	3.4 (1.5)	3.8 (1.5)
No Belt	3.2 (1.7)	2.6 (1.3)	3.0 (1.4)	3.1 (1.5)	3.3 (1.9)	3.4 (1.8)	3.9 (2.1)
RPE Belt	13.3 (1.9)	11.9 (2.4)	12.9 (2.4)	13.1 (1.3)	13.3 (1.5)	14.1 (1.5)	14.5 (1.5)
No Belt	13.2 (1.7)	12.4 (2.2)	12.4 (2.7)	13.1 (1.4)	13.4 (1.5)	13.6 (1.6)	14.1 (1.8)

In general, mean work pulse increased more with the belt (8 bpm) across the periods than without the belt (4.2 bpm), but work pulse increased more during the first period without belt wearing. The overall mean responses were not significantly different. The mean WP of 32 bpm was above the recommendations of Grandjean (1988) to avoid fatigue, since the baseline pulse rate was obtained in a standing posture. The average ΔSBP increased in the latter periods with ΔSBP reaching the highest level (23 mmHg) in the last period. The change in systolic blood pressure was low and fairly constant without belt wearing. The positive differential blood pressures observed with belt wearing indicates that some of the subjects experienced an increase in physiological workload with belt wearing. The physiological strain data were analyzed using a repeated measures design with belt wearing, weight of lift, and period as within-subjects factors. Trial served as a blocking factor for the sequence of belt wearing. The experimental model can be stated as follows:

$$y_{ijk} = \mu + B_i + P_j + S_k + T_l + BP_{ij} + BS_{il} + PS_{jl} + e_{ijkl}$$

where,

y_{ijkl} = criterion measure under consideration
μ = overall main effect
B_i = effect due to belt level, i = 1, 2
P_j = effect due to period, j = 1,......6
S_k = effect due to subject, k = 1,...... 8
T_l = effect due to order of belt wearing, l = 1, 2.

The ANOVA summary results for the criterion measures are presented in Table 6.7. The descriptive statistics for the criterion measures across the periods between the belt treatments for each subject are provided in Table 6.8.

Table 6.7. ANOVA Summary for the Criterion Measures.

FACTOR		WORK PULSE		Δ SBP		Δ DBP		LBD		RBD		RPE	
SOURCE	**DF**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**
BELT	1	0.01	0.920	7.61	0.033 **	2.70	0.143	6.05	0.049 **	0.16	0.699	0.13	0.726
PERIOD	5	7.53	0.001 ***	2.19	0.077	0.74	0.601	1.17	0.343	4.38	0.003 ***	3.07	0.021 **
SUBJECT	7	147	.0001 ***	10.3	0.001 ***	12.1	.0001 ***	11.50	.0001 ***	31.6	0.001 ***	39.0	.0001 ***
BELT x PERIOD	5	1.31	0.280	1.94	0.113	0.23	0.948	0.38	0.864	0.30	0.909	1.65	0.173
BELT x SUBJECT	6	54.30	.0001 ***	7.42	0.001 ***	6.83	.0001 ***	7.57	.0001 ***	13.3	.0001 ***	4.26	.0025 ***
PERIOD x SUBJECT	35	1.44	0.142	0.66	0.888	0.91	0.610	3.63	.0001 ***	1.40	0.161	7.05	.0001 ***
TRIAL	1	0.59	0.446	0.33	0.586	0.16	0.698	28.20	.0001 ***	0.45	0.505	0.57	0.456
LEGEND: * p<0.1 ** p<0.05 ***p<0.005	Factors: O = order of belt wearing, B = belt, *P* = work period, S = subject. Criterion Variables: Δ SB*P* = change in systolic blood pressure, Δ DB*P* = change in diastolic blood pressure, LBD = left back discomfort, RBD = right back discomfort, and RPE = rating of perceived exertion.												

Table 6.8. Subject Descriptive Statistics.

	CRITERION MEASURES											
SUBJECT	**WP Mean (S.D.)**		**ΔSBP Mean (S.D.)**		**ΔDBP Mean (S.D.)**		**LBD Mean (S.D.)**		**RBD Mean (S.D.)**		**RPE Mean (S.D.)**	
	Belt	**No Belt**	**Belt**	**No Belt**	**Belt**	**No Belt**	**Belt**	**No Belt**	**Belt**	**No Belt**	**Belt**	**No Belt**
1	37.0	40.5	9.2	4.0	6.5	4.3	3.6	3.0	5.0	3.8	15.5	14.3
			B (s.)						**B (s.)**		**B (s.)**	
2	17.2	21.3	-4.3	1.5	-10.5	-3.5	2.4	3.7	1.3	2.3	12.8	12.8
			NB (s.)		**NB (s.)**		**NB (s.)**					
3	33.3	34.7	31.0	8.2	21.3	17.2	3.8	4.2	3.7	4.3	13.0	14.0
			B (s.)		**B (s.)**				**NB (s.)**			
4	30.8	19.3	11.7	2.0	7.7	8.3	2.8	6.2	4.0	5.8	14.3	14.7
	B (s.)		**B (s.)**				**NB (s.)**		**NB (s.)**			
5	51.2	27.6	19.0	0.2	2.0	-12.5	2.7	2.0	2.4	2.6	11.8	11.8
	B (s.)		**B (s.)**		**B (s.)**						**B(s.)**	
6	33.7	45.8	27.7	4.7	16.5	-3.3	2.7	3.5	1.3	1.6	11.3	11.7
	NB (s.)		**B (s.)**		**B (s.)**		**NB (s.)**					
7	16.8	19.3	6.5	5.8	-7.2	-7.5	2.0	3.5	2.0	3.5	13.0	12.8
							NB (s.)		**NB (s.)**			
8	41.0	48.6	21.8	7.3	21.7	-10.0	2.1	3.8	4.0	1.3	14.6	13.3
	NB (s.)		**B (s.)**		**B (s.)**		**NB (s.)**		**B (s.)**		**B (s.)**	
LEGEND:	NB – not wearing a belt resulted in a higher criterion response than wearing a belt. B - wearing a belt resulted in a higher criterion response than not wearing a belt. n.s. – not significant at the 0.05 level. s. – significant at the 0.05 level.											

Two of the eight subjects had a significant negative differential WP and two had a significant positive differential WP. The belt had a significant effect on ΔSBP for seven of the eight subjects. Six of the subjects had a significant positive differential ΔSBP, and one subject had a significant negative differential ΔSBP. Five of the subjects experienced a significant differential ΔDBP. Four of those were significant increases in ΔDBP with belt wearing in comparison with not wearing a belt. One subject had a significant decrease in ΔDBP. The four subjects that experienced the positive differential ΔDBP also had a positive differential ΔSBP. The one subject that experienced a significant decrease in ΔDBP with belt wearing also had a significantly negative differential ΔSBP. The two subjects that experienced significantly positive differential WPs also experienced significantly positive differential ΔSBPs. One of those that had a significant increase in WP also experienced a significant positive differential ΔSBP and ΔDBP.

6.5.1 Work Pulse

The effect of the belt on work pulse was not significant, but the subject x belt interaction was significant. Thus, the slope of the WP for belt and no belt wearing was not the same for each of the eight subjects. The period also had a significant effect on work pulse ($F(5,35) = 7.53$, $p = 0.0001$). Two additional ANOVAs were conducted followed by Newman-Keuls multiple range comparison tests to examine the differences between the 16 belt conditions (8 subjects x 2 belt levels), and the 8 differential conditions (8 subjects x work pulse differential (belt – no belt)). These results are provided in Appendix N. The results of the comparison tests revealed that subjects 4, 5, 6 and 8 experienced significantly different work pulses with belt wearing than without belt wearing. Subjects 4 and 5 had a significantly higher WP with the belt than without. Subjects 6 and 8 were the only subjects that had WPs that were significantly lower with belt wearing than without belt wearing. Subject 5 had a significantly higher positive differential WP than all of the other subjects. Subject 4 experienced the second highest positive differential WP. Subject 4's differential WP was significantly higher than the remainder of the subject's differential WPs. Subjects 1, 2, 3, 7 and 8 had differential WPs that were not significantly different. Subject 6 experienced the lowest significant negative differential WP. The rankings of these subjects with respect to their individual characteristics and task settings is provided in Table 6.9.

Table 6.9. Ranking of Subjects by Subject and Task Characteristics.

Subject or Task Factor	**Subject**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Static Strength	5	7	1	6	2	3	8	4
Abdominal Girth	6	8	3	1	5	2	7	4
Body Weight	8	6	3	2	5	1	7	4
Strength Decrease (belt - no belt)	1	8	3	6	2	5	7	4
Lean Body Mass	8	6	5	3	4	1	7	2
Fat Mass	5	8	2	1	7	3	6	4
Vertical Distance of Lift	2	3	7	6	8	4	1	5
Horizontal Distance of Lift	4	2	1	3	8	6	5	7

Subject 4 had the largest abdominal girth, the largest predicted fat mass, and the second largest body weight, and was the least "fit". Subject 5 had the second largest weight of lift, and the largest differential strength decrease (belt – no belt). Subject 5 lifted a load that represented the highest proportion of body weight. These two subjects were the only subjects to develop higher work pulses with belt wearing than without. Subject 6 was the heaviest subject, had the largest predicted lean body mass and the third largest fat mass, the second largest abdominal girth, and lifted the third heaviest weight. Subject 8 had the second largest lean body mass and 4th highest body weight. The subject factors do not indicate why opposing belt effects occurred for these two pairs of subjects (Subjects 4 and 5 versus subjects 6 and 8), since high measures for the same factor appeared within both groups, and measure contrasts for the same factor occurred within group. However, Subject 4 was the least fit and had the largest abdominal girth. The belt added the greatest incremental strain to this subject per unit of work and this was demonstrated through a positive differential WP. Subject 5 had the second largest differential strength decrement. Muscle fatigue may have contributed to the increase in WP. The belt did not have a significant effect on differential WP for subjects 1, 2, 3 and 7. Subject 1, 7 and 2 had the lowest body weights, respectively. Subjects 1, 2 and 7 were also in the lower half of the subjects in terms of static lift strength and abdominal girth. Subject 2 was conditioned to the task having participated in the first experiment (subject 1). Subject 3 was the most active weight lifter, and had the highest static lift strength, the third highest abdominal girth and body weight. These four subjects also appeared to be the most physically active. These results might mean that there are several factors that contribute to a significant negative or positive differential work pulse. However, body weight, static lift strength, weight of lift, lean body mass, and fitness are factors that appear to be related to the effect of belt wearing on differential work pulse. A higher fitness level may also decrease the likelihood of a significant belt effect for differential WP. The work pulse in the last period was significantly higher than the WP for the other periods with and without belt wearing. Belt wearing also resulted in a significantly lower differential WP for the first work period. However, the belt x period factor was not significant indicating that the average WP pattern across the periods was similar with and without back belt wearing.

6.5.2 Change in Systolic Blood Pressure

Belt wearing ($F(1,6) = 7.61$, $p = 0.033$) and the belt x subject interaction were significant. The subjects did not demonstrate the same slope for ΔSBP across the belt factor. Evaluation of the belt x subject interaction was performed. Two additional ANOVAs followed by a Newman-Keuls multiple comparison tests (see Appendix N) were performed to test the differences between the 16 subject-belt conditions (8 subjects x 2 belt levels), and the 8 differential conditions (8 subjects x work pulse differential). Six of the eight subjects had a significantly higher ΔSBP with belt wearing. One subject had a significantly lower ΔSBP with belt wearing. The belt-subject means comparison test showed Subjects 1, 3, 4, 5, 6, and 8 experienced significantly greater ΔSBP with belt wearing than without, and Subject 2 experienced a significantly negative differential ΔSBP. The positive differential ΔSBPs associated with belt wearing were significantly higher than the remainder of the ΔSBPs. Six of the seven lowest ΔSBPs occurred when a belt was not worn. These ΔSBPs were significantly lower than the other belt-subject conditions. Subjects 6 and 3, respectively, experienced the significantly highest differential ΔSBPs. However, Subjects 6, 3, 5 and 8, respectively, experienced significantly higher ΔSBPs than the other subjects. Subject 2 experienced the lowest (negative) differential ΔSBP. Review of Table 6.9 shows that Subjects 3, 6, 8 and 5 had the largest static strengths, respectively. Subjects 6 and 8 had the highest lean body mass, and subject 4 had the 3rd highest. Subjects 3, 6 and 8 had abdominal girths that were among the top four of the eight subjects. Subject 5 had a positive ΔSBP with the belt, but a significantly lower ΔSBP without the belt (next to the lowest without the belt). This subject had the second highest static strength and the 5th highest abdominal girth, and the 4th highest lean body mass, and 5th lowest body weight. Subjects 2, 7, 1 and 4, respectively, had the significantly lowest ΔSBPs. Subject 2 experienced the lowest ΔSBP with the belt and the next to the lowest ΔSBP without the belt. Subject 2 was conditioned to the task having participated in Experiment 1 (subject 1). Subject 2 also had the lowest static strength, the smallest abdominal girth, the 6th lowest body weight, and the 6th lowest predicted lean body mass. Subject 7 had the lowest static lift strength, and the 7th smallest abdominal girth, body weight and predicted lean body mass. Subject 4 had the 6th lowest static strength, the largest abdominal girth and the 3rd highest lean body mass. Subject 1 had the 5th highest static strength, the 6th smallest abdominal girth, and the lightest predicted lean body mass and body weight.

Review of the ANOVAs and means comparison data for the ΔSBP differentials revealed that subjects 6 and 3 had ΔSBP differentials that were significantly higher than the remainder of the subjects. Subject 3 had the highest static strength and weight of lift, while subject 6 had the 3rd highest static strength. Subject 3 had the 3rd largest abdominal girth and Subject 6 had the 2nd largest. Their body weights were in the upper three, and Subject 6 had the highest predicted lean body mass. Subject 2 had a differential work pulse that was significantly lower than the other subjects. These results suggest that a significantly higher positive differential blood systolic blood pressure with belt wearing is dependent on many factors, among them a relatively high static lift strength, body weight, lean muscle mass, abdominal girth, and fitness level. A significantly lower or negative differential blood pressure response was seen in those individuals with relatively low static strength, small muscle mass, light body weight, and small abdominal girth.

The average of the largest recovery blood pressures across the subjects and the estimated peak intra-arterial SBP during work and DBP during recovery with and without back belt wearing is provided in Table 6.10. Table 6.10 also includes these same measures for only the subjects that experienced significant differential blood pressures.

Table 6.10. Comparison of Highest Blood Pressures.

SUBJECT	**BELT**		**NO BELT**	
	SBP **SBP Est.** **(mmHg)**	**DBP** **DBP Est.** **(mmHg)**	**SBP** **SBP Est.** **(mmHg)**	**DBP** **SBP Est.** **(mmHg)**
All Subjects	145 ± 16.2 (189)	113 ± 20.2 (126)	129 ± 4.8 (168)	95 ± 11.6 (106)
8	154 (199)	109 (123)	137 (178)	85 (95)
6	168 (216)	138 (155)	134 (149)	82 (91)
Legend: SBP= Measured recovery SBP, SBP Est. = Estimated Peak intra-arterial SBP, DBP = Measured recovery DBP, DBP Est. = Estimated Intra-arterial DBP in recovery..				

Back belt wearing resulted in a meaningful differential increase in recovery blood pressure and estimated peak SBP.

6.5.3 Change in Diastolic Blood Pressure

The ANOVA summary revealed that none of the main factors had a significant effect on ΔDBP, however, the belt x subject interaction was significant. The subjects did not respond with the same pattern of response for the belt factor. Four of the subjects experienced a significantly higher ΔDBP with belt wearing, and one had a significant decrease. The four subjects that experienced a significantly elevated ΔDBP with belt wearing also had a significant positive differential ΔSBP with belt wearing. Two of the four subjects had a significant negative differential WP, one had a positive differential WP, and one was not affected. Evaluation of the belt x subject interaction was performed. Two additional ANOVAs followed by a Newman-Keuls multiple comparison test (see Appendix N) were performed to test the differences between the 16 belt conditions (8 subjects x 2 belt levels), and the 8 differential conditions (8 subjects x work pulse differential (belt – no belt)). The two highest ΔDBPs, and five of the highest seven ΔDBPs occurred with belt wearing. Four of the seven lowest ΔDBPs occurred without belt wearing. However, two of the three lowest ΔDBPs that occurred with belt wearing were associated with the same subjects (Subjects 2 and 7) who also developed significantly lower ΔDBPs without the belt. Subjects 3, 5, 6 and 8, respectively, had significantly higher ΔDBPs with belt wearing than without. The belt significantly decreased ΔDBP for Subject 2. Subjects 8 and 6 had significantly higher differential ΔDBPs than those seen with the other subjects. Subject 2 had the lowest negative differential work pulse followed by Subject 4 (negative differentials). Subject 2 had the next to the smallest static strength, the smallest abdominal girth, and the 6th lowest lean body mass. Subject 8 had the next to the highest lean body mass, and the 4th highest static strength and abdominal girth. Subject 6 had the 3rd highest static strength, the 2nd highest abdominal girth, the highest body weight and lean body mass. Subject 5 had the next highest differential effect on ΔDBP although it was not significantly different than the other ΔDBPs. Subject 5 had the next to the highest static strength, and the 2nd highest decrease in differential static lift strength (belt – no-belt). The characteristics and task measures that distinguished the subjects that had the largest positive differential ΔDBPs from those that had the smallest negative differential ΔDBPs were the static lift strength, the body weight, lean body mass and abdominal girth. Subjects with the highest positive differential ΔDBP had the four highest static lift strengths. The belt did not significantly effect ΔDBP for Subjects 4 and 7. Subject 4 had the largest abdominal girth, the second heaviest body weight, and the 6th highest static strength. The SLS for subject 4 was the smallest proportion of predicted lean body mass in comparison with the other subjects. Subject 4 had the second highest positive differential ΔWP. The lower weight lifted by Subject 4 might have caused the lower ΔDBP. Subject 7 had the lowest static strength, next to the lowest body weight, muscle mass and abdominal girth.

6.5.4 Subjective Responses

The lower left back discomfort was significantly lower with back belt wearing than without back belt wearing for 5 of the 8 subjects (see Appendix N). One of these subjects had a negative significant ΔSBP or ΔDBP with back belt wearing. Two of the five subjects had a positive significant differential ΔSBP and/or ΔDBP with back belt wearing. The remaining three subjects did not experience a significant back belt effect on LBD. The back belt resulted in a negative differential lower right back discomfort for three of the subjects. Two of these three subjects experienced a significantly negative LBD with back belt wearing. Two subjects experienced a significant positive differential RBD with back belt wearing. Both of these subjects had a positive differential blood pressure with back belt wearing. Three subjects had a significant differential RPE effect with back belt wearing. Two of these subjects had a positive differential lower back discomfort effect, and all three of these subjects had a positive differential blood pressure effect with back belt wearing. This suggests that RPE is potentiated with an increase in blood pressure.

6.5.5 Criterion Measures Summary

Table 6.11 presents the subject's rankings for the differential effect of the belt factor on the physiological criterion measures along with the subject characteristic and task factor rankings. Table 6.11 also presents the sign (±) of the differential effect (belt – no belt), and whether the effect was significant (s. or n.s.).

Subjects 1, 3, 5, 6, 7 and 8 had higher ΔSBP and ΔDBP with belt wearing. Subjects 3, 5, 6 and 8 had significant increases in both ΔSBP and ΔDBP. All of the subjects except Subjects 4 and 5 had negative differential WPs with back belt wearing. Subjects 4 and 5 had a significant positive differential WP with belt wearing, and Subjects 6 and 8 had significant negative differential WP with belt wearing. Subjects 3, 5, 6 and 8 had the four highest static lift strengths and weights of lift, and were among those with the highest body weights.

Table 6.11. Summary of Differential Criterion Rankings.

Criterion Measure	Subject							
	1	2	3	4	5	6	7	8
WP	6 (-)	5 (-)	3 (-)	2 (+) s.	1 (+) s.	8 (-) s.	4 (-)	7 (-) s.
ΔSBP	6 (+) s.	8 (-) s.	2(+) s.	5(+) s.	3(+) s.	1(+) s.	7(+)	4(+) s.
ΔDBP	5 (+)	8(-) s.	4 (+) s.	7(-)	3(+) s.	2(+) s.	6(+)	1(+) s.
Subject and Task Factors								
Static Strength	5	7	1	6	2	3	8	4
Abdominal Girth	6	8	3	1	5	2	7	4
Body Weight	8	6	3	2	5	1	7	4
Strength Decrease (belt - no Belt)	1	8	3	6	2	5	7	4
Lean Body Mass	8	6	5	3	4	1	7	2
Fat Mass	5	8	2	1	7	3	6	4
Vertical Distance of Lift	2	3	7	6	8	4	1	5
Horizontal Distance of Lift	4	2	1	3	8	6	5	7

Legend: s.– significant at $p = 0.05$, + (positive differential), - (negative differential)

All of these subjects experienced significantly positive differential ΔSBP and ΔDBP with belt wearing. These individuals would be expected to have a larger workload due to the weight of the torso, and static component due to the increased trunk muscle preload, and decreased trunk muscle compliance associated with the higher weights of lift. Stronger individuals that lift at the same percentage of SLS might incur higher intra-muscular tension. Typically, individuals that are stronger have lower muscle occlusion pressures and shorter endurance limits and experience blood flow occlusion earlier (Heyward, 1975). Muscle bulging and volume increases are associated with work intensity (Gullestad et. al., 1993). Subjects with a larger active muscle mass lifting a heavier absolute weight of lift would be expected to experience a larger muscle volume increase than individuals with a smaller muscle mass lifting lighter weights. An increase in movement resistance might increase the work intensity of the compartmentalized contralateral paraspinals and increase their intramuscular tissue pressures, as well. In addition, the external pressure applied by the belt straps directly to the compartmental muscles might further elevate intramuscular tissue pressure. An increase in IMP from either external compression O'Leary, 1993; Osterziel et. al., 1984) or muscle contraction (Kaufman et. al., 1984) augments blood pressure. The use of the valsalva also causes blood pressure to be temporarily potentiated after lifting (Wiecek et. al., 1990). Reflex vasodilation will result in a blood pressure decrease after lifting (MacDougall et. al., 1985). Subjects 6 and 8 experienced a significant negative differential WP with back belt wearing. These two subjects had the two highest predicted lean muscle masses, the highest and the fourth highest body weights, and the 3rd and 4th highest static lift strengths. A larger active muscle mass combined with heavy rhythmic weight lifting will augment muscle pump, venous return and stroke volume (Miles et. al., 1987). A higher body weight and weight of lift might compress the abdominal cavity more during flexion increasing IAP. A resetting of the baroreceptor limits and a rise in parasympathetic activity may obscure centrally mediated sympathetic activity associated with IMP (O'Leary, 1993). Pulse rate and blood pressure might also be disassociated during fatiguing contractions (Mark et. al., 1985). Subjects 4 and 5 were the only subjects to experience a significant positive differential WP with back belt wearing. Subject 4 also had a significantly positive differential ΔSBP with back belt wearing, but a negative differential ΔDBP with back belt wearing. Subject 4 was the least physically active of all of the subjects. An individual that has lower aerobic fitness will experience a larger increase in pulse rate per unit of incremental workload (McArdle et. al., 1991). Assuming the back belt increased workload, the pulse rate of this subject would be more sensitive to the workload augmentation (McCardle et. al., 1991). An elevated pulse rate due to an increase in dynamic workload is also associated with an increase in systolic blood pressure (Lewis et. al., 1983). In addition, Subject 4 had the 6th lowest static lift strength, but the 3rd highest predicted lean body mass. A lower weight of lift distributed across a larger active muscle mass will possibly decrease IMP (Jarvholm et. al., 1989) and muscle pump. A decrease in muscle pump will reduce venous return (Hargens et. al., 1987). Therefore, to maintain or augment cardiac output would require an increase in pulse rate. A lower IMP would be expected to decrease the peripherally induced, centrally mediated increases in diastolic blood pressure, as well. Subject 5 also experienced a significant positive differential WP with back belt wearing in combination with a significant positive differential ΔSBP and ΔDBP. Observation of the SLS measures revealed that this subject experienced the largest decrease in strength with and without back belt wearing, and the second largest differential decrease. Subject 5 had the second highest static lift strength. A large contraction force increases IMP, and fatigue increases IMP. Back belt wearing might have further augmented work intensity and IMP for this subject. The elevated IMP from the additional workload associated with bending against the back belt might have increased pulse rate and blood pressure through the pressor reflex response (Mitchell et. al., 1983). The significant positive differential ΔDBP for this subject is consistent with the pressor reflex. Subject 2 was the only subject to exhibit a significantly negative ΔSBP and ΔDBP. Subject 2 had the 7th lowest static lift strength, the 6th lowest body weight and lean body mass, and the smallest abdominal girth. Subject 2 was also the most task conditioned of all of the subjects having participated in 24 hours of lifting in Experiment 1 (Subject 1). The hypotensive response is typical with non-fatiguing resistance exercise or dynamic exercise (Kaufman et. al., 1987).

To better understand the pattern of physiological strain across the periods, the physiological criterion measures were regressed on the periods and are provided in Table 6.12. In general, the four subjects that experienced a significant differential WP attained a higher or lower differential WP early in the work session. Three of the six subjects that experienced a significant positive differential SBP had a higher rate of change in differential SBP across the work periods, while three had a higher differential SBP early in the work period. Two of the 4 subjects that experienced a significantly positive differential DBP also had a higher rate of change in differential DBP across the periods.

Table 6.12. Regression of Physiological Criterion Measures on Work Period.

Subject	**Back Belt Worn**			**Back Belt Not Worn**		
	Work Pulse	**ΔSBP**	**ΔDBP**	**Work Pulse**	**ΔSBP**	**ΔDBP**
1	$24.4 + 3.6*P$ $(r^2 = 0.95)$	$8.2 + 0.25*P$ $(r^2 = 0.004)$	$18.2 - 3.3*P$ $(r^2 = 0.24)$	$38.2 + 0.6*P$ $(r^2 = 0.04)$	$6.0 - 0.57*P$ $(r^2 = 0.28)$	$3.7 + 0.1*P$ $(r^2 = 0.008)$
2	$15.4 + 0.4*P$ $(r^2 = 0.38)$	$-13.3 + 2.2*P$ $(r^2 = 0.52)$	$-6.4 - 1.2*P$ $(r^2 = 0.33)$	$17.3 + 1.1*P$ $(r^2 = 0.83)$	$-3.0 + 1.2*P$ $(r^2 = 0.004)$	$-0.4 - 0.8*P$ $(r^2 = 0.15)$
3	$27.3 + 1.7*P$ $(r^2 = 0.74)$	$29.0 + 0.5*P$ $(r^2 = 0.03)$	$46.3 - 7.1*P$ $(r^2 = 0.94)$	$26.8 + 2.2*P$ $(r^2 = 0.95)$	$5.4 + 0.7*P$ $(r^2 = 0.55)$	$10.2 + 1.9*P$ $(r^2 = 0.17)$
4	$25.3 + 1.5*P$ $(r^2 = 0.81)$	$-6.3 + 5.1*P$ $(r^2 = 0.66)$	$7.2 + 0.11*P$ $(r^2 = 0.0009)$	$13.9 + 1.5*P$ $(r^2 = 0.70)$	$-1.0 + 0.85*P$ $(r^2 = 0.004)$	$8.5 - 0.05$ $(r^2 = 0.0006)$
5	$43.6 + 2.1*P$ $(r^2 = 0.88)$	$18.0 + 0.3*P$ $(r^2 = 0.012)$	$1.2 + 0.22*P$ $(r^2 = 0.013)$	$19.6 + 2.2*P$ $(r^2 = 0.90)$	$0.4 - 0.08*P$ $(r^2 = 0.005)$	$-13.4 + 0.2*P$ $(r^2 = 0.005)$
6	$29.4 + 1.2*P$ $(r^2 = 0.20)$	$5.4 + 6.3*P$ $(r^2 = 0.70)$	$-11.6 + 8.0*P$ $(r^2 = 0.72)$	$44.7 + 0.3*P$ $(r^2 = 0.25)$	$17.4 - 3.6*P$ $(r^2 = 0.86)$	$-8.1 + 1.3*P$ $(r^2 = 0.38)$
7	$15.9 + 0.2*P$ $(r^2 = 0.05)$	$9.0 - 0.7*P$ $(r^2 = 0.09)$	$1.9 -2.6*P$ $(r^2 = 0.35)$	$21.3 - 0.5*P$ $(r^2 = 0.004)$	$-0.06 + 1.6*P$ $(r^2 = 0.31)$	$-4.8 - 0.7*P$ $(r^2 = 0.127)$
8	$37.8 + 0.9*P$ $(r^2 = 0.41)$	$15.3 + 1.8*P$ $(r^2 = 0.116)$	$13.4 + 2.2*P$ $(r^2 = 0.107)$	$54.2 - 1.6*P$ $(r^2 = 0.42)$	$18.5 - 3.2*P$ $(r^2 = 0.531)$	$-8.0 - 0.5*P$ $(r^2 = 0.089)$

Legend: P = work period, ΔSB*P* = change in systolic blood pressure, ΔDB*P* = change in diastolic blood pressure.

6.6 Belt Effect on Static Lift Strength in the Asymmetric Stoop Posture

Static strength measurements in the 90 degree lateral plane (without belt wearing) were conducted prior to (pre) and immediately after (post) each work session. Table 6.13 displays the static lift strength data for each of the four subjects. The coefficient of variation ranged from 4 % to 13% for the static strength measurement sessions. The repeatability of the strength trials was within the expected ranges, indicating high consistency between trials. The strength data were analyzed using a repeated measures design with belt wearing and trial (pre-session strength and post-session strength) as the within-subjects trial factor. The ANOVA summary results in Table 6.14 demonstrate that the effect of the belt x trial interaction on static strength was not significant at the 0.05 level ($F(1,3) = 6.06, p = 0.0908$).

Table 6.13. Pre-Session and Post-Session Static Lift Strength Data.

	Belt Wearing Mean (S.D.)					No Belt Wearing Mean (S.D.)				
Trial	**Pre-Session**	**CoV**	**Post-Session**	**CoV**	**% Diff.**	**Pre-Session**	**CoV**	**Post-Session**	**CoV**	**% Diff.**
Subject										
1	145.7	0.06	115.0	0.09	21.07	159.3	0.1	159.2	0.04	0.1
2	101.6	0.04	99.2	0.04	2.56	110.3	0.04	104	0.03	5.71
3	204.3	0.02	174.7	0.02	14.49	198.7	0.01	174.3	0.01	12.3
4	175.1	0.06	162.3	0.08	7.43	187.3	0.03	179.4	0.03	4.4
5	206.3	0.02	146.5	0.06	29.13	164	0.05	131.6	0.06	20.1
6	195.7	0.02	171.2	0.07	12.31	172	0.03	160.1	0.03	6.9
7	84.1	0.10	73.3	0.05	12.84	81.2	0.03	73.8	0.04	9.1
8	240.4	0.05	225.8	0.04	6.07	244.5	0.08	225.4	0.04	7.8

Table 6.14. ANOVA Summary Results for the Static Lift Strength Measures.

	STATIC STRENGTH		
SOURCE	DEGREES OF FREEDOM	F VALUE	PROB > F
BELT	1	0.32	0.5960
TRIAL	1	10.75	0.0130
ORDER	1	2.33	0.1770
BELT X TRIAL	1	2.42	0.1710
SUBJECT	7	330.30	0.0001
BELT X SUBJECT	5	8.56	0.0100
TRIAL X SUBJECT	7	6.53	0.0180

6.7 Analyses of the Relationships among the Criterion Measures

Similar correlation analyses to those performed in Experiment 2 were performed on the data in Experiment 3. All of the criterion measures were evaluated pair-wise in the correlation analyses. In addition, the subject factors of lean body mass, strength decrease (belt – no belt), and abdominal girth were included. Also, the subject specific task factors of weight of lift, horizontal distance of lift, vertical distance of lift (difference between the tote box height in the lateral plane and the tote box height in the sagittal plane) were incorporated. Table 6.15 provides the significant results of the correlation analyses across the subjects for the criterion measures. Table 6.16 provides the correlation analyses across the subjects for each subject and task measure across and between belt levels. Table 6.17 provides the regression analyses for the criterion measures with respect to the subject and task parameters. Several speculations can be developed from the results displayed in Table 6.15. First, the significant correlation between SBP and DBP with belt wearing, and the lack of an association without belt wearing may be indicative of greater physiological strain, with belt wearing, since the majority of subjects that wore the belt had both higher ΔSBP and ΔDBP. The lack of a relationship between DBP and RPE with belt wearing versus a significant relationship without belt wearing may suggest that the perception of exertion disassociates from the actual physiological strain responses with belt wearing.

Table 6.15. Correlation Analyses Results Across Subjects Between Criterion Measures (P > |R| under Ho: Rho = 0).

CRITERION MEASURES	ACROSS ALL SUBJECTS & BELTS BETWEEN CRITERION MEASURES	ACROSS ALL SUBJECTS BETWEEN CRITERION MEASURES		ACROSS ALL SUBJECTS BETWEEN BELT LEVELS	
		Belt	No Belt	Criterion Measure	
WP & SBP	0.382 (0.0001)	0.538 (0.0001)	0.290 (0.045)	WP	0.437 (0.001)
WP & DBP	0.190 (0.062)	0.367 (0.010)	-0.041 (0.780)	SBP	0.510 (0.0002)
WP & LBD	0.043 (0.676)	0.213 (0.145)	-0.059 (0.687)	DBP	0.504 (0.0003)
WP & RBD	0.010 (0.920)	0.406 (0.004)	-0.337 (0.019)	RBD	0.365 (0.010)
SBP & DBP	0.604 (0.001)	0.695 (0.0001)	0.094 (0.523)		
DBP & LBD	0.104 (0.311)	0.129 (0.382)	0.365 (0.010)		
DBP & RBD	0.381 (0.0001)	0.335 (0.019)	0.562 (0.0001)		
DBP & RPE	0.266 (0.008)	0.148 (0.313)	0.470 (0.0007)		
LBD & RBD	0.581 (0.0001)	0.432 (0.002)	0.710 (0.0001)		
RPE & RBD	0.739 (0.0001)	0.768 (0.0001)	0.726 (0.0001)		
RPE & LBD	0.0156 (0.879)	0.432 (0.002)	0.761 (0.0001)		
STRD & WP	0.491 (0.0001)	0.781 (0.0001)	0.128 (0.383)		
STRD & SBP	0.410 (0.0001)	0.387 (0.006)	0.011 (0.937)		
Legend:	WP = work pulse, SBP = systolic blood pressure, DBP = diastolic blood pressure, LBD = lower left back discomfort, RBD = lower right back discomfort and RPE = Rating of Perceived Exertion, STRD = static lift strength decrease (belt (pre-session – post-session) – no-belt (pre-session – post-session)				

The positive and significant relationship between work pulse, SBP and strength decrement with belt wearing versus a very low relationship without belt wearing may suggest that the physiological responses are responding in a specific pattern to the strength decrement, whereas in a task that is not stressful, no such pattern would be observed. The physiological measures were highly correlated between belt and no belt wearing which suggests that the pattern of the responses were similar.

Table 6.16 provides the correlation analysis results across subjects between the subject factors, task factors, and criterion variables. Weight of lift and work pulse were significantly related in the no belt condition, but not significantly correlated in the belt condition. However, removing Subject 5 (the subject that was thought to be fatigued) from the analysis resulted in a significant correlation between work pulse and weight of lift for both belt conditions (r =0.75, p = 0.001 with belt wearing, and r =0.79, p = 0.001 without belt wearing).

A significant relationship between SBP and load weight with belt wearing and not without back belt wearing may suggest that the neural and peripheral factors that control blood pressure during recovery with belt wearing are stimulated due to a higher intramuscular tissue pressure, external pressure or the Valsalva maneuver. A lack of a correlation may be indicative of a stable physiological state without belt wearing. The significant correlation between weight and lower right back discomfort with belt wearing but not without may be indicative of higher intra-muscular pressure in the lower right back muscles due to the external pressure of the belt, or an increase in work intensity with back belt wearing. The high correlation between SBP, DBP, WP and lean body mass with belt wearing and the lack of a significant correlation without the belt may be indicative of a higher physiological strain with belt wearing that is related to the size of the active muscle mass.

Table 6.16. Correlation Analyses Results Across Subjects Between Response Measures. (P > |R| under Ho: Rho = 0).

CRITERION MEASURES	ACROSS ALL SUBJECTS & BELTS BETWEEN CRITERION MEASURES	ACROSS ALL SUBJECTS BETWEEN CRITERION MEASURES	
		Belt	No Belt
WT & WP	0.294 (0.003)	0.206 (0.160)	0.380 (0.0076)
WT & SBP	0.361 (0.001)	0.568 (0.0001)	0.141 (0.336)
WT & DBP	0.390 (0.0001)	0.543 (0.0001)	0.231 (0.112)
WT & LBD	0.2067 (0.043)	0.0188 (0.899)	0.372 (0.009)
WT & RBD	-0.015 (0.883)	0.260 (0.073)	-0.006 (0.966)
FM & SBP	0.335 (0.0008)	0.467 (0.0008)	0.182 (0.213)
FM & DBP	0.504 (0.0001)	0.528 (0.0001)	0.522 (0.0001)
LBM & WP	0.343 (0.0006)	0.209 (0.153)	0.473 (0.0007)
LBM & SBP	0.279 (0.005)	0.463 (0.0009)	0.049 (0.738)
LBM & DBP	0.135 (0.187)	0.371 (0.009)	-0.184 (0.210)
AG & WP	0.245 (0.015)	0.266 (0.067)	0.226 (0.121)
AG & SBP	0.307 (0.002)	0.486 (0.0005)	0.115 (0.435)
AG & DBP	0.444 (0.0001)	0.535 (0.0001)	0.115 (0.435)
VERTD & WP	0.260 (0.010)	0.075 (0.610)	0.439 (0.001)
VERTD & DBP	0.265 (0.008)	0.248 (0.089)	0.333 (0.020)
LATD & WP	0.314 (0.001)	0.482 (0.0005)	-0.274 (0.059)
Legend:	WT = Weight of Lift, AG = Abdominal Girth, VERTD = Vertical Distance of Lift, LATD =Lateral Distance of Lift		

A larger active muscle mass increases blood pressure more than a smaller active muscle mass for a contraction performed at the same percentage of MVC during static work.

The regression of the difference in the criterion measures (belt – no belt) on the task and subject measures was performed to better understand the nature of these relationships. Table 6.17 provides the results of the regression analysis.

Table 6.17. Regression Analyses Summary on Criterion Measures (Belt – No Belt).

Criterion Measure	Variable(s)	Partial R^2	Model R^2	F	Prob > F
WP (all subjects) (Highest R^2 equation)	VERTD	0.1413	0.1413	7.56	0.0085
	SAGH	0.0667	0.2080	3.79	0.0578
	NSAGH	0.0589	0.2669	3.53	0.0668
	AG	0.1331	0.4000	9.54	0.0035
	BDWT	0.1799	0.5799	17.97	0.0001
Regression Equation	WP= -259.6 – 1.09*BDWT + 1.56*AG – 0.47*VERTD + 1.38*NSAGH + 3.16*SAGH				
WP (subject 5 removed) (Highest R^2 equation)	WT/(25%SLS)	0.126	0.126	7.80	0.0080
	AG	0.123	0.249	9.27	0.0042
	BDWT	0.216	0.459	27.5	0.0001
Regression Equation	W*P* = -46.0 – 0.93*WT + 1.12*AG – 0.21*BDWT				
SBP (Highest R^2 equation)	WT/(25%SLS)	0.385	0.383	28.61	0.0001
	BDWT	0.073	0.456	6.07	0.0170
	VERTD	0.033	0.490	2.92	0.0945
Regression Equation	SB*P* = -50.86 +2.08*WT + 0.45*BDWT + 0.26*VERTD				
DBP (Highest R^2 equation)	WT/(25%SLS)	0.213	0.213	12.5	0.0009
	SAGH	0.075	0.288	4.73	0.0348
	BDWT	0.113	0.402	8.35	0.0060
Regression Equation	DBP= -183.9 + 0.94*WT + 0.64*BDWT +2.2*SAGH				
LBD	WT/(25%SLS)	0.22	0.22	77.7	0.0001
	AC	0.39	0.62	71.2	0.0001
Regression Equation	LBD = 3.1 + 0.27*WT – 0.105*AG				
RBD (Highest R^2 equation)	WT/(25%SLS)	0.194	0.194	11.1	0.0017
	NSAGH	0.137	0.331	9.2	0.0040
	VERTD	0.097	0.428	7.5	0.0089
	LBM	0.093	0.522	8.4	0.0059
Regression Equation	RBD = 8.5 + 0.18 WT – 0.11 LBM – 0.22*NSAGH + 0.076*VERTD				
RPE (Highest R^2 equation)	NSAGH	0.12	0.12	6.2	0.01
	LBM	0.06	0.18	3.8	0.05
	VERTD	0.11	0.29	8.9	0.009

Table 6.17. Regression Analyses Summary on Criterion Measures (Belt – No Belt) (cont.).

Regression Equation	RPE = 9.42 – 0.09*LBM – 0.14*NSAGH +0.04*VERTD
Legend:	Criterion Measures: WP = work pulse, SB*P* = systolic blood pressure, DB*P* = diastolic blood pressure, LBD = lower left back discomfort, RBD = lower right back discomfort, RPE = rating of perceived exertion. Subject Measures: AG = abdominal girth, LBM = lean body mass, BDWT = body weight. Task Measures: WT = weight of lift, 25% SLS = 25% of Static lift strength = WT, LATD = lateral distance in nonsagittal plane, VERTD = vertical distance of lift, NSAGH = non-sagittal horizontal distance.

One of the prediction equations that explained the highest percentage of variability in the differential WP (58%) included body weight, vertical and horizontal distance of lift and abdominal girth. Body weight explained 17.9% of the WP difference. An individual with higher body weight might have a higher muscle pump and compression of the abdominal cavity during flexion, acceleration and deceleration of the torso with belt wearing. These events might increase muscle pump and IAP and aid in returning blood to the central column during trunk lowering or inspiration. A larger abdominal girth combined with belt wearing might reduce the compliance of the torso due to the differential increase in belt stiffness with bending and twisting and the potential increase in the activity of the internal and external obliques. An increase in the vertical distance of lift might increase the acceleration requirements at the beginning of the lift, and IAP, and venous return. Exclusion of subject 5 from the data resulted in a regression equation that included the weight of lift, abdominal girth and body weight. However, the weight of lift only explained 12.4% of the variability in differential WP, and the body weight accounted for 21.6%. It is speculated that weight of lift and body weight result in a larger muscle pump and IMP with back belt wearing due to the higher work intensity, IAP and muscle pump resulting in an increase in venous return. Body weight appears to be more important than the weight of lift in increasing venous return in the asymmetric stoop lift. However, the effect of body weight combined with back belt wearing appears to differ depending on the fitness of the subject. Experiment 2 showed that an increase in body weight combined with back belt wearing resulted in an increase in WP in comparison with not wearing a back belt. An increase in abdominal girth with back belt wearing might increase trunk muscle work. Body weight, weight of lift, and vertical distance of lift comprised a linear regression equation that explained 49% of the variability in differential ΔSBP. The L5-S1 moment will increase with a heavier body weight and weight of lift. An increase in muscle force requirements will increase IMP. A greater vertical distance will increase the trunk muscle workload. This might increase the intensity of the extensor muscle activity and IMP, and subsequently ΔSBP. The addition of the back belt might further increase work intensity and external pressure, and subsequently IMP and ΔSBP. Back belt wearing has been shown to increase differential trunk high-level motion. In addition, the breath-holding has been demonstrated to increase IAP more with belt wearing (McGill et. al., 1993), and IAP has been shown to increase with later lifts with back belt wearing. The effect of the breath-holding on blood pressure has been shown to increase with latter lifts. The back belt may augment blood pressure more than not wearing a belt with a greater distance of lift. An increase in the valsalva maneuver and IAP with back belt wearing might also elevate differential ΔSBP. Forty-percent of the variability in ΔDBP was explained by the sagittal plane horizontal distance, the weight of lift and body weight. An increase in the sagittal horizontal distance will increase the applied moment at the L5/S1, and potentially trunk muscle activity, and IMP. An increase in the weight of lift and torso weight will also increase trunk muscle work, and IMP. Back belt wearing might increase external pressure, and further potentiate trunk muscle activity and IMP elevating ΔDBP. A greater valsalva with back belt wearing will also potentiate ΔDBP. Over 22% of the variability in LBD was explained by the weight of lift, and 39% of the variability in LBD was explained by the abdominal girth. It is speculated that the weight of lift combined with back belt wearing increases IMP and the potential for LBD in this task. It is speculated that the abdominal girth would also increase IMP. The decrease in differential LBD with abdominal girth might suggest that the subjects with the larger abdominal girths perceive a lower discomfort with back belt wearing. This might be due to the passive stretch of the lumbar muscles with tight belt tensions and compression of the abdominal compartment and a reduced perception of discomfort. The back belt combined with abdominal girth reduces the positive differential perceived discomfort of the low left back muscles, but the weight of lift combined with back belt wearing increased the differential discomfort rating. The differential RBD with back belt wearing increased with the weight of lift, as well.

6.8 Subjective Measures of the Perceived Effectiveness of Belt Wearing

A subjective evaluation of the effectiveness of belt wearing during the continuous asymmetric stoop lift was performed. The evaluation was administered to each subject after they had completed all of the sessions. Three questions were used to evaluate the subject's overall perception of the effectiveness of belt wearing. Question 1 evaluated the perceived support provided by the belt. Question 8 examined whether the subject would wear the belt in a job that required a lot of asymmetric stoop lifting, and Question 9 explored the general helpfulness of the belt during the asymmetric stoop lift. In addition, the intent of the analysis was to evaluate the relationship between the perceived effectiveness and the sensory dimensions of comfort, pressure, temperature, circulation and restriction. Seven questions were used to evaluate the subject's response to these sensory dimensions. Table 6.18 presents the ten questions that were asked of the subjects after the completion of the lifting sessions.

Table 6.18. Belt Effectiveness Questions.

1) How would you rate the support provided by the belt?

2) How would you rate the pressure provided to the lower back?

3) How would you rate the pressure provided to the sides of the trunk?

4) How would you rate the pressure provided to the abdomen?

5) How restrictive was the belt to movement in this task?

6) How was the temperature of the belt?

7) Did the belt cut-off any circulation?

8) If your employer provided you with this belt to wear in a job that required allot of this type of lifting. Would you wear the belt?

9) How much help do you feel that the belt provided?

10) How comfortable was the belt?

The scale used for the nine questions was as follows:

SCALE:

RATING	**RESPONSE**	
0	*Nothing at all*	
0.5	*Extremely weak*	*(just noticeable)*
1	*Very weak*	
2	*Weak*	
3	*Moderate*	
4		
5	*Strong*	*(heavy)*
6		
7	*Very Strong*	
8		
9		
10	*Extremely Strong*	*(almost maximal)*
*	*Maximal*	

A summary of the mean responses to the subjective questions is provided in Table 6.19 that follows.

Table 6.19. Summary of Subjective Questionnaire Responses.

Question	Mean	Std Dev	Median	Minimum	Maximum
Q1	3.75	1.28	4.00	2.00	5.00
Q2	4.31	1.48	4.50	2.00	6.00
Q3	4.12	1.45	4.00	1.00	6.00
Q4	5.37	0.91	5.00	4.00	7.00
Q5	3.81	2.20	3.50	1.00	7.00
Q6	3.62	1.76	3.00	2.00	6.00
Q7	2.75	1.98	2.00	1.00	7.00
Q8	5.50	2.82	6.50	1.00	8.00
Q9	4.37	2.50	4.00	1.00	8.00
Q10	3.50	1.85	3.00	1.00	7.00

The mean response of 3.75 for Question 1 (support) suggests that the belt offered slightly more than moderate support to the subjects during the continuous asymmetric stoop lift. The mean response for Question 8 of 5.50 indicated that the subjects would strongly consider wearing the belt during this type of lifting task. The mean response of 4.37 for Question 9 implied that the belt provided slightly more than moderate help during the lifting task. The response for Question 2 of 4.31 indicates that the belt applied slightly less than heavy pressure to the muscles of the lower back. The mean response for Question 3 of 4.12 indicates that belt applied moderate pressure to the sides of the torso; and the mean response of 5.37 for Question 4 indicates that the belt provided heavy pressure to the abdomen. The mean value of 3.81 for Question 5 implies that the restriction of the belt to movement was between moderately restrictive and strongly restrictive during the lifting task. The rating of

3.62 for the temperature of the belt (Question 6) was judged to be between moderate and strong. The rating of 2.75 for whether the belt cut off circulation (Question 7) indicates that the effect of the belt on circulation was perceived to be between weak and moderate. The rating of 3.5 for Question 10 suggested that the belt was moderately comfortable.

Spearman's correlation coeficients were computed to explore the direction and strength of the relationship between the judged effectiveness of the belt and the sensory dimensions of comfort, pressure, temperature, circulation and restriction experienced by the subjects. In addition, the relationships that existed within the effectiveness and sensory dimensions were explored. Table 6.20 below presents the significant relationships, and their direction.

Table 6.20. Spearman Correlation Coefficients (P > |R| under H0: Rho = 0) for Questionnaire Survey Questions.

Q	1	2	4	6	8	9	10
1	1.00 (0.00)	0.68 (0.063)	(NS)	(NS)	0.76 (0.028)	(NS)	(NS)
4	(NS)	(NS)	1.0 (0.00)	(NS)	(NS)	(NS)	0.76 (0.029)
6	(NS)	(NS)	(NS)	1.0 (0.00)	-0.65 (0.08)	-0.84 (0.009)	(NS)
8	0.76 (0.028)	(NS)	(NS)	-0.65 (0.08)	1.0 (0.00)	0.86 (0.006)	(NS)

The belt effectiveness questions were significantly correlated. Question 8 (compliance) was positively related to Question 1 (support). Compliance was also positively associated with Question 9 (help). The sensory dimensions that were positively correlated with each other were Question 4 (abdominal pressure) and Question 10 (comfort). Also, Question 1 (support) was positively correlated with Question 2 (back pressure). Question 6 (temperature) was negatively and significantly associated with Question 8 (compliance) and Question 9 (help). In summary, the results suggest that the subjects would strongly consider wearing the belt during this lifting task. The primary factors that were related to this decision were the perceived support and help provided by the belt. Also, higher pressures applied to the lower back muscles were positively related to the support that the belt provided. In addition, higher pressures applied to the abdomen were related to higher comfort levels.

6.9 Relationships Among Subjective Response and Subject Characteristics

Tests for relationships were done using the data collected on the subjective questionnaire and the subject characteristics and the subject dependent task parameters. The significant correlations between the subjective responses and subject characteristics were computed. Table 6.21 relates the body parts and task parameters to the pressure, movement restriction and comfort perceived with belt wearing.

In general, age was negatively related to perceived pressure on the lower back muscles with belt wearing. It is possible that the older subjects had prior experience with belt wearing, however, this question was not addressed in the study. Body weight was positively correlated with perceived abdominal pressure. Body weight was negatively correlated with WP (see Section 6.7). The compression of the abdomen by the belt during bending might increase IAP and increase muscle pump and venous return. Subjects that were heavier did not notice less restriction. Movement restriction was negatively related to the body weight and lean body mass. Moreover, chest width, abdominal girth, abdominal depth, hip girth and hip breadth were negatively related to the perception of movement restriction. The weight of the torso of the larger subjects may aid in the downward movement, by decreasing the force requirements of the agonist muscles.

Table 6.21. Spearman Correlation Coefficients (P > |R| under H0: Rho = 0) for Subjective Responses and Subject Anthropometrics.

	Lower Back Pressure	Abdomen Pressure	Movement Restriction	Circulation Impairment
GENERAL BODY				
Age	-0.78 (0.02)			
Body Weight		0.68 (0.05)	-0.64 (0.08)	
Lean Body Mass			-0.77(0.02)	
Knuckle Height			-0.78(0.02)	
TORSO				
Chest Width			-0.73 (0.03)	
Abdominal Girth			-0.77(0.03)	
Abdominal Depth		0.62(0.09)		-0.63(0.08)
Hip Girth		0.62(0.09)	-0.73(0.04)	
Hip Breath			-0.670.06)	

Also, the perception of movement restriction for the heavier subjects might have been masked by the comfort and support associated with wearing the belt, since abdominal girth was positively correlated with comfort (r =0.68, p = 0.06) and hip girth (r =0.83, p = 0.01) was positively related to compliance. Moreover, hip girth (r =0.73, p = 0.0068) and abdominal depth (r =0.17) were significant predictors of belt comfort. Circulation impairment was negatively related to abdominal depth. Regression analysis revealed that abdominal depth (r =0.51, p = 0.044), the ratio of abdominal girth to hip girth (r =0.27, p = 0.05), and the percent fat mass (r =0.15, p =

0.026) were significant predictors of perceived circulation impairment. The practical significance of these relationships is not understood.

The relationship of the task parameters with subjective response was also evaluated. Non-sagittal plane horizontal distance (r =0.70, p = 0.05) and vertical distance (r =0.69, p = 0.05) were positively correlated with perceived pressure to the sides of the torso.

6.10 Conclusions

The following conclusions were drawn from analysis of the Experiment 3 data:

1. Wearing the belt during rest did not result in a significant difference in heart rate, SBP or DBP. The duration of the rest period also did not have a significant effect on these measures.

2. Belt tension was not significantly correlated with the weight of the lift due to the instructions to tightly tension the belt to a level that did not restrict breathing. The tensions obtained in Trial 1 were highly correlated with the tensions in Trial 2 (same session). The tensions in Trials 1 and 2 were also correlated to abdominal girth and predicted fat mass at the 0.10 level of significance. The mean acceptable tension was 7.9 kg.

3. Two subjects experienced a significantly higher WP with the belt (Subjects 4 and 5) and two subjects experienced a significantly lower WP with the belt (subjects 6 and 8). In general, the subjects with the lowest body weight, static lift strength, and abdominal girth (Subjects 1, 2 and 7), and the subject that was the

most fit for the task (Subject 3) did not demonstrate a significant change in WP with belt wearing. Examination of the subject and task factors did not reveal why differing belt effects occurred. A speculative statement is that Subject 4 was the least fit and experienced a notable increase in physiological strain with belt wearing because his pulse rate was more sensitive to the increase in incremental workload (O_2 consumption) and external pressure added by the back belt than to the increase in the muscle pump. It is speculated that Subject 5 was fit but not conditioned for the repetitive lifting task and experienced an increase in WP with the belt due to a greater differential increase in muscle fatigue and an increasing dependence on the anaerobic energy sources with back belt wearing (Subject 5 had the greatest strength loss with and without the belt). The subjects that were observed to be most fit, lifted the heaviest weights, and had the larger body weights and predicted lean body masses experienced a decrease in WP with belt wearing. The change in WP with back belt wearing for these subjects is speculated to be due to a larger muscle pump and IAP in relation to the other subjects.

4. Six of the eight subjects had a significantly higher ΔSBP with belt wearing, while Subject 2 had a significantly lower ΔSBP. The four subjects that experienced the highest differential ΔSBPs (Subjects 3, 5, 6 and 8) had the largest static lift strengths, and were among the heaviest subjects. The exception was Subject 5 who was speculated to be more fatigued from the task than the other subjects. The two subjects that experienced the greatest positive differential ΔSBPs were the strongest subjects with body weights that were the highest and third

highest, respectively. The two subjects that had the lowest differential ΔSBPs were the weakest subjects, and had the two lowest body weights.

5. The two highest ΔDBPs and five of the seven highest ΔDBPs occurred with belt wearing. Four subjects had significantly higher ΔDBPs with belt wearing than without (Subjects 3, 5, 6 and 8), while Subject 2 had a significantly lower ΔDBP with belt wearing than without. The characteristics and task measures that distinguished the subjects with the largest positive differential ΔDBPs from those that had the largest negative differential ΔDBPs were static lift strength, body weight, lean body mass and abdominal girth.

6. The four subjects with the highest static lift strengths were among the heaviest subjects and had significantly higher ΔSBPs and ΔDBPs with belt wearing. The belt did not significantly effect WP, ΔSBP and ΔDBP for the subject with the lowest static lift strength. The subject that was the most task conditioned (Subject 2) and had the next lowest static lift strength and body weight demonstrated a significantly lower ΔSBP and ΔDBP with belt wearing. Subject 4, who had the largest abdominal girth and lifted the 6th lowest weight, experienced a higher WP and ΔSBP with the belt, but ΔDBP was not affected. The increase in WP and ΔSBP with back belt wearing for Subject 4 (the least fit subject) is speculated to be due to an overriding sympathetic response associated with the augmented workload with back belt wearing. In addition, it is theorized that the relatively small vertical distance of lift (6th smallest) for this subject and the low weight of

lift decreased the muscle pump. The lack of a significant difference in ΔDBP for this subject is speculated to be due to the relatively low weight of lift for this subject in comparison with the subject's body weight and estimated muscle mass.

7. The highest recovery SBP and DBP (168 mmHg and 138 mmHg) occurred with the back belt. The means and standard deviations across all subjects of the highest SBP and DBP with back belt wearing were 145 ± 16.2 mmHg and 113 ± 20.2 mmHg compared to 129 ± 4.8 mmHg and 95 ± 11.6 mmHg without the back belt. The highest estimated peak intra-arterial SBP (216 mmHg) occurred with the back belt. The estimated peak intra-arterial SBP without the back belt for this subject was 149 mmHg.

8. The four subjects that experienced a significant change in WP attained that higher or lower WP early in the work session. Three of the six subjects that experienced a higher ΔSBP had a higher rate of change in differential SBP across the work periods, while three had a higher differential ΔSBP early in the work period. Two of the four subjects that experienced a significantly higher ΔDBP also had a higher rate of change in ΔDBP across the periods.

9. The belt did not significantly affect the pre-post change in static lift strength. However, it is speculated that Subject 1 and Subject 5 experienced meaningful decreases in static lift strength with belt wearing in comparison with the no-belt wearing condition.

10. Body weight (17.9%), abdominal girth (13.3%), and horizontal (6.6%) and vertical distance of lift (14.1%) explained a large proportion of the variability in WP difference (belt – no-belt). However, removal of the fatigued subject from the data analyses demonstrated that weight of lift (12.6%), body weight (21.6%) and abdominal girth (12.3%) were significantly related to work pulse. Higher body weight resulted in a lower WP difference in both regression equations, as did a higher weight of lift in the latter equation. Greater abdominal girth resulted in a higher WP difference in both equations. It is speculated that individuals that have high body weights might generate higher IAPs during trunk flexion in comparison with lighter individuals. The higher weight of lift will also increase IAP, especially in trunk flexion. Both body weight and weight of lift would be expected to increase muscle pump and venous return. A larger abdominal girth would be expected to increase trunk muscle activity more than a smaller abdominal girth during bending and twisting due to a larger belt strap displacement for the individuals with larger abdominal girths.

11. Back belt wearing resulted in significantly greater increases in ΔSBP and ΔDBP when body weight and weight of lift were high. Weight of lift explained 38.5% of the variability in ΔSBP and body weight explained 7.3%. The vertical distance was responsible for 3.3% of the variability. This might suggest that load stabilization and handling increase IMP and IAP more than postural maintenance and support. Moreover, the change in diastolic blood pressure with back belt

wearing was explained by weight of lift (21.3%), body weight (11.3%) and the horizontal distance of lift.

12. Weight of lift explained 22% of the variability in low left back discomfort and the abdominal circumference explained 39% of the variability. Lifting heavier weights increased differential LBD, but a larger abdominal girth decreased differential LBD.

13. The questionnaire survey indicated that the subjects would strongly consider wearing the belt during this type of lifting task. The primary factors that were related to this decision were the perceived support and help provided by the belt. The support that the belt provided was correlated with the perceived pressure applied to the lower back muscles. The comfort of the belt was related to the pressure that the belt applied to the abdomen. The pressure applied to the abdomen by the belt during bending and twisting is theorized to increase the muscle pump and venous return.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Discussion

This research study evaluated the effect of back belt wearing on physiological and psychological strain during a manual lifting task. Specifically, this effort evaluated the effect of the elastic back belt on work pulse, change in systolic blood pressure, change in diastolic blood pressure, lower left back discomfort, lower right back discomfort and rating of perceived exertion. A weight of 25% of SLS was continuously lifted and lowered for 120 cycles from a low-lying position in the 90-degree lateral plane to slightly above knuckle height in the sagittal plane.

Three prior studies have evaluated the effect of the elastic back belt on physiological strain during manual lifting tasks. One prior study examined the effect of the weightlifter's belt on cardiovascular strain during non-production tasks. Two of the three back belt studies evaluated the ability of the back belt to temporary alter cardiovascular strain through mechanical compression, IAP, ITP and the pressor reflex response (Hunter et al., 1989; Madala, 1996). The effect of the belt to alter energy consumption through the resistance of the back belt was not evaluated in these studies.

All of the work periods in the prior studies were of short duration (i.e., less than 20 minutes). The tasks incorporated in these studies all possessed high static components, and one of the tasks (Madala, 1996) was a knuckle-to-shoulder lift, which involves a relatively small muscle mass concentrated at the shoulders and upper thorax regions. All of these tasks promoted the pressor reflex due to high mechanical compression and peripheral resistance, and the use of the Valsalva maneuver. A differential blood pressure effect with back belt wearing in these tasks would be expected to be temporary and attributable to mechanical compression, the pressor reflex, and the Valsalva (MacDougall et al., 1985). Many studies have shown that vasodilation, hypotension, and dizziness occurred after these types of lifting efforts (Vitcenda et al., 1990).

Heavy lifting efforts with a high static component place a severe pressure load on the left ventricle and increase the risk of myocardial infarction for those with existing cardiovascular disease (Amsterdam et al., 1974). However, recent studies have demonstrated that repetitive resistance exercise with heavy weights is associated with a lower cardiovascular risk than dynamic exercise (Featherston et al. 1993; Crozier et al., 1989). Repetitive resistance work does not appear to pose an extraordinary risk to cardiovascular patients that are aerobically trained and clinically stable (Featherstone et al., 1993).

The current study sought to evaluate the effect of the back belt on pulse rate and systolic blood pressure through the mechanisms of increased workload, muscle pump and IAP, and upon diastolic blood pressure through the mechanisms of work intensity, external pressure, intramuscular pressure, and ischemia. Avoidance of the Valsalva was sought in the third experiment of this research effort by instructing the individuals to breathe normally and to avoid breath-holding. However, it is not known whether the

Valsalva was avoided since expiratory pressures were not measured and breathing rate was not controlled. The Valsalva is commonly not used unless the weight of lift is high or the individual is fatigued (MacDougall et al., 1985). It is possible that breath-holding occurred, but studies have demonstrated that upon release of a heavy load, where the Valsalva was known to have occurred, blood pressure returned to normal in less than 10 seconds (MacDougall et al., 1985).

Two additional task studies, Contreras et al. (1984) and Hunter et al. (1989), evaluated the effect of the back belt during tasks that had a lower static component than the previous studies. Contreras et al. (1984) demonstrated that lifting a load that was equivalent to the NIOSH (1991) recommended weight of lift at a low frequency with and without an elastic back belt did not significantly affect WP or blood pressure changes. Hunter et al. (1989) determined that wearing a rigid back belt during a cycle ergometer task resulted in a higher work pulse and greater ΔSBP. These differences were due to the increased workload associated with moving against the resistance of the back belt during the cycling task. Systolic blood pressure is increased with work pulse in dynamic work (Lewis et al., 1983).

7.1.1 Discussion of Experiment 1

The first experiment of the current research effort demonstrated that a 25% SLS load lifted over a period of two hours was slightly fatiguing. It revealed that the heavier load weight of 25% of SLS resulted in a significantly lower WP (minimum load weight of 15.9 kg combined with a body weight of 66.9 kg) with back belt wearing. However, all weight levels resulted in a lower WP. The back belt augmented the muscle pump and

IAP by compressing the musculature and restricting the volume of the abdominal compartment during trunk bending and twisting.

Experiment 1 also demonstrated that the heaviest weight of lift (17.9 kg combined with a body weight of 66.9 kg) resulted in the greatest increase in ΔSBP with belt wearing. The increase in ΔSBP with heavy weights and back belt wearing is associated with a reduced trunk compliance due to supporting the heavier load, as well as the resistance provided by the back belt during bending and twisting. Breath holding and the Valsalva might also elevate recovery ΔSBP.

Experiment 1 also demonstrated that blood pressure measurement is sensitive to the precise positioning of the cuff, since blood pressure inconsistencies existed. The cuff was not worn during lifting, and the cuff position was not marked. However, some of the inconsistency may have been due to breath holding, since the subjects in Experiment 1 were also not instructed to breathe normally or to avoid breath holding.

It was found that the order of back belt wearing affected the WP results. The order factor was not significant in Experiment 3 due to pre-experiment practice sessions and the use of subjects that were better conditioned.

The weight factor did not significantly affect ΔDBP. The recovery patterns for DBP were not consistent. The study also revealed that a recovery period of 48 hours was necessary to prevent fatigue for the task conditions used.

7.1.2 Discussion of Experiment 2

The second experiment demonstrated that back belt tension setting from day-to-day was highly correlated for the lower (7.2 kg) and higher load (10 kg) (r = 0.95, p =

0.04) but not for the moderate load (8.8 kg). The tension set for the heaviest load weight (4.45 kg ± 0.77) was significantly tighter than the tension set for the lowest weight of lift (3.3 kg ± 0.59 kg), but the tension set for the moderate load was not significantly different from the tension set for the heaviest and lightest loads. These results suggest that preferred belt tension is repeatable for low and high load weights. In addition, it was shown that preferred tension varies with the instructions, the task conditions and the method of tension measurement. Also the tensions selected did not sufficiently compress the trunk muscles to cause a hemodynamic effect during rest through the peripheral activation of the Group II mechanoreceptors. The tightest tension (4.5 kg) did not sufficiently compress the vasculature of the abdomen or trunk to restrict blood flow return to the heart or to reduce muscle perfusion during rest. The pulse rate and blood pressure were not affected by the length of the rest period, or by back belt wearing during rest. Additional studies are required to better understand the effect of rest time on pre-test anxiety.

The individuals participating in the second experiment were, in general, not well conditioned, with the exception of one participant. Wearing the back belt resulted in a significant overall increase in ΔDBP, which may be attributable to the lack of conditioning of the group, since ΔDBP was not significantly affected in the third experiment where well-conditioned subjects were used. The individual that was the most fit and task conditioned, who possessed the smallest body weight (66.9 kg), abdominal girth, and next to the lowest static lift strength, and lifted the lightest weight (11.5 kg) had a significantly lower WP, and a substantially lower blood pressure with back belt wearing. The hypotensive recovery blood pressure is common for individuals during recovery after nonfatiguing resistance work (Hill et al., 1989). The lower WP does not imply that workload was reduced, but rather that stroke volume was increased to maintain or augment cardiac output. The lower WP for this subject demonstrates that WP can be significantly reduced with back belt wearing without lifting heavy loads. It is theorized that WP was reduced because the individual was fit and his abdominal girth was small, thus reducing the effect of a submaximal workload effort on cardiac output. Therefore, minimal preload would decrease pulse rate.

Two participants experienced a significant increase in ΔDBP with back belt wearing in Experiment 2. Both subjects also experienced higher ΔSBPs with belt wearing, although the difference was not statistically significant. The higher ΔSBP is indicative of a workload increase with back belt wearing. One of these subjects also had a significantly higher WP. This subject had the heaviest body weight (98.2 kg), largest abdominal girth (105 cm), and lifted the heaviest load (20.5 kg). The back belt significantly increased his workload and WP. Regression equations ($\alpha = 0.10$) indicated that higher body weights were associated with greater WP differences while greater load weights (and static lift strength) reduced the WP difference. It is theorized that the weight of the torso alone will create high IMPs in the contralateral paraspinals, and that tight belt tensions will potentiate trunk muscle workload and IMP. In this case, the individual was not fit, and therefore a submaximal increase in workload resulted in a higher pulse rate response that masked the preload effect on WP.

An individual that has a relatively high body weight and is not fit, and lifts a relatively light weight may experience a lower WP with back belt wearing, but might still incur a raised ΔSBP or ΔDBP due to the pressor reflex triggered by mechanical pressure, IMP or ischemia in the paraspinals. However, a similar sized individual who is task conditioned would have a muscle metabolism that could better tolerate the intramuscular pressure due to specificity of training.

A larger muscle mass augments stroke volume due to the greater muscle pump that can be developed, but stronger individuals have lower occlusion pressures than weaker individuals (Heyward, 1975) for a load that is a fixed percentage of static strength.

The individual that weighs more will experience a greater applied moment at L5/S1. A heavier torso weight increases workload and IMP, and if the additional workload added by the resistance of the belt combined with the external pressure of the belt is sufficient to elevate IMP above perfusion pressures, then local muscle fatigue may occur, especially in the deep contralateral paraspinals. Muscle swelling is fast to occur with an increase in work intensity but the volume of the muscle is slow to recover (Gullested et. al., 1984). Back belt wearing in combination with higher muscle volumes might decrease blood perfusion during work, and slow muscle volume recovery between lifts or during rest. These events would eventually increase blood pressure and slow the recovery of blood pressure to control levels.

7.1.3 Discussion of Experiment 3

The third study also demonstrated that rest period duration and level of belt tension (7.9 kg) did not significantly affect WP, SBP or DBP. The tension set in the third study was a tension that was as tight as an individual could obtain and not restrict breathing. Sufficient external pressure elevates blood pressure through a pressor reflex that is not mediated by central command, and that is different than the IMP associated with voluntary contraction. The preferred tensions set in the two trials of the belt tension adjustment session were highly correlated. The additional sensory parameter of "not restricting breathing" aided the individuals in reliably setting belt tension between trials.

With one exception, the third experiment used individuals that were fit. Still, the back belt significantly increased physiological work, IMP and/or modified breathing patterns for the four strongest individuals that lifted the heaviest loads (minimum body weight of 72.3 kg combined with a 21.3 kg load, and a body weight of 95.4 kg combined with a minimum load weight of 20.4 kg). The difference in ΔSBP and ΔDBP for these four individuals was significantly higher. In addition, physiological workload (WP and/or ΔSBP) was significantly higher for two of the other participants. The participant who had a significantly higher WP and ΔSBP with belt wearing was the least fit, had a body weight of 88.6 kg, and lifted a load of only 15 kg. The individual who had a higher ΔSBP had a body weight of 72.3 kg and lifted a 21.3 kg load. The back belt significantly increased WP for two participants and decreased WP for two participants. The increase in WP was due to an increase in physiological workload or IMP and the pressor reflex. The significant decrease in WP for two of the subjects was due to an increase in preload and heart muscle contractility that slowed pulse rate. This speculation is supported by the significant increase in ΔSBP and ΔDBP for both of these participants. It is speculated that cardiac output was maintained or elevated for all of the participants.

Experiment 3 demonstrated that the individuals with the lowest body weights, lowest static lift strengths, smallest abdominal girths, and that were the most task conditioned did not demonstrate a significant increase in WP with belt wearing. An individual that was not fit and lifted a load that was a small proportion of muscle mass did experience an increased WP and ΔSBP with back belt wearing. A speculative statement is that the individual experienced a notable increase in physiological strain with belt wearing because cardiac output increased due to the incremental workload (O_2 consumption) and external pressure added by the back belt, and the pulse rate effect of muscle pump was diminished. The back belt did not affect ΔDBP for this participant due to the rather low load weight in comparison with muscle mass. This allowed the individual to distribute the load weight across a larger muscle mass reducing muscle tension. One other individual had a higher WP with belt wearing. This individual was fit but was not conditioned for the repetitive lifting task and experienced the higher WP due to lifting a load weight that was the highest proportion of muscle mass of the group. The wearing of the back belt increased workload and IMP through the external pressure and work intensity increase. The higher IMP decreased blood perfusion and possibly increased dependence on the anaerobic energy sources. This might have caused the higher WP, ΔSBP and ΔDBP for this participant.

The four individuals that were the most fit, strongest, and had the largest body weights and predicted lean body masses experienced a significant decrease in WP with belt wearing. The lower WP for these individuals is thought to be due to a larger muscle pump and venous return. It is speculated that cardiac output increased for these individuals but a larger muscle pump and more developed stroke volume due to their aerobic and resistance training allowed them to satisfy cardiac demands without significant augmentation of sympathetic activity. Also, resetting the baroreceptor limits and increasing parasympathetic activity may obscure the pulse rate effects of elevated sympathetic activity (Stramba-Badiale et al., 1991). A higher ΔSBP for these subjects supports an increase in cardiac output, even though WP was lower.

Body weight aids compression of the abdominal cavity during trunk flexion. The back belt augments the compression and IAP is elevated. It is theorized that an individual with a larger abdominal girth will displace the belt straps more than an individual that does not have a large abdominal girth and this will increase the work of the trunk muscles and the external pressure on the trunk musculature. The results of this research effort also demonstrated that individuals who produce the largest static lift strength, body weight, distance of lift, and lower height at the origin of lift tended to experience a positive differential ΔSBP. Lifting a heavier weight or torso weight will result in greater trunk muscle work and IMP. A longer moment arm form the L5/S1 to the torso center of mass might also increase trunk muscle work and IMP. Wearing a back belt will further increase the work intensity and external pressure, and subsequently cardiac output and ΔSBP will increase, either due to the additional workload or the additional external mechanical pressure through the pressor reflex. An increase in submaximal workload will elevate pulse rate and ΔSBP, whereas an increase in IMP will trigger the pressor reflex and increase ΔSBP and ΔDBP.

The strongest individuals might attain the largest increases in blood pressure with back belt wearing due to the greater compression of the vasculature during voluntary contraction. The stronger individuals will also experience occlusion at a lower IMP level (Heyward, 1975), and back belt wearing may augment the pressure, thus increasing the likelihood of a reflex-triggered increase in blood pressure due to the activation of the mechanoreceptors or metaboreceptors. Individuals that have lower strength experience lower IMPs and their occlusion pressures are higher (Heyward, 1975).

Work intensity increases muscle volume (Gullestad et al., 1993). It is speculated that an individual with a smaller muscle mass will experience a smaller volume increase in comparison with an individual who is stronger and tends to have a larger muscle mass. A fixed back belt tension will apply more external pressure to a larger trunk muscle volume. An increase in the vertical distance of lift with back belt wearing will increase the workload of the trunk muscles. A longer moment arm from L5/S1 to the torso center of mass may also increase workload and IMP. Higher work intensities will result in a higher IMP in the trunk muscles and the back belt will further compress the musculature. An increase in external compression on a resting muscle will result in a reflex blood pressure increase that is not centrally controlled (Osterzeil et al., 1983). In addition, resistance may reduce the variation in trunk muscle pattern activation and decrease the time to fatigue for some muscles (Lavender et al., 1995). An individual that is stronger will experience a larger increase in ΔDBP with back belt wearing due to the application of external pressure to a muscle that already has a high intramuscular tissue pressure from the voluntary contraction. Weight of lift will also increase IAP, especially in trunk flexion. Both body weight and weight of lift would be expected to increase muscle pump and venous return.

Back belt wearing resulted in significantly lower LBD. Regression equations demonstrated that increased weight of lift potentiated the LBD difference, and larger abdominal girths decreased the LBD difference. The questionnaire survey indicated that the participants would strongly consider wearing the belt during this type of lifting task.

The primary factors that were related to this decision were the perceived support and help provided by the belt. The support that the belt provided was significantly related to the perceived pressure applied to the lower back muscles. The comfort of the belt was significantly related to the pressure that the belt applied to the abdomen. The pressure applied to the abdomen by the belt during bending and twisting is theorized to increase IAP, muscle pump activity, and venous return.

Finally, a looser belt tension (4.4 kg) by participants that were less fit resulted in similar physiological strain as was experienced by more fit participants wearing a tighter belt tension (7.9 kg). A significant positive or negative change in WP tended to occur in the beginning stages of work indicating that work demand was increased and/or belt pressure and muscle pump potentiated venous return. The positive change in ΔSBP and/or ΔDBP rose steadily across the work periods due to an elevated muscle oxygen demand or a decrease in muscle efficiency. Some individuals experienced blood pressures that were higher in the beginning stages of the work session supporting immediate sympathetic sensitivity to additional workload and/or external pressure.

7.2 Conclusions

The weight of lift, body weight, abdominal girth and fitness of the worker are theorized to be the four most important determinants of the effect of a tightly tensioned back belt on physiological responses during asymmetric stoop lifting. Higher load weights or body weights (and torso weight), and nonsagittal and sagittal distances of lift were associated with lower WP differences. However, if an individual was not fit, then a higher body weight contributed to a higher WP with the belt (see Table 5.16). Higher

ΔSBP and ΔDBP with the belt were associated with higher weights of lift and body weights. A larger horizontal distance of lift also was associated with a higher ΔDBP with belt wearing.

An increase in the differential blood pressure is expected if the load is low-lying. An increase in the sagittal plane horizontal distance also contributed to an increase in blood pressure due to the larger applied trunk moments. The regression equation for diastolic blood pressure difference suggested that postural support of the trunk and trunk movement increased IMP more than load stabilization and handling. Voluntary muscle contractions increase IMP, and the IMP would be expected to increase with external pressure (Styf et al., 1994), and with an increase in resistance.

Low strength individuals with low body weights, small abdominal circumferences, and light weights of lift, but who are fit and work-hardened are not likely to experience sufficient increase in differential work intensity with belt wearing to significantly potentiate cardiac output and blood pressure. In addition, these same individuals may or may not benefit from additional muscle pump, and augmented preload and stroke volume. Individuals that have relatively heavy body weights, who are fit and strong, and lift moderately heavy weights will be more likely to experience an increase in differential ΔSBP and ΔDBP with belt wearing, and demonstrate a decrease in differential WP. However, it is speculated that work intensity and IMP increase for these individuals. Individuals who are not fit, no matter what their body weight or strength, and who repetitively lift the torso might experience an increase in WP and blood pressure difference due to the weight of the unloaded carriage alone. These results suggest that the effect of the back belt on the physiological strain of the worker is dependent on individual and task factors. The effect of the back belt on biomechanical strain has also been shown to be subject dependent. The elastic back belt reduced mean compression and anterior-posterior shear forces during the asymmetric stoop lift, but some subjects experienced greater trunk loading (Granata et al., 1997). However, the reductions in compression and anterior-posterior shear were due to greater pelvic movement, whereas in this task the pelvis is constrained to approximately 90 degrees of flexion due to the tension in the hamstrings.

Finally, the individuals that participated in this experiment would strongly consider wearing the back belt in this type of lifting task. The primary factors that were related to this decision were the perceived support and help provided by the back belt. The support that the back belt provided was highly related to the perceived pressure applied to the lower back muscles. The comfort of the back belt was related to the pressure that the belt applied to the abdomen. The pressure applied to the abdomen by the back belt during bending and twisting is theorized to increase muscle pump and venous return. The lower back discomfort was significantly lower with back belt wearing than without. In some cases, individuals that experienced increases in physiological strain indicated reduced discomfort in the paraspinals. Individuals with the larger abdominal girths consistently demonstrated smaller differences in discomfort between belt conditions. The lower discomfort levels with belt wearing may be due to an improved postural stance with a tightly cinched back belt, especially for those workers with larger abdominal girths. The passive stretch of the lower back muscles with a tightly cinched belt might also contribute to the lower discomfort levels with the belt.

Perception of exertion may also have been influenced by the reduced pulse rate that some of the individuals experienced while wearing the belt.

It does not appear that the additional physiological strain associated with wearing a tightly tensioned elastic back belt during the high-frequency, continuous asymmetric stoop lift would promote an increased cardiovascular risk to individuals diagnosed with coronary heart disease who are aerobically fit (Featherstone et. al., 1993). The repetitious nature of the task, as well as the improved myocardial perfusion associated with the elevated diastolic blood pressure, and raised venous return with back belt wearing would appear to mitigate the elevated systolic blood pressure. But, workers should avoid breath holding during lifting with and without the back belt.

It appears that individuals would not obtain a biomechanical benefit from wearing the back belt in this work task, and that physiological strain would be increased. In addition, individuals with chronic compartment syndrome might be at greater risk for muscle fatigue and tissue damage due to the possibility that intramuscular tissue pressure may be increased in the deeper, contralateral paraspinals. Therefore, the back belt is not recommended for use in this type of lifting task. However, if the back belt is worn, then individuals should not tension the back belt too tightly and they should pivot at the feet when lifting loads in the lateral plane.

7.3 Recommendations for Future Research

The performance of a similar research study with a slightly lower weight of lift, and with replications for the belt wearing and no-belt wearing conditions would provide added support to the results obtained in this study. It is believed that the use of individuals that are less fit would result in a more significant effect size. Individuals could perform the experiment two times with the back belt and two times without the back belt over a period of 12 weeks. This would reduce carry-over effects, and provide beneficial data that would aid in the evaluation of intermittent, or occasional back belt wearing. The current research effort could be improved by measuring expiratory pressure and breathing patterns. Pre-session and post-session measurement of lumbar muscle endurance would increase the repeatability, and validity of the strength measures. Potential extensions to the research include lifting only, and decreasing the weight and extending the length of the work period. The use of a more rigid belt or a wider belt would allow the evaluation of different belt types. The use of female individuals with a back belt designed for females and with a back belt not designed for females would allow the physiological effects of back belt design to be evaluated.

REFERENCES

Adams, M.A. and Hutton, W.C. (1981). The relevance of torsion to the mechanical derangement of the lumbar spine. Spine, 6, 241-248.

Aleksiev, A. Magnusson, M., Pope, M., Coblin, E., and Luota, S. (1996). Effect of back support on blood pressure during lifting. In Overview of Recent Back Support Studies (Ed. D. Norlander), Chase Ergonomics: Albuguerque, NM., pg. 7.

Amendola, A.A. (1989). An investigation of the effects of external supports on manual lifting. Unpublished Doctorial Dissertation, Texas A&M University, College Station, TX 77843.

Amsterdam, E., Hughes, J., DeMaria, A., Mason, D. (1974). Indirect assessment of myocardial oxygen consumption in the evaluation of mechanisms and therapy for angina pectoris. American Journal of Cardiology, 33: 737-743.

Andersson, G. (1981). LBP in industry, Spine, 6, 53-59.

Andersson, G., Ortengren, R., Nachemson, A. (1977). Intra-discal pressure, IAP and Myoelectric back muscle activity related to posture and loading. Clinical Orthopaedics and Related Research, 129, 156-164.

Aspden, R.M. (1987). Intra-abdominal pressure and its role in spinal mechanics. Clinical Biomechanics, 2, 168-174.

Aspden, R.M. (1988). A new mathmatical model of the spine and its relationship to spinal loading in the workplace. Applied Ergonomics, 19, 319-323.

Aspden, R.M. (1989). The spine as an arch - a mathematical model. Spine, 14, 266-274.

Astrand, P., Ekblom, B., and Messin, R. (1965). Intra arterial blood pressure during exercise with different muscle groups. Journal of Applied Physiology, 20: 253-259.

Astrand, P. and Rodahl, K. (1986). Textbook of Work Physiology. 3rd ed. New York, McGraw-Hill.

Atkins, J., Mathews, O., Blomqvist, C., Mullins, C. (1976). Incidence of arrhythmia induced by isometric and dynamic exercise. British Heart Journal, 38: 465-471.

Barnes, G., Laine, G., Giam, P., Smith, E. and Granger, H. (1985). Cardiovascular responses to elevation of intra-abdominal hydrostatic pressure. American Journal of Physiology, 248, 208 - 213.

Barnes, G., Tomoshige, O., Scully, J. (1974). Cardiovascular effects of increased intraabdominal pressure in newborne piglets. Journal of Pediatrics Surgery, 9, 621.

Bartelink, D. (1957). The role of the abdominal pressure in relieving the pressure of the lumbar vertebral discs. Journal of Bone and Joint Surgery, 39B, 718-725.

Berkson, M., Schultz, A., Nachemson, A., Andersson, G. (1977). Voluntary strengths of male adults with acute low back syndromes. Clinical Orthopaedics, 129, 84.

Bezucha, G., Lenser, P., Hanson, G. and Nagle, F. (1982). Comparison of hemodynamic responses to static and dynamic exercise. Journal of Applied Physiology, 63(1), 116-120.

Biering-Sorensen, F. (1984). Physical measurements as risk indicators for low-back trouble over a one-year period. Spine, 9(2), 107-119.

Bigland-Ritchie, B., Cafarelli, E., Vollestad, N. (1986a). Fatigue of submaximal static contractions. Acta Physiologica Scandinavica, 128, 137-148.

Bigland-Ritchie, B., and Woods, J. (1986b). Changes in muscle contractile properties and neural control during human muscular fatigue. Muscle and Nerve, 7, 691-699.

Bond, M. (1970). Low back injuries in industry. Industrial Medicine and Surgery, 39, 28-32.

Borg, G. (1985). An introduction to Borg's RPE-Scale. Ithica, NY.Movement Publications.

Bourne, N. and Reilly, T. (1991). Effect of a weightlifting belt on spinal shrinkage. British Journal Sports Medicine, 25(4), 209-212.

Bowen, D., Purswell, J.L., Schlegel, R., Purswell, J.P. (1995). Preferred tension and psychophysical lifting limits with and without back belts. Advances in Industrial Ergonomics and Safety VII. (Edited by A.C. Bittner and P.C. Champney. Taylor and Francis), 736-739

Brown, J. (1973). Lifting as an industrial hazard. American Industrial Hygiene Association Journal, 34, 292-297.

Brown, K., McArthur, D., Peek-Asa, C. and Zhou, L. (1996). Reduction of acute low back injuries by use of back supports. In Overview of Recent Back Support Studies (Ed. D. Norlander), p. 3. Chase Ergonomics: Albuquerque, NM.

Brown, S., Clemons, J., He, Q. and Liu, S. (1994). Effects of resistance exercise and cycling on recovery blood pressure. Journal of Sports Sciences, 12, 463-468.

Burchard, K., Slotman, G., Jed, E. (1985). Positive pressure respirations and pneumatic antishock garment application – hemodynamic response. Journal of Trauma 25:83.

Cady, L., Bischoff, D., O'Connell, E. (1979). Strength and fitness and subsequent back injuries in firefighters. Journal of Occupational Medicine, 21, 269.

Cady, L., Thomas, P., Karwasky, R. (1985). Program for increasing health and physical fitness of firefighters. Journal of Occupational Medicine, 27, 110.

Caldwell, L., Chaffin, D., Dukes-Dobos, F., Kroemer, K., Laubach, L., Snook, S. and Wasserman, D. (1971). A Proposed standard procedure for static muscle strength testing. American Industrial Hygiene Association Journal, 21(3), 201-206.

Carlton, R. (1987). The effects of body mechanics instruction on work performance, American Journal of Occupational Therapy, 41(1), 16-20.

Carswell, H. (1984). Headaches: a weighty problem for lifters? Physician Sports Medicine, 12: 23.

Ciriello, V. and Snook, S. (1995). The effect of back belts on lumbar muscle fatigue. Spine, 20(11), 1271-1278.

Chaffin, D., Herrin, G., Keyserling, W., Faulke, J. (1976). Preemployment strength testing in select workers for material handling jobs. U.S. Department of Health and Human Services. NIOSH CDC-99-74-62, Cincinnati. OH.

Christenson, J., Hamilton, D., Scott-Douglass, N. and Tyberg, J. (1992). Abdominal compressions during CPR; hemodynamic effects of altering timing and force. The Journal of Emergency Medicine, 10, 257-256.

Clemente, C.D. (1986). Gray's Anatomy. Lea and Febiger: Philadelphia.

Cobb, L., Facc, W. and Weaver, D. (1986). Exercise: A risk for sudden death in patients with coronary heart disease. Journal of the American College of Cardiology, 7, 215-219.

Contreras, L.R., Rys, M., and Konz, S. (1995). Back belts in lifting and lowering tasks. Advances in Industrial Ergonomics and Safety VII. Taylor and Francis. New York.

Coote, J., Hilton, S. and Perez-Gonzalez, J. (1971). The reflex nature of the pressor response in isometric exercise. Journal of Physiology (London), 215: 789-793.

Corlett, E. and Bishop, R. (1976). A technique for assessing postural discomfort. Ergonomics, 9(2), 175-182.

Cozier, G., Holly, R., Amsterdam, E. (1987). Effects of high resistance training in coronary artery disease. Journal of Cardiopulmonary Rehabilitation, 7, 402-409.

Crandall, C., Williamson, J., Potts, J., Shi, J., and Raven, P. (1992). 45 Torr lower-body positive pressure increases resting blood pressure. Physiologist, 35, A238.

Cresswell, A. (1993). Responses of intra-abdominal pressure and abdominal muscle activity during dynamic trunk loading in man. European Journal of Applied Physiology, 66, 315-320.

Cresswell, A. and Thorstensson, A. (1989). The role of the abdominal musculature in the elevation of the intra-abdominal pressure during specified tasks. Ergonomics, 32(10), 1237-1246.

Cresswell, A., Grundstrom, H. and Thorstensson, A. (1992). Observations on intra-abdominal pressure and patterns of abdominal intra-muscular activity in man. Acta Physiologica Scandinavia, 144, 409-418.

Crozier, L., Ghilarducci, M., Holly, R., and Amsterdam, E. (1989). Effects of high resistance training in coronary artery disease. The Amercian Journal of Cardiology, 64, 866-870.

CTDNews (1995). Back-belt debate reignited by new studies and lawsuit. CTDNews, 4(9), 1, 8.

CTDNews (1993). Back support use spreads, do the devices work? CTDNews, 2(8), 1, 4.

Davies, B.T. (1978). Training in manual material handling and lifting. In C.G. Drury (ed.) Safety in Manual Material Handling. (NIOSH Government Printing Office, Cincinatti, OH), 175-178.

Davis, P. (1985). Intratruncal pressure mechanisms. Ergonomics, 28(1), 293-297.

Davis, P. and Troup, J. (1964). Pressures in the trunk cavities when pulling, pushing and lifting. Ergonomics, 7, 465.

Deluca, C. and Mambrito, C. (1987). Voluntary control of motor units in human antagonist muscles. Journal of Neurophysiology, 58, 525-542.

Donald, , K., Lind, A., McNicol, G., Humphreys, P., Taylor, S. and Staunton, H. (1967). Cardiovascular response to static exercise. Circulatory Research, 48 (Suppl. 1): 15-32.

Drury, C., Law, C., Pawenski, C. (1982). A survey of industrial box handling. Human Factors, 24, 553-565.

Drury, C., Deeb, J., Hartman, B., Woolley, S., Drury, C. and Gallagher, S. (1989). Symmetric and asymmetric manual materials handling. Part I. Physiology and psychophysics. Ergonomics, 32(5), 467-489.

Eckblom, B., Astrand, P., Saltin, B., Stenberg, J. and Wallstrom, B. (1968). Effect of training on circulatory response to exercise. Journal of Applied Physiology, 24(4), 518-528.

Edwards, R. (1986). Interaction of chemical with electromechanical factors in human skeletal muscle fatigue. Journal of Applied Physiology, 61, 149-155.

Edwards, R., Hill, D., McConnell, M. (1972). Monothermal and intramuscular pressure measurements during isometric contractions of the human quadriceps muscle. Journal of Physiology (London), 224: 58-59.

Featherstone, J., Holly, R. and Amsterdam, E. (1993). Physiological response to weight lifting in coronary artery disease. American Journal of Cardiology, 71: 287-292.

Fang, J., Madhavin, S., Cohen, H. and Alderman, M. (1995). Isolated Diastolic Hypertension. Hypertension, 26(3), 377-381.

Fleck, S. and Dean, L. (1987). Resistance-training experience and the pressor response during resistance exercise. Journal of Applied Physiology, 63(1), 116-120.

Floras, J., Sinkey, C., Aylward, P., Seals, D., Thoren, P. and Mark, A. (1989). Postexercise hypotension and sympathoinhibition in borderline hypertensive men. Hypertension, 14, 28-35.

Fox, I., Crowley, E., Grace, J. and Wood, E. (1966). Effects of the Valsalva maneuver on blood flow in the thoracic aorta in men. Journal of Applied Physiology, 21, 1553-1560.

Gaffney, A., Thal, E., Taylor, F., Bastian, B., Weigelt, J., Atkins, J., and Blomqvist, G. (1981). Hemodynamic effects of medical anti-shock trousers (Mast Garment). The Journal of Trauma, 21(11), 931-937.

Gagnon, M., Plamondon, A. and Gravel, D. (1993). Pivoting with the load. Spine, 18(11), 1515-1524.

Garg, A., Chaffin, D. and Herrin, G. (1978). Prediction of metabolic rates for manual materials handling jobs. American Industrial Hygiene Association Journal, 39(8), 661-673.

Garg, A. (1989). Basis for the guide: Biomechanical Approach. In V. Putz-Anderson (ed.). Revised Work Practices Guide for Manual Handling (NIOSH, Cincinatti, OH.), Chapter 3.

Garg, A. and Banaag, J. (1988). Maximum acceptable weights, heart rate, and RPEs for one hour's repetitive asymmetric lifting. Ergonomics, 31(1), 77-96.

Garg, A. and Badger, D. (1986). Maximum acceptable weights and maximum voluntary isometric strengths for asymmetric lifting. Ergonomics, 29(7), 879-892.

Garg, A. and Herrin, G. (1979). Stoop or squat. A biomechanical and metabolic evaluation. AIIE Transactions, 11(4), 293-304.

Garg, A. and Saxena, U. (1979). Effects of lifting frequency and technique on physical fatigue with special reference to psychophysical methodology and metabolic rate. American Industrial Hygiene Association Journal, 40, 894-903.

Gay, W. and Rothenburger, A. (1991). Color Atlas of Physiology. New York: Thieme Medical Publishers, Inc.

Ghilarducci, L., Holly, R., and Amsterdam, E. (1989). Effects of high resistance training in coronary disease. American Journal of Cardiology, 64: 866-870.

Gracovetsky, S., Farfan, H., and Lamy, C. (1977). A mathematical model of the lumbar spine using an optimization system to control muscles and ligaments. Orthopaedica Clinica North America, 8(1), 135-154.

Gracovetsky, S., Farfan, H., and Helleur, C. (1985). The abdominal mechanism. Spine, 10(4), 317-324.

Grandjean, E. (1986). Fitting the Task to the Man. Taylor and Francis, Ltd., London.

Granata, K., Marras, W. and Davis, K. (1997). Biomechanical assessment of lifting dynamics, muscle activity and spinal loads while using three different styles of lifting belt. Clinical Biomechanics, Vol 12, No. 2., 107-115.

Grew, N. (1980). Intraabdominal pressure response to loads applied to the torso in normal subjects. Spine, 5(2), 149-154.

Grew, N.D. and Deane, G.(1982). The physical effect of lumbar spinal supports. Prosthetics and Orthotics International, 6, 79-87.

Gates, D. (1988). Muscle weakness is leading cause for nurses' lower back injuries and pain. Occupational Health and Safety, 4, 57-59.

Grillner, S. and Nilsson, J. (1978). Intra-discal pressure, IAP and myoelectric back muscle activity related to posture and loading. Acta Physiologica Scandinavia, 103, 275-283.

Gullestad, L., Hallen, J. and Sejersted, O. (1993). Variable effects of B-adrenoceptor blockage on muscle blood flow during exercise. Acta Physiological Scandinavica, 149, 257-271.

Haennel, R., Snydmiller, G., Teo, K., Greenwood, P., Quinney, A. and Kappagoda, T. (1992). Changes in blood pressure and cardiac output during maximal isokinetic exercise. Archives Physical Medicine Rehabilitation, 73, 150-154.

Hannum, S. and Kash, F. (1981). Acute post-exercise blood pressure response of hypertensive and normotensive men. Scandinvian Journal of Sports Science, 2: 11-15.

Hargens, A., Millard, R., Pettersson, K. and Johansen, K. (1987). Gravitational haemodynamics and oedma prevention in the giraffe. Nature, 329, 59-60.

Harman, E., Rosenstein, R., Frykman, N. and Nigro, G. (1989). Effects of a belt on intra-abdominal pressure during weight lifting. Medicine and Science in Sports and Exercise, 21, 186-190.

Harris, K., and Holly, R. (1987). Physiological response to circuit weight training in borderline hypertensive subjects. Medicine Science Sports Exercise, 19, 246-256.

Haslam, D., McCartney, N., McKelvie, R. and MacDougall, J. (1988). Direct measurements of arterial blood pressure during formal weightlifting in cardiac patients. Journal of Cardiopulmonary Rehabilitation, 8, 213-225.

Hemborg, B., Moritz, N. (1985) IAP and trunk muscle activity during lifting. II. Chronic low back pain patients. Scandinavia Journal of Rehabilitative Medicine, 17, 5-13.

Hemborg, B. and Moritz, U. and Lowing, H. (1985). Intra-abdominal pressure and trunk muscle activity during lifting, the causal factors of intra-abdominal pressure rise. Scandinavian Journal of Rehabilitative Medicine, 17, 25-38.

Heyward, V. (1975). Influence of static strength and intramuscular occlusion on submaximal static muscle endurance. Research Quarterly, 46(4), 393-403.

Heyward, V. and McCreary, L. (1978). Comparison of the relative endurance and critical occluding tension levels of men and women. The Research Quarterly, 49(3), 301-307.

Hilgen, T. (1990). The minimum abdominal belt-aided lifting weight. Published Masters Thesis. Auburn University, Auburn GA.

Hill, D., Collins, M., Cureton, K. and Demello, J. (1989). Blood pressure response after weight training exercise. Journal of Applied Sports Science Research, 3, 44-47.

Holmstrom, E. and Moritz, U. (1992). Effects of lumbar belts on trunk muscle strength and endurance: a follow-up study of construction workers. Journal of Spinal disorders, 5(3), 260-266.

Humphreys, P. and Lind, A. (1963). The blood flow through active and inactive muscles of the forearm during sustained hand-grip contraction. Journal of Physiology (London) 166:120-135.

Hunter, G.R., McGuirk, J., Mitrano, N., Pearman, P., Thomas, B., Arrington, R. (1989). The effects of weight training belt on blood pressure during exercise. Journal of Applied Sport Science Research, 3(1), 13-18.

James, D. (1985). A multi-disciplinary approach for reducing back injury disability. Professional Safety, 9, 17-23.

Jones, L., McEnvoy, P., Mills, S. and Perkins, J. (1985). The effect of a restrictive device on stress in the lumbar region of the back. Unpublished Thesis, Purdue University.

Jarvhom, U., Palmerud, G., Herberts, P., Hogfors, C. and Kadefors, R. (1989). Intramuscular pressure and electromyography in the supraspinatus muscle at shoulder abduction. Clinical Orthopaedics and Related Research, 245, 102-109.

Kahn, J. and Monod, H. (1989). Fatigue induced by static work. Ergonomics, 32(7), 839-846.

Kashtan, J., Green, J., Parsons, E., and Holcroft, J. (1981). Hemodynamic effects of increased abdominal pressure. Journal of Surgical Research, 30, 249-255.

Kaufman, M., Rybicki, K., Waldrop, T. and Ordway, G. (1980). Effect of ischemia on response of group III and IV afferents to contraction. Journal of Applied Physiology, 57(3), 644-650.

Kaufman, M., Longhurst, J., Rybicki, K., Wallach, J. and Mitchell, J. (1983). Effects of static muscular contraction on impulse activity of groups III and IV afferents in cats. Journal of Applied Physiology, 55, 105-112.

Kaufman, F., Hughson, R. and Schaman, J. (1987). Effect of exercise on recovery blood pressure in normotensive and hypertenisve subjects. Medicine and Science in Sports and Exercise, 19, 17-20.

Kelsy, J., Githens, P., White, A. (1984). An epidemiological study of lifting and twisting on the job and risk for acute prolapsed lumbar intervertebral disc. Journal of Orthopaedic Research, 2, 61-66.

Kim, J. and Marras, W. (1987). Quantitative trunk muscle electromyography during lifting at different speeds. International Journal of Industrial Ergonomics, 1, 219-229.

Kim, S., Chung, M., and Lee, E. (1994). The effects of task conditions on trunk muscular fatigue during dynamic lifting. Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting. Nashville, TN.

Krag, M., Gilbertson, L., Pope, L. (1985). IAP and ITP effects on load bearing of the spine. 31st Annual ORS Meeting, Las Vegas, NV.

Kraus, J., Brown, K., McArthur, D., Peek-Asa, C., Samaniego, L., Kraus, C., and Zhou, L. (1996). Reduction of acute low back injuries by use of back supports. International Journal of Occupational Environmental Health, 2, 264-273.

Kromodihardio, S. and Mital, A. (1985a). Biomechanical analysis of task variables in manual lifting. In Proceedings of the 1985 Biomechanics Symposium (Edited by D. Butler, T.K. Hung and R.E. Mates) (New York: The American Society for Mechanical Engineers), 117-120.

Kumar, S. (1980). Physiological responses to weight lifting in different planes. Ergonomics, 23(10), 987-993.

Kumar, S. and Davis, P. (1973). Lumbar vertebral innervation and intra-abdominal pressure. Journal of Anatomy, 114(1), 47-53.

Kumar, S. (1984). The physiological cost of three different methods of lifting in sagittal and lateral planes. Ergonomics, 27(4), 425-433.

Kumar, S. and Garand, D. (1992). Static and dynamic lifting strength at different reach distances in symmetrical and asymmetrical planes. Ergonomics, 35(7/8), 861-880.

Kumar, S. and Godfrey, C.M. (1986). Spinal braces and abdominal support. Trends in Ergonomics/Human Factors III., Elsevier Science Publishers, North Holland.

Lander, J.E., Hundley, J.R. and Simonton, R.L. (1991). The effectiveness of weight belts during multiple repetitions of the squat exercise. Medicine and Science in Sports and Exercise, 24(5),603-609.

Lander, J.E. (1987). The effectiveness of weight-belts during squatting. Medicine and Science in Sports and Exercise, Abstract in Supplement 19, 2, #379.

Lander, J.E., Simonton, R.L. and Giacobbe, J.K. (1990). The effectiveness of weight-belts during the squat exercise. Medicine and Science in Sports and Exercise, 22(1), 117-126.

Lantz, S.A. and Schultz, A.B. (1986a). Lumbar spine orthosis wearing: I. Restriction of gross body motions. Spine, 11, 834-837.

Lavender, S., Thomas, J. and Andersson, B. (1995). Effect of lifting belts, foot movement, and lift asymmetry on trunk motions. Human Factors, 37(4), 844-853.

Lavendar, S.A., Tsuang, Y., Anderson, G., Hafez, A. and Shin, C. (1992). Trunk muscle cocontraction: the effects of moment direction and moment magnitude. Journal of Orthopaedic Research, 10(5), 691-700.

Lavendar, S.A., Thomas, J.S., Chang, D. and Andersson, G.B. (1994). The effect of lifting belts on trunk motions. Advances in Industrial Ergonomics and Safety VI. (Ed. F. Aghazadeh). Taylor and Francis: London.

Lavendar, S.A., Andersson, G., Corcos, D. and Thomas, J. (1996). The effectiveness of lifting belts in controlling trunk muscle electromyography activity during sudden unexpected loading. In Overview of Recent Back Support Studies (Ed. D. Norlander), p. 4. Chase Ergonomics: Albuquerque, NM.

Legg, S. (1981). The effect of abdominal muscle fatigue and training on the IAP developed during lifting. Ergonomics, 24, 191-195.

Lewis, S., Taylor, F., Graham, M., Pettinger, W., Shutte, J. and Blomqvist, G. (1983). Circulatory response to sustained handgrip contraction performed during other exercise both rythemic and static, Journal of Applied Physiology, 54(5), 1314-1323.

Lind, A. and McNicol, W. (1967). Muscular factors which determine the cardiovascular response to sustained and rhythemic exercise. Canadian Medical Association Journal, 96, 706-713.

Lind, A., Taylaor, S., Humphreys, Kennelly, B. and Donald, K. (1964). The circulatory effects of sustained voluntary muscle contraction. Clinical Science, 27, 229-244.

Lisenbardt, S., Thomas, T., and Madsen, R. (1992). Effect of breathing techniques on blood pressure response to resistance exercise. British Journal of Sports Medicine, 26(2), 97-100.

Lloyd, T. (1983). Effect of inspiration on inferior vena cava blood flow in dogs. Journal of Applied Physiology, 55: 1701-1706.

Magnusson, M., Pope, M. and Wilder, D. (1996). Kinematic changes in the trunk caused by the wearing of industrial back supports. In Overview of Recent Back Support Studies (Ed. D. Norlander), p. 5. Chase Ergonomics: Albuquerque, NM.

Madala, D. (1996). The effects of abdominal belt use on heart rate, blood pressure and recovery time during a lifting task. Unpublished Masters Thesis. University of Oklahoma, Norman, OK.

Mantysaari, M., Antila, K., Peltonen, J. (1984). Relationship between the changes in heart rate and cardiac output during Valsalva maneuver. Acta Physiologica Scandinavia, Supplement 537, 45-49.

Mark, A., Victor, R., Herhed, C. and Wallin, B. (1985). Microneurographic studies of the mechanisms of sympathetic nerve responses to static exercise in humans. Circulatory Research, 57: 461-465.

Marras, W., Lavender, S., Leurgans, S. (1993). Biomechanical risk factors for occupationally related low back disorder risk. Ergonomics, 38(2), 377-410.

Marras, W. and Granata, K. (1996). The effects of lifting belts upon trunk motion, trunk muscle activity and spine loading. In Overview of Recent Back Support Studies (Ed. D. Norlander), p. 6. Chase Ergonomics: Albuquerque, NM.

Marras, W., Lavendar, S., Leurgans, S., Rajulu, S., Allread, G., Fathallah, F., and Ferguson, S. (1992). The role of dynamic three-dimensional trunk motion in occupationally related low-back disorders. Spine, 18(5), 617-628.

Marras, W.S. and Mirka, G.A. (1989). Trunk strength during asymmetric trunk motion. Human Factors, 31, 667-677.

Marras, W.S. and Mirka, G.A. (1991a). A comprehensive evaluation of trunk response to asymmetric trunk motion. Spine, 17(3), 318-333.

Marras, W.S. and Mirka, G.A. (1991b). Muscle activities during asymmetric trunk angular accelerations. Advances in Industrial Ergonomics and Safety III. Edited by W. Karwowski and J.W. Yates. Taylor and Francis, 1991.

Marras, W.S., Joynt, R. and King, A. (1985). The force-velocity relation and intra-abdominal pressure during lifting activities. Ergonomics, 28(3), 603-613.

Marras, W.S., King, A.I., Joynt, R.L. (1984). Measurements of loads on the lumbar spine under isometric and isokinetic conditions. Spine, 9(2), 176-187.

Marras, W.S., Karwowski, W., Smith, J. and Pacholski, L. (Ed.), 1993. The Ergonomics of Manual Work. London: Taylor and Francis. pp. 1-2.

Marras, W.S. and Sommerich, C.M. (1991). A three-dimensional model of loads on the lumbar spine: I. model structure. Human Factors, 33(2), 123-137.

Marras, W.S. and Sommerich, C.M. (1991). A three-dimensional motion model of loads on the lumbar spine: II. model validation. Human Factors, 33(2), 139-149.

Masey, S., Koehler, J., Pepple, M., Rogers, M., and Traystman, R. (1985). Effect of abdominal distension on central and regional hemodynamics in neonatal lambs. Pediatrics Research, 19: 1244-1249.

McCardle, W., Katch, F., and Katch, V. (1991). Exercise Physiology. Third Edition. Lea and Febiger. Philadelpia.

McClosky, D. and Mitchell, J. (1972). Reflex cardiovascular and respiratory responses originating in exercising muscle. Journal of Physiology, 224, 173-180.

McCoy, M. A. (1986). An evaluation of back support devices for lifting tasks. Unpublished Unpublished Masters Thesis, Lubbock, Tx.

MacDougall, J., Tuxen, Sale, D., Moroz, J. and Sutton, J. (1994). Arterial blood pressure response to heavy resistance exercise. Journal of Applied Physiology, 58(3), 785-790.

McGill, S. (1991). Electromyographic activity of the abdominal and low back muscles during the generation of isometric and dynamic torque: implications for lumbar mechanics. Journal of Orthopaedic Research, 9(1), 91-103.

McGill. S.M. and Norman, R.W. (1987). Reassessment of the role of intra-abdominal pressure in spinal compression. Ergonomics, 30(11), 1565-1588.

McGill, S. and Norman, R. (1987). Effects of anatomically detailed erector spinae model on L4/L5 disc compression and shear. Journal of Biomechanics, 20, 591-600.

McGill, S. and Norman, R. (1988). The potential contribution of lumbosacral fascia forces to generate back extension moments during squat lifts. Ergonomics, 33, 147-160.

McGill, S.M., Norman, R.W. and Sharratt, M.T. (1990). The effect of an abdominal belt on trunk muscle activity and intra-abdominal pressure during squat lifts. Ergonomics, 33(2), 147-160.

McGill, S.M. (1993). Abdominal belts in industry: a position paper on their assets, liabilities and use. Work Injury Management, 3(1), 10-11.

McGill, S., Sequin, F. and Bennett, G. (1994). Passive stiffness of the lumbar torson in flexion, extension, lateral bending and axial rotation. Effect of belt wearing and breath holding. Spine, 19(6), 696-704.

Michael, E., Hutton, K., and Horvath, S. (1961). Cardiovascular responses during prolonged exercise. Journal of Applied Physiology, 16(6), 997-1000.

Miles, D., Owens, J., Golden, J. and Gotshall, R. (1987). Central and peripheral hemodynamics during maximal leg extension exercise. European Journal of Applied Physiology, 56, 12-17.

Miller, R., Moussavi, R., Green, A., Carson, P. and Weiner, M. (1993). The fatigue of rapid repetitive movements. Neurology, 43, 755-761.

Million, R., Nilsen, K.H., Jayson, M.I. and Baker, R.D. (1981). Evaluation of low back pain and assessment of lumbar corsets with and without back supports. Annals of the Rheumatic Diseases, 40, 449-454.

Mital, A. and Fard, H. (1986). Psychophysical and physiological responses to lifting symmetrical and asymmetrical loads symmetrically and asymmetrically. Ergonomics, 29(10), 1263-1272.

Mital, A. and Fard, H. (1986). Maximum acceptable weights and maximum voluntary isometric strength for asymmetric lifting. Ergonomics, 29(7), 879-892.

Mitchell, J. (1985). Cardiovascular control during exercise: control and reflex neural mechanisms. American Journal of Cardiology, 55, 34D – 41D.

Mitchell, J. (1990). Neural control of circulation during exercise. Medicine and Science in Sports and Exercise, 22, 141-158.

Mitchell, J., Payne, Saltin, Schibye, B. (1980). The role of muscle mass in the cardiovascular response to static contractions. Journal of Physiology (London), 309, 45-54.

Mitchell, J., Kaufman, M. and Iwamato, G. (1983). The exercise pressor relex; its cardiovascular effects, afferent mechanisms and central pathways. Annual Review of Physiology, 45, 229-242.

Mitchell, L.V., Lawler, F.H., Bowen, D., Mote, W., Asundi, P. and Purswell, J. (1994). Effectiveness and cost-effectiveness of employer-issued back belts in areas of high risk for back injury. Journal of Occupational Medicine, 36(10), 90-94.

Moretz, S. (1987). How to prevent costly back injuries. Occupational Hazards, 7, 34-45.

Morris, J.M., Lucas, D.B., and Bresler, B. (1961). Role of the trunk in stability of the spine. The Journal of Bone and Joint Surgery, 43-A(3), 1961.

Mittleman, M., Maclure, M., Tofler, G., Sherwood, J., Goldberg, R. and Muller, J. (1993). Triggering of acute myocardial infarction by heavy physical exertion. The New England Journal of Medicine. 329, 1678-1687.

Nachemson, A., Andersson, G. and Schultz, A. (1986). Valsalva manoeuver biomechanics: affects on lumbar trunk loads of elevated IAP pressure. Spine, 11(5), 476-479.

Nachemson, A., Schultz, A. and Andersson, G. (1983). Mechanical effectiveness studies of lumbar spine orthoses. Scandinavian Journal of Rehabilitative Medicine, 9, 139-149.

Ng, A., Agre, J., Hanson, P., Harrington, M. and Nagle, F. (1994). Influence of muscle length and force on endurance and pressor response to isometric exercise. Journal of Applied Physiology, 76(6), 2561-2569.

National Technical Information Service (1991). Scientific Support Documentation for the Revised 1991 NIOSH Lifting Equation, PB91-226274 (U. S. Department of Commerce, Springfield, VA.)

NIOSH (1981). Work practices guide for manual lifting. NIOSH Technical Report No. 81-122. US Department of Health and Human Services, National Institute for Occupational Safety and Health, Cincinatti, OH.

NIOSH (1994). (National Institute for Occupational Safety and Health). Workplace use of back belts. (DHHS (NIOSH) Number 94-122, U.S. Dept. of Health and Human Services), Cincinnati, OH.

O'Conner, P., Bryant, C., Vettr, J. and Gebhardt, S. (1993). State anxiety and ambulatory blood pressure following resistance exercise in females. Medicine Science Sports Exercise, 25(4), 516-521.

O'Leary, D. (1993). Autonomic mechanisms of muscle metaboreflex control of heart rate. Journal of Applied Physiology, 74(4), 1748-1754.

Osterziel, K., Julius, S. and Brant, D. (1984). Blood pressure elevation during hindquarter compression in dogs is neurogenic. Journal of Hypertension, 2, 411-417.

Owen, B. (1986). Posture, exercise can help prevent low back injury. Occupational Health and Safety, 55(6), 33-38.

Parnianpour, M., Nordin, M., Kahanovitz, N. and Frankel, V. (1988). The triaxial coupling of torque generation of trunk muscles during isometric exertions and the effect of fatiguing isoinertial movements on the motor output and movement patterns. Spine, 13(9), 982-992.

Pate, R. (eds.) (1991). Guidelines for Exercise Testing and Prescription. Philadelphia: Lea and Febiger.

Pedowitz, R., Hargens, A., Mubarak, S., and Gershuni, S. (1990). Modified criteria for the objective diagnosis of chronic compartment syndrome of the leg. American Journal of Sports Medicine, 18, 35-40.

Penrose, K.W., Chook, K. and Stump, J.L. (1991). Acute and chronic effects of pneumatic lumbar support on muscular strength, flexibility and functional impairment index. Sports Training, Medicine and Rehabilitation, 2, 121-129.

Petrofsky, J. and Lind, A. (1980). The blood pressure response during isometric exercise in fast and slow twitch skeletal muscle in the cat. European Journal of Applied Physiology, 44, 223-230.

Potvin, J., McGill, S. and Norman, R. (1991). Trunk muscle and lumbar ligament contributions to dynamic lifts with varying degrees of trunk flexion. Spine, 19(9), 1099-1107.

Raglin, J. and Morgan, W. (1987). Influence of exercise and quiet rest on state anxiety and blood pressure. Medicine and Science in Sports Exercise, 19, 456-463.

Reddell, C.R., Congleton, J.J., Huchingson, R.D. and Montgomery, J.F. (1992). An evaluation of a weightlifting belt and back injury prevention training class of airline baggage handlers. Applied Ergonomics, 23(5), 319-329.

Rhomert, W. (1973a). Problems in determining rest allowances. Part 1: use of modern methods to evaluate stress and strain in static muscle work. Applied Ergonomics, 4, 91-95.

Robotham, J., Wise, R., Bromberger-Bernea, B. (1985). Effects of changes in abdominal pressure on left ventricular performance and regional blood flow. Critical Care Medicine, 13(10), 803-809.

Rodgers, S., Yates, J. and Garg, A. (1991). The physiological basis for manual lifting guidelines. National Technical Information Service, Report number 91-227-330.

Rodgers, S. and Eggleton, E. ed. (1986). Work/rest cycles. Chapter 11 in Ergonomic Design for People at Work, compiled and edited by S. Rodgers and E. Eggleton. New York: Van Nostrand Reinhold, p 212-214.

Ross, E., Parnianpour, M. and Martin, D. (1993). The effects of resistance level on muscle coordination patterns and movement profile during trunk extension. Spine, 18(13), 1829-1838.

Rowe, M. (1971). Low back disability in industry. Updated position. Journal of Occupational Medicine, 13, 476-478.

Rowell, L., Freund, P. and Hobbs, S. (1981). Cardiovascular responses to muscle ischemia in humans. Circulatory Research, 48, Suppl. 1, 37-41.

Roy, F., Deluca, G. and Casavant, T. (1988). Lumbar muscle fatigue and chronic low back pain. Spine, 14(9), 991-1001.

Sadamoto, T., Bonde-Petersen, F. and Suzuki, Y. (1983). Skeletal muscle tension, flow, pressure and EMG during sustained isometric contractions in humans. European Journal of Applied Physiology and Occupational Physiology, 51, 395-408.

Sahlin, K., Edstrom, L. and Sjoholm, H. (1987). Force, relaxation and energy metabolism of rate soleus muscle during aerobic contractions. American Physiological Society, 129, 1-7.

Sejersted, O., Hargens, A., Kardel, K., Blom, P., Jennsen, O. and Hermansen, L. (1984). Intramuscular fluid pressure during isometric contraction of human skeletal muscle. Journal of Applied Physiology, 56(2), 287-295.

Sejersted, O. and Hargens, A. (1986). Regional pressure and nutrition of skeletal muscle during isometric contraction. In: Hargens AR (ed.)., Tissue Nutrition and Viability, pp. 263-283. New York: Springer Verlag.

Seroussi, R. and Pope, M. (1987). The relationship between trunk muscle EMG and lifting moments in the sagittal and frontal planes. Journal of Biomechanics, 20, 135-146.

Snook, S. (1978). The design of manual material handling tasks. Ergonomics, 21(12), 963-985.

Snook, S. (1987). Approaches to the control of back pain in industry: Job design, job placement and education/training. Spine, 2(1), 43-57.

Snook, S., Campanelli, R., and Hart, J. (1978). A study of three preventive approaches to low back injury. Journal of Occupational Medicine, 20(7), 478-481.

Sjogaard, G., Adams, R. and Saltin, B. (1985). Water and ion shifts in skeletal muscle of man with intense dynamic knee-extension. American Journal of Physiology, 248, R190-R196.

Sommerich, C. and Marras, W. (1992). Temporal patterns of trunk muscle activity throughout a dynamic, asymmetric lifting motion. Human Factors, 34(2), 215-230.

Staunton, H., Taylor, S. and Donald, K. (1964). The effect of vascular occlusion on the pressor response to static muscle work. Clinical Science, 27, 283-287.

Stramba-Badiale, M., Vanoli, G., De Farrari, G., Cerati, D., Foreman, R. and Schartz, P. (1991). Sympathetic-parasympathetic interaction and accentuated antagonism in conscious dogs. American Journal of Physiology, 260, H335-H340.

Styf, J., Lundin, O., and Gershuni, D. (1994). Effects of a functional knee brace on leg muscle function. The American Journal of Sports Medicine, 22(6), 830-834.

Sullivan, J., Hanson, P., Rahko, P. and Folts, J. (1992). Continuous measurement of left ventricular performance during and after maximal isometric deadlift exercise. Circulation, 85, 1406-1413.

Takata, M., Wise, R. and Robotham, J. (1990). Effects of abdominal pressure on venous return: abdominal vascular zone conditions. Journal of Applied Physiology, 69(6), 1961-1972.

Troup, J., Leskinen, T., Stalhammer, H. and Kuorinka, I. (1983). A comparison of intra-abdominal pressure increases, hip torque and lumbar vertebral compression in different lifting techniques. Human Factors, 25, 517-525.

Tuttle, W. and Horvath, S. (1956). Comparison of effects of static and dynamic work on blood pressure and heart rate. Journal of Applied Physiology, 10(2), 294-296.

Waters, R.L. and Morris, J.M. (1970). Effect of spinal supports on the electrical activity of muscles of he trunk. The Journal of Bone and Joint Surgery, 52-A (1), 51-60.

Walsh, N.E. and Schwartz, R.K. (1990). The influence of prophylactic orthosis on abdominal strength and low back injury in the workplace. American Journal of Physical Medicine and Rehabilitation, 69(5), 245-249.

Wannamethee, G., Whincup, P., Shaper, G. and Walker, M. and MacFarlane, P. (1995). Factors determining case fatality in myocardial infarction. "who dies in a heart attack?". British Heart Journal, 74, 324-331.

Waters, T., Putz-Anderson, V., Garg, A. and Fine, L. (1993). Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics, 36(7), 749-776.

Weicek, E., McCartney, N. and McKelvie, R. (1990). Comparison of direct and indirect measures of systemic arterial pressure during weightlifting in coronary artery disease. American Journal of Cardiology, 66, 1065-1069.

Wiley, R., Dunn, C., Cox, R., Hueppchen, N. and Scott, M. (1992). Isometric exercise training lowers resting blood pressure. Medicine Science Sports Exercise, 24(7), 749-754.

Williamson, J., Mitchell, J., Olesen, H., Raven, P. and Secher, N. (1994). Reflex increases in blood pressure induced by leg compression in man. Journal of Physiology, 475(2), 351-357.

Woodhouse, M.L., Heinen, J.R., Shall, L. and Bragg, K. (1990). Selected Isokinetic lifting parameters of adult male athletes utilizing lumbar/sacral supports. The Journal of Orthopaedic and Sports Physical Therapy, 11(10), 467-473.

Woodhouse, M., McCoy, R., Redondo, D. and Shall, L. (1995). Effects of back support on intra-abdominal pressure and lumbar kinetics during heavy lifting. Human Factors, 582-590.

Van Dieen, J., Thissen, C., Ven, G. and Toussaint, H. (1991). The electromechanical delay of the erector spinae muscle: influence of rate of force development, fatigue and electrode location. European Journal of Applied Physiology, 63, 216-222.

Vitcenda, M., Hanson, P., Folts, J. and Besozzi, M. (1990). Impairment of left ventricular function during maximal isometric dead lifting. Journal of Applied Physiology, 69(6), 2062-2066.

APPENDIX A

Rating of Perceived Exertion (Borg Scale RPE), Heart Rate and Blood Pressure

Subject # ____ Freq: ____ Weight: _____ Belt: ____ Task: ____ Date: ___1997

INSTRUCTIONS:
On each space below write the heart rate, systolic blood pressure, and diastolic blood pressure when they appear on the digital read-out of the pulse and blood pressure measurement equipment. Also, at the same time that the blood pressure measurements are taken, please give your thoughts about your perceived exertion from the lifting task at this point in time using the Rating of Perceived Exertion scale below.

RPE SCALE	
6	
7	*Very, very light*
8	
9	*Very light*
10	
11	*Fairly light*
12	
13	*Somewhat hard*
14	
15	*Hard*
16	
17	*Very hard*
18	
19	*Very, very hard*
20	

Physiological/ Perceptive Strain	**Pre-Work**	**20 min.**	**40 min.**	**60 min.**	**80 min.**	**100 min.**	**120 min**
Heart Rate	_____	_____	_____	_____	_____	_____	_____
Systolic Blood Pressure	_____	_____	_____	_____	_____	_____	_____
Diastolic Blood Pressure	_____	_____	_____	_____	_____	_____	_____
Rating of Perceived Exertion	_____	_____	_____	_____	_____	_____	_____

APPENDIX B

SUBJECTIVE DISCOMFORT RESPONSE SURVEY

INSTRUCTIONS. At the end of each of the 20-minute periods, and at the end of the final recovery period you will be asked to choose one of the following descriptions that best matches the discomfort. You will assess the discomfort in the region under the belt on both the right and left sides of the lower trunk.

DISCOMFORT RESPONSE

0 No Discomfort
.5 Extremely Mild Discomfort
1 Very Mild Discomfort

2 Mild Discomfort

3 Moderate Discomfort

4
5 Distressing Discomfort

6

7 Horrible Discomfort

8
9
10 Excruciating Discomfort (almost intolerable)
** Intolerable Discomfort*

Body Region	Pre-Work Comfort Rating	20 min. Comfort Rating	40 min. Comfort Rating	60 min. Comfort Rating	80 min. Comfort Rating	100 min.	120 min
LLB	____	____	____	____	____	____	____
RLB	____	____	____	____	____	____	____

APPENDIX C

SUBJECTIVE BELT SURVEY

Subject # ____ Belt: ____ Freq: ____ Weight: ____ Date: ____1997

<u>INSTRUCTIONS</u>. At the end of all of the lifting sessions

<u>RATING RESPONSE</u>
0 Nothing at all
.5 Extremely weak
1 Very weak

2 Weak

3 Moderate

4

5 Strong

6

7 Very Strong

8
9
10 Extremely Strong

** Maximal*

ffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffff

1. **How would you rate the support provided by the belt?**
2. **How would you rate the pressure provided to the lower back?**
3. **How would you rate the pressure provided to the sides of the trunk?**
4. **How would you rate the pressure provided to the abdomen?**
5. **How restrictive was the belt to movement in this task?**
6. **How was the temperature of the belt?**
7. **Did the belt cut off any circulation?**
8. **If your employer provided you with this belt to wear in a job that required alot of this type of lifting, would you wear the belt?**
9. **How much help do you feel the belt provided?**
10. **How comfortable was the belt?**

ffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffff

APPENDIX D

MEDICAL HISTORY QUESTIONNAIRE

Subject Identification Number __________
Subject Phone Number ________________

A. Personal Data
1) Name:_______________ Date:
Name and Phone Number of Individual to be Contacted in Case of Emergency:________________

2) Age:_____ 3) Weight:_________ 4) Height:_________

5) Do You Smoke? ______If so, How many cigarettes per day _______________
6) Are you currently engaged in aerobic exercise ______________
7) If so, Describe____
8) Are you currently involved in some form of strength and/or flexibility training? ______________
9) If so, Please Describe ____
10)Have you eaten within the last 3 hours? ___________
11)Have you smoked within the last 3 hours? __________
12)Have you performed strenuous exercise in the last 24 hours? __________

B: Medical Data
1) Resting Heart Rate: ______________ *2) Resting Blood Pressure:* ________
3) Have you had a normal amount of sleep and food within the past 24 hours? _____
4) Are you currently taking any type of medication? _____________________________
5) If so, explain ____________________________
6) Do you have any allergies or reactions to drugs of any kind? __
7) If so, Please Describe ____

C: Please mark the items with which you have had problems with in the past:

1) Shortness of breath ________
2) Chronic headaches _________
3) Dizziness ________
4) Fatigue ______
5) Pain in arm or chest __________
6) Fast heart rate ________
7) High or low blood pressure ________
8) Breathing or respiratory system _________
9) Skin sensitivity _______
10) Heart attack _______
11) Diabetes _______________
12) Hernia ______________
13) Any type of surgery or serious illness within the past 6 months? __________
14) Any Back Pain, particularly in the low-back, within the past 6 months? ______
15) Any Shoulder, Wrist, Hip, Knee, or Ankle Problems or Operations? _____

COMMENTS: Please comment on the items that you checked above on the reverse side. List the section and item number, (i.e., C1): I have shortness of breath during heavy exercise or during fast walks. This has not (or has) been diagnosed by a doctor and will (or will not) negatively affect me in any way, and will (will not) decrease my capability below what I would normally be able to do.

APPENDIX E

MEDICAL HISTORY CHECKLIST

Subject Identification Number ______
Subject Phone Number ______________

ILLNESSES AND MEDICAL PROBLEMS: PLEASE ANSWER ALL QUESTIONS.

	YES	NO	YEAR
Tuberculosis	___	___	___
Shortness of breath	___	___	___
Appendectomy	___	___	___
Pain/Pressure in chest	___	___	___
Palpitations (heart)	___	___	___
High or low blood pressure	___	___	___
Disease or injury of joints	___	___	___
Back problems	___	___	___
Rupture, Hernia	___	___	___
Dizziness, fainting	___	___	___
Heart problems	___	___	___
Asthma	___	___	___
Bronchitis	___	___	___
Abnormal Electrocardiogram	___	___	___

COMMENTS: Please comment on all positive responses in the space below or attach an additional page.

Has your physical activity been restricted during the past five years? Give reasons and lengths of time.

_________________________ ______________1997____

Signature *Date*

APPENDIX F

STATEMENT OF PHYSICAL CONDITION FOR PARTICIPANT

I hereby state that to the best of my knowledge I am physically able to perform the lifting tasks that have been described to me for the research project supervised by Rick D. Whitney. I further state that I have no previous back injuries or other back condition that could be aggravated by lifting. To the best of my knowledge I am free of hypertension or high blood pressure, or any other physical condition that could be worsened by physical exercise and lifting. I am in good health, and not currently taking medication or under the care of a physician.

________________________________ ____________________1997_____

Signature of Participant Date

APPENDIX G

UNIVERSITY OF OKLAHOMA

SUBJECT CONSENT FORM

Research Title: Back Belt Effect on Physiological Strain, Perceived Effort, Body Part Discomfort, and Subjective Rating of Belt Effectiveness During Continuous Asymmetric Stoop Lifting Tasks

Researcher: This research is conducted under the auspices of the University of Oklahoma, Norman Campus. The faculty sponsor for this research effort is Dr. Robert Schlegel (325-4342) and the principle investigator is Rick Whitney (Lab: Carson Engineering Sub-basement 23, Office or Home Phone (325-3721 or 360-4953).

PLEASE READ THE FOLLOWING CAREFULLY:

This is to certify that I,______________________________, hereby agree to participate as a volunteer in a scientific experiment as part of an authorized Ph.D. dissertation experiment at the University of Oklahoma under the supervision of Dr. Robert Schlegel.

The purpose of this research is to evaluate the effect of back belt wearing and lift duration on physiological and perceived strain during asymmetric stoop lifting tasks. The tasks are modeled after the lifting tasks that are commonly performed by truck loaders and unloaders, grocery and beverage delivery route workers, and palletizers and depalletizers.

I understand that as a subject in this experiment, I will be asked to participate in a total of four experimental sessions. The first session is a Familiarization, Body Size Measurement, and Belt Tension Adjustment Session. The session is of duration 1 hour and 20 minutes. One practice experimental lifting session will be performed that will last 2 hours and 20 minutes. In addition, two actual experimental lifting sessions (one with belt wearing and one without belt wearing) will be performed. The duration of these sessions is 2 hours and 20 minutes each. Each of the sessions will be performed on a separate day. Each of the experimental lifting sessions (including the practice lifting session) must be separated by a time period of at least 48 hours but not more than 96 hours.

I understand that there is a slight potential risk that I may have a medical problem develop (such as orthopedic or cardiovascular problems) while I am participating in the program, which may or may not be related to the testing

I understand that my participation is completely voluntary. I will be paid at a rate of $5.00 per hour. I can withdraw from participation or refuse to answer any question at any time without prejudice to me. However, if I withdraw from the experiment prior to completing all of the sessions, I understand that I will only be paid $2.00 per hour for work completed. I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

All information obtained during this study by which I could be identified will be held in strict confidence. If I have additional questions about the research or my rights as a research subject, I may contact either

Rick Whitney or Dr. Robert Schlegel, School of Industrial Engineering, University of Oklahoma or contact the Office of Research Administration at 325-4757.

I have read and understood the informed consent form and signed the herein informed consent statement this ____ day of _____ 1997.

Signature: ____

APPENDIX H

DEMOGRAPHIC DATA COLLECTION FORM

Subject # ____ Experiment: ____ Date: ________1997

BODY SIZE MEASURES (RIGHT SIDE OF THE BODY):

- age (years)
- body weight (kg)
- stature (cm)
- acromion height (cm)
- standing iliac crest height (cm)
- knuckle height (cm)
- knee height (cm)
- upper arm circumference
- forearm circumference
- forearm grip distance
- wrist circumference
- chest width (cm)
- chest depth (cm)
- abdominal circumference
- abdominal depth
- abdominal breadth
- hip circumference
- hip breadth
- ratio of abdominal girth to hip girth

LEAN MUSCLE MASS CALCULATIONS:

% fat ______ fat mass ______ lean body mass

TASK PARAMETERS:

Horizontal distance from right heel to tote box face ____________
Vertical height of tote box handles in Sagittal Plane ____________
Vertical height of tote box handles in Non-saggital Plane ____________
Distance of tote box handles from mid-point between heels ____________

Appendix I.

OK-1 505 Belt Dimensions

		OK-1 505 Belt Dimensions																		
		STRAP DIMENSIONS																		
		LEFT INNER STRAP				RIGHT INNER STRAP					Left Outer Strap				Right Outer Strap					
Abdominal Circumference		Left strap total length	Velcro Overlap Length	Rear Seam Length	Elastic Length	Right Strap Total Length	Velcro Length	Rear Seam Length	Elastic Length	Total Length of Inner Belt	Left Strap Total Length	Velcro Length	Rear Seam Length	Elastic Length	Right Strap Total Length	Velcro Length	Rear Seam Length	Elastic Length	Outer Belt Length
Small Size	24"-33"	18"	7.5"	0.5"	10"	18"	7.5"	0.5"	10"	36"	13.5"	6"	.5"	7"	13.5"	3" buckle/2" velcro	0.5"	10"	27"
Medium Size	29"-38" (5)	19.5" (1.5")	8.5" (1")	0.5"	10.5" (0.5")	19.5" (1.5")	8.5" (1")	0.5"	10.5" (0.5")	39" (3")	15.5" (2")	6"	0.5"	9" (2") (4")	15.5" (2")	3" buckle/2" velcro	0.5"	12" (2")	30" (3")
Large Size	35-44" (6)	22" (2.5")	9.0" (.5")	0.5"	12.5 (2")	22" (2.5")	9.0" (0.5")	0.5"	12.5 (2")	44" (4")	18.5" (3")	6"	0.5"	12" (3")	18.5" (3")	3" buckle/2" velcro	0.5"	15" (3")	33.5" (7")
X-Large /Size	42-52" (7")	26" (4")	9.5" (.5")	0.5"	16" (3.5")	26" (4")	9.5" (0.5")	0.5"	16" (3.5")	52" (8")	22.5 (4")	6"	0.5"	16" (4")	22.5" (4")	3" buckle/2" velcro	0.5"	19" (4")	44" (7")

APPENDIX J

EXPERIMENT BELT TENSION ADJUSTMENT DATA

EXPERIMENT 1 BELT TENSION EQUATIONS:

Small Belt: Force = 1.89 lbf * (linear displacement in inches) - 0.067 lbf
Medium Belt: Force = 1.67 lbf *(linear displacement in inches) - 0.046 lbf
Large Belt: Force = 1.1 lbf * (linear displacement in inches) + 1.0 lbf *($r^2 = 0.99$).*

EXPERIMENT 1 TENSIONS:

SUBJ.	WT	DAY1 (IN.)	ABD. CIRC. (IN.)	BELT SIZE (IN.)	L & R STRAP (IN.)	MAXCIR. (IN.)	LSL (IN.)	USL (LBS)	TENSION
1	5% SLS	2	31	MEDIUM	30.5	30.5	0.5	7.5	4.2
1	15% SLS	3.25	31	MEDIUM	30.5	30.5	0.5	7.5	6.3
1	25% SLS	4.5	31	MEDIUM	30.5	30.5	0.5	7.5	8.4
2	5% SLS	1.25	32	SMALL	27.5	27.5	4.5	11.5	10.9
2	15% SLS	3.5	32	SMALL	27.5	27.5	4.5	11.5	15.1
2	25% SLS	4.25	32	SMALL	27.5	27.5	4.5	11.5	16.5

SUBJ.	WT	DAY2 (IN.)	ABD. CIRC. (IN.)	BELT SIZE (IN.)	STRAP (IN.)	MAXCIR. (IN.)	LSL (IN.)	USL (IN.)	TENSION (LBS)
1	5% SLS	2	31	MEDIUM	30.5	30.5	0.5	7.5	4.2
1	15% SLS	3	31	MEDIUM	30.5	30.5	0.5	7.5	5.8
1	25% SLS	4	31	MEDIUM	30.5	30.5	0.5	7.5	7.5
2	5% SLS	1.5	32	SMALL	27.5	27.5	4.5	11.5	10
2	15% SLS	2.25	32	SMALL	27.5	27.5	4.5	11.5	11.3
2	25% SLS	4	32	SMALL	27.5	27.5	4.5	11.5	14.2

AVERAGE BELT TENSION DAY 1 (5% SLS) = 7.5 LB
AVERAGE BELT TENSION DAY 1 (15% SLS) = 10.7 LB
AVERAGE BELT TENSION DAY 1 (25% SLS) = **12.4 LB <<TENSION USED**

FOR EXPERIMENT 1

Overlap in medium belt for subject 1 = (12.4 - .5(1.67))/1.67= 6.9 inches << overlap setting
Overlap in small belt for subject2 = (12.4 - 4.5(1.89))/1.89 = 2 inch << for pre-pilot study

Average belt tension day 2 (5% SLS load)= 7.1 lbs
Average belt tension day 2 (15% SLS load) = 8.5 lbs
Average belt tension day 2 (25% SLS load) = 10.85 lbs

Reference:

Maximum circumference = maximum length of the belt with no tension
Lower stretch limit (LSL) = abdominal girth - maximum circumference with no tension
Upper stretch limit (USL) = LSL + left velcro length + right velcro length (2* the velcro overlap of the left and right belt straps)
USL = LSL + 6 inches + 2 inches - 1.0 inches
USL = LSL + 7 inches
Small belt force versus displacement: force (lbs) = 1.89 lbs per inch * x (inches) - .06 lbs
Medium belt force versus displacement: force (lbs) = 1.65% SLS per inch * x (inches) - .04 lbs
Large belt force versus displacement: force (lbs) = 1.08 lbs per inch * x (inches) - .1.09 lbs

EXPERIMENT 2 BELT TENSION DATA:

TRIAL 1

SUBJECT	WT	DAY1[a] (IN)	ABD. CIRC. (IN)	BELT SIZE (IN.)	L & R STRAP (IN.)	LSL. (IN.)	USL (IN)	USL TENS. (LBS)	TENSION (LBS)
1	LOW	1.25	32	SMALL	30.5	1.5	8.5	15.9	5.1
1	MED	3.5	32	SMALL	30.5	1.5	8.5	15.9	9.3
1	HI	4.25	32	SMALL	30.5	1.5	8.5	15.9	10.8
2	LOW	1.5	39	LARGE	33.5	5.5	12.5	14.7	7.6
2	MED	1.5	39	LARGE	33.5	5.5	12.5	14.7	7.6
2	HI	1.5	39	LARGE	33.5	5.5	12.5	14.7	7.6
3	LOW	2	38	LARGE	33.5	4.5	11.5	13.7	7.1
3	MED	3	38	LARGE	33.5	4.5	11.5	13.7	8.2
3	HI	3.5	38	LARGE	33.5	4.5	11.5	13.7	8.7
4	LOW	1.75	40	LARGE	33.5	6.5	13.5	15.9	9.0
4	MED	3	40	LARGE	33.5	6.5	13.5	15.9	10.4
4	HI	4.75	40	LARGE	33.5	6.5	13.5	15.9	12.3

[a]. Belt displacement in inches.

AVERAGE BELT TENSION DAY 1 (5% MVC LOAD) = 7.2 LBS
AVERAGE BELT TENSION DAY 1 (15% MVC LOAD) =8.8 LBS
AVERAGE BELT TENSION DAY 1 (25% MVC LOAD) =**10.0 LBS<<TENSION USED FOR PILOT STUDY**

TRIAL 2

SUBJECT	WT	DAY2 (IN)	ABD. CIRC. (IN)	BELT SIZE (IN.)	L & R STRAP (IN.)	MAXCIRC (IN.)	LSL (IN)	USL (IN)	TENSION (LBS)
1	LOW	1.5	32	SMALL	30.5	30.5	1.5	8.5	5.6
1	MED	2.25	32	SMALL	30.5	30.5	1.5	8.5	7.0
1	HI	4	32	SMALL	30.5	30.5	1.5	8.5	10.3
2	LOW	1	39	LARGE	33.5	33.5	5.5	12.5	7.1
2	MED	2	39	LARGE	33.5	33.5	5.5	12.5	8.2
2	HI	2.5	39	LARGE	33.5	33.5	5.5	12.5	8.7
3	LOW	2.5	38	LARGE	33.5	33.5	4.5	11.5	7.6
3	MED	3.5	38	LARGE	33.5	33.5	4.5	11.5	8.7
3	HI	3.25	38	LARGE	33.5	33.5	4.5	11.5	8.5
4	LOW	1.75	40	LARGE	33.5	33.5	6.5	13.5	9.0
4	MED	3.5	40	LARGE	33.5	33.5	6.5	13.5	10.9
4	HI	4.5	40	LARGE	33.5	33.5	6.5	13.5	12.0

AVERAGE BELT TENSION DAY 2 (5% MVC LOAD) = 7.3 LBS
AVERAGE BELT TENSION DAY 2 (15% MVC LOAD) = 8.7 LBS
AVERAGE BELT TENSION DAY 2 (25% MVC LOAD) = 9.9 LBS

EXPERIMENT 3 TENSION EQUATIONS:

Small Belt: Force = 1.76 lb. * (linear displacement in inches) + 0.49 lb. ($r^2 = 0.99$)

Medium Belt: Force = 1.69 lb. * (linear displacement in inches) + 0.18 lb. ($r^2 = 0.99$)

Large Belt: Force = 1.41 lb. * (linear displacement in inches) + 0.79 lb. ($r^2 = 0.99$)

EXPERIMENT 3 BELT TENSION DATA:

TRIAL 1:

SUBJECT	WT (LBS)	OVERLAP (IN)	ABD. CIRC. (IN)	BELT SIZE	L & R STRAP (IN.)	MAXCIRC (IN.)	LSL (IN)	USL (IN)	TOT. DISP. (IN)	TENSION (LBS)
1	40	6.0	31.5	SMALL	27.5	27.5	4.0	11.0	10.0	18.09
2	30	3.5	32.0	SMALL	27.5	27.5	4.5	11.5	8.0	14.57
3	50	4.5	37.0	MEDIUM	30.5	30.5	6.5	13.5	11.0	18.77
4	35	6.0	41.5	LARGE	33.5	33.5	8.0	15.0	14.0	20.53
5	47	7.0	32.5	MEDIUM	30.5	30.5	2.0	9.0	9.0	15.39
6	45	4.0	37.5	MEDIUM	30.5	30.5	7.0	14.0	11.0	18.77
7	28	4.0	31.0	SMALL	27.5	27.5	3.5	10.5	7.5	13.69
8	45	3.0	36.5	MEDIUM	30.5	30.5	6.0	13.0	9.0	15.39

AVERAGE = 16.9

LBS

TRIAL 2:

SUBJECT	WT (LBS)	OVERLAP (IN)	ABD. CIRC. (IN)	BELT SIZE	L & R STRAP (IN.)	MAXCIRC (IN.)	LSL (IN)	USL (IN)	TOT. DISP. (IN)	TENSION (LBS)
1	40	5.0	31.5	SMALL	27.5	27.5	4.0	11.0	10.0	16.33
2	30	3.5	32.0	SMALL	27.5	27.5	4.5	11.5	8.0	14.57
3	50	6.0	37.0	MEDIUM	30.5	30.5	6.5	13.5	12.5	21.31
4	35	6.0	41.5	LARGE	33.5	33.5	8.0	15.0	14.0	20.53
5	47	7.0	32.5	MEDIUM	30.5	30.5	2.0	9.0	9.0	15.39
6	45	4.5	37.5	MEDIUM	30.5	30.5	7.0	14.0	11.5	19.61
7	28	7.0	31.0	SMALL	27.5	27.5	3.5	10.5	10.5	18.97
8	45	3.0	36.5	MEDIUM	30.5	30.5	6.0	13.0	9.0	15.39

AVERAGE = 17.8

LBS

AVERAGE:

SUBJECT	WT (LBS)	OVERLAP (IN)	ABD. CIRC. (IN)	BELT SIZE	L & R STRAP (IN.)	MAXCIRC (IN.)	LSL (IN)	USL (IN)	TOT. DISP. (IN)	TENSION (LBS)
1	40	5.5	31.5	SMALL	27.5	27.5	4.0	11.0	9.5	17.21
2	30	3.5	32.0	SMALL	27.5	27.5	4.5	11.5	8.0	14.57
3	50	5.25	37.0	MEDIUM	30.5	30.5	6.5	13.5	11.75	20.03
4	35	6.0	41.5	LARGE	33.5	33.5	8.0	15.0	14.0	20.53
5	47	7.0	32.5	MEDIUM	30.5	30.5	2.0	9.0	9.0	15.39
6	45	4.25	37.5	MEDIUM	30.5	30.5	7.0	14.0	11.25	19.19
7	28	5.5	31.0	SMALL	27.5	27.5	3.5	10.5	9.0	16.33
8	45	3.0	36.5	MEDIUM	30.5	30.5	6.0	13.0	9.0	15.39

AVERAGE = 17.3

LBS

AVERAGE BELT TRIAL 1 = 16.9 LBS
AVERAGE BELT TRIAL 2 = 17.8 LBS
AVERAGE BELT TENSION = **17.3 LBS << TENSION USED FOR MAIN STUDY**

APPENDIX K

EXPERIMENT 1 RESTING HEART RATE AND BLOOD PRESSURE WITH AND WITHOUT BACK BELT

CONDITION	**INITIAL REST TIME**											
Subject/%SLS/ Belt	**5 MINUTES**			**10 MINUTES**			**15 MINUTES**			**20 MINUTES**		
	SBP	**DBP**	**PR**	**SBP**	**DBP**	**PR**	**SBP**	**DBP**	**PR**	**SBP**	**DBP**	**PR**
1/5/NB										110	72	93
1/5/B	112	76	95	122	68	93	108	77	95	115	74	94
1/15/NB	130	84	102	121	80	95	121	78	94	118	75	94
1/15/B			90	108	65	88			90			92
1/25/NB	130	85	90	121	80	85	121	78	83	118	75	85
1/25/B	115	70	92	105	68	92	97	63	90	107	65	88
2/5/NB	129	79	72	128	77	70	122	75	74	121	71	71
2/5/B	112	72	75	109	67	74	106	57	73	108	65	70
2/15/NB	110	68	81	124	68	76	123	68	77	115	62	73
2/15/B	119	65	66	121	66	66	119	67	66	120	65	65
2/25/NB	118	69	86	118	69	82	117	71	84	119	79	72
2/25/B	127	75	76	117	79	73	119	71	75	124	70	72

EXPERIMENT 2 RESTING HEART RATE AND BLOOD PRESSURE WITH AND WITHOUT BELT

Subject/Belt Condition	5 Minutes No Belt			10 Minutes No Belt			15 Minutes Belt/ No Belt			20 Minutes Belt / No Belt		
	SBP	DPB	HR	SBP	DPB	HR	SBP	DPB	HR	SBP	DPB	HR
1 – Belt	113	74	79	114	78	74	114	76	77	114	74	72
1 – No Belt	111	67	79	118	76	81	113	71	82	116	74	82
2 – Belt	123	100	110	132	93	109	114	90	109	112	88	109
2 – No Belt	138	86	104	128	86	106	147	106	106	122	104	104
3 – Belt	111	74	83	104	68	79	117	71	75	110	72	73
3 – No Belt	114	78	82	117	78	76	125	76	72	122	83	70
4 – Belt	132	88	119	123	84	114	116	78	111	123	83	112
4 – No Belt	136	92	100	128	92	97	129	91	97	128	90	96

EXPERIMENT 3 RESTING HEART RATE AND BLOOD PRESSURE WITH AND WITHOUT BELT

Subject/Belt Condition	5 Minutes No Belt			10 Minutes No Belt		
	SBP	DP	HR	SBP	DP	HR
1 – Belt	122	73	93	110	70	89
1 – No Belt	118	79	93	126	79	95
2 – Belt	123	75	82	123	79	83
2 – No Belt	120	76	82	118	78	83
3 – Belt	123	79	59	110	72	57
3 – No Belt	118	85	60	113	76	61
4 – Belt	130	91	67	128	92	75
4 – No Belt	134	89	89	138	92	91
5 – Belt	117	79	52	123	81	50
5 – No Belt	125	83	57	129	87	58
6 – Belt	115	80	96	108	86	97
6 – No Belt	126	100	85	122	93	87
7 – Belt	121	64	71	122	76	70
7 – No Belt	119	76	79	123	80	79
8 – Belt	122	93	90	120	88	88
8 – No Belt	120	96	87	122	98	86

APPENDIX L

EXPERIMENTAL DATA

EXPERIMENT 1 RAW DATA:

S	%SLS	B	P	WP	ΔSBP	ΔDBP	LBD	RBD	RPE
1	5	B	1	14	-4	14	0	0	9
1	5	B	2	12	-7	6	0	0	9
1	5	B	3	12	-16	3	1	0	10
1	5	B	4	12	-20	-2	2	0	10
1	5	B	5	12	-15	10	2	0	10
1	5	B	6	17	-4	7	2	0	10
1	5	NB	1	17	4	-1	1	0.5	7
1	5	NB	2	16	15	7	2	1	8
1	5	NB	3	14	10	-1	2	1	9
1	5	NB	4	15	-1	1	2	1	9
1	5	NB	5	18	15	3	2	1	10
1	5	NB	6	12	10	12	2	1	10
1	15	B	1	22	3	4	0.5	0	9
1	15	B	2	23	11	-6	0	0.5	9
1	15	B	3	24	17	0	0	0	10
1	15	B	4	22	19	0	3	0	12
1	15	B	5	21	10	-2	3	0	12
1	15	B	6	23	13	0	3	0	12
1	15	NB	1	22	-5	-9	1	0	9
1	15	NB	2	20	-14	-10	1	0	10
1	15	NB	3	19	-19	-14	2	0	11
1	15	NB	4	23	-11	-7	2	0	11
1	15	NB	5	23	-10	-1	5	0	12
1	15	NB	6	23	-8	0	4	0	12
1	25	B	1	19	1	-6	2	0	12
1	25	B	2	17	-2	-6	3	0	12
1	25	B	3	21	3	-5	3	0	12
1	25	B	4	21	-5	-13	4	0	13
1	25	B	5	15	-2	-6	5	0	15
1	25	B	6	16	4	-6	7	0	16
1	25	NB	1	21	13	-5	2	0	10
1	25	NB	2	35	0	9	2	0	11
1	25	NB	3	29	8	-7	3	0	12
1	25	NB	4	26	-1	6	4	0	13
1	25	NB	5	28	29	33	5	0	14
1	25	NB	6	30	5	-10	5	0	14
2	5	B	1	12	7	17	0	0	9
2	5	B	2	10	9	16	1	0	9
2	5	B	3	10	-9	-6	2	0.5	10

2	5	B	5	12	-9	-1	3	0	12
2	5	B	6	13	-2	25	3	0	11
2	5	NB	1	17	-7	0	3	0	11
2	5	NB	2	19	4	8	3	0.5	11
2	5	NB	3	17	-1	0	3	0.5	11
2	5	NB	4	15	-12	2	3	0.5	12
2	5	NB	5	18	4	4	3	0.5	12
2	5	NB	6	16	-1	13	3	0.5	12
2	15	B	1	29	6	1	2	2	13
2	15	B	2	27	9	-1	4	1	14
2	15	B	3	23	-1	3	6	1	15
2	15	B	4	23	32	4	6	1	15
2	15	B	5	21	5	-4	6	1	16
2	15	B	6	27	9	-8	6	1	16
2	15	NB	1	32	10	-9	0	0	12
2	15	NB	2	32	7	-2	0	0	12
2	15	NB	3	34	13	5	2	0	12
2	15	NB	4	30	1	13	3	0	13
2	15	NB	5	25	-3	14	3	0	13
2	15	NB	6	26	10	-5	4	0	14
2	25	B	1	22	12	21	0.5	0	13
2	25	B	2	24	13	-21	3	0	13
2	25	B	3	34	11	-16	3	0	14
2	25	B	4	37	15	-10	5	0	15
2	25	B	5	34	16	-7	6	0	16
2	25	B	6	43	16	-6	7	0	17
2	15	NB	1	42	17	-6	1	0	11
2	25	NB	2	44	-5	-21	3	0	11
2	25	NB	3	42	9	-10	3	0	12
2	25	NB	4	46	6	-20	3	1	12
2	25	NB	5	48	7	-15	4	1	13
2	25	NB	6	47	8	-21	4	1	14

EXPERIMENT 2 RAW DATA:

S	O/B	P	WP	SBP	DBP	LBD	RBD	RPE
1	2b	1	13	8	2	0	0	13
1	2b	2	15	6	-5	0.5	0	14
1	2b	3	14	6	-4	1	0	15
1	2b	4	15	7	-14	2	0	15
1	2b	5	20	19	-9	2	0	15
1	2b	6	21	11	-10	3	0	15
1	1nb	1	23	8	-23	0	0	13
1	1nb	2	25	16	-10	0.5	0	14
1	1nb	3	26	-2	-18	1	0	15
1	1nb	4	28	-2	-9	2	0	15
1	1nb	5	30	-13	-25	2	0	16
1	1nb	6	31	-4	-19	3	0	16
2	1b	1	18	19	12	0.5	0.5	8
2	1b	2	25	28	22	1	1	9
2	1b	3	22	30	27	1	2	9
2	1b	4	24	5	4	2	3	12
2	1b	5	17	28	32	3	4	13
2	1b	6	20	-10	-5	4	5	14
2	2nb	1	18	9	-4	0.5	1	8
2	2nb	2	20	10	6	2	3	11
2	2nb	3	23	12	11	3	4	13
2	2nb	4	23	-5	-12	4	5	14
2	2nb	5	26	-18	16	5	6	14
2	2nb	6	26	-20	-21	6	6	16
3	2b	1	42	6	3	0.5	0	11
3	2b	2	39	6	10	0.5	0.5	11
3	2b	3	41	15	-3	0.5	0.5	11
3	2b	4	39	12	18	0.5	0.5	12
3	2b	5	40	13	11	1	0.5	12
3	2b	6	44	12	9	2	1	13
3	1nb	1	41	18	1	0	0	11
3	1nb	2	38	10	1	0	0	11
3	1nb	3	42	0	-14	0.5	0	11
3	1nb	4	47	-1	-18	0.5	0	12
3	1nb	5	48	25	34	1	0	13
3	1nb	6	49	23	32	1	0	13
4	1b	1	43	10	-3	3	2	13
4	1b	2	43	15	5	3	2	13
4	1b	3	42	36	45	4	4	14
4	1b	4	39	9	-3	4	4	14
4	1b	5	46	14	32	4	5	15
4	1b	6	49	7	7	4	4	17
4	2nb	1	31	12	-1	2	1	12

4	2nb	2	31	15	2	2	2	13
4	2nb	3	30	3	-1	3	2	13
4	2nb	4	28	8	17	3	2	13
4	2nb	5	26	2	-2	3	2	13
4	2nb	6	30	6	-6	3	2	14

EXPERIMENT 3 RAW DATA:

S	O	B	P	WP	SBP	DBP	LBP	RBP	RPE;
1	2	NB	1	44	4	0	4	5	14
1	2	NB	2	42	8	8	3	4	14
1	2	NB	3	31	3	8	2	3	14
1	2	NB	4	36	3	2	2	3	14
1	2	NB	5	43	3	2	3	4	15
1	2	NB	6	47	3	6	4	4	15
1	1	B	1	28	4	1	3	5	15
1	1	B	2	33	6	15	3	5	15
1	1	B	3	35	12	26	3	5	15
1	1	B	4	36	22	6	5	5	16
1	1	B	5	43	9	1	4	5	16
1	1	B	6	47	2	-10	4	5	16
2	2	NB	1	18	0	-1	2	1	12
2	2	NB	2	21	-1	-7	3	2	12
2	2	NB	3	20	-1	1	3	2	12
2	2	NB	4	21	1	-3	4	2	13
2	2	NB	5	24	5	-1	4.5	3	13
2	2	NB	6	24	5	-10	5.5	4	14.5
2	1	B	1	17	-7	-5	1	0.5	11
2	1	B	2	16	-8	-11	2	0.5	12
2	1	B	3	17	-8	-9	2	1	13
2	1	B	4	16	-7	-16	3	1	13
2	1	B	5	17	-5	-9	3	2	14
2	1	B	6	20	9	-13	3.5	2.5	14
3	1	NB	1	28	5	9	3	3	12
3	1	NB	2	33	7	10	4	3	12
3	1	NB	3	33	10	19	4	4	14
3	1	NB	4	36	9	26	4	5	15
3	1	NB	5	38	8	29	4	5	15
3	1	NB	6	40	10	10	6	6	16
3	2	B	1	28	37	44	4	3	11
3	2	B	2	34	26	27	5	4	13
3	2	B	3	31	26	23	4	4	13
3	2	B	4	33	26	18	3	3	12
3	2	B	5	35	36	12	4	4	14
3	2	B	6	39	35	4	3	4	15
4	1	NB	1	18	2	7	4	3	12
4	1	NB	2	16	3	8	6	6	13
4	1	NB	3	16	0	8	6	6	15
4	1	NB	4	20	-2	10	7	7	16
4	1	NB	5	21	-3	15	7	6	16
4	1	NB	6	25	12	2	7	7	16
4	2	B	1	26	-6	7	2	2	11

4	2	B	2	30	13	3	3	3	13
4	2	B	3	30	9	5	2	4	14
4	2	B	4	32	13	22	2	4	15
4	2	B	5	31	10	7	4	5	16
4	2	B	6	36	31	2	4	6	17
5	2	NB	1	23	2	-10	1	1.5	11
5	2	NB	2	23	-3	-13	2	2.5	11
5	2	NB	3	27	3	-23	2	2.5	11.5
5	2	NB	4	27	-1	-8	2.5	3	12
5	2	NB	5	33	-1	-5	2.5	3	12.5
5	2	NB	6	33	1	-16	2.5	3	12.5
5	1	B	1	45	22	-3	2	2	11
5	1	B	2	50	13	4	2	1	11
5	1	B	3	50	19	3	2	3	11.5
5	1	B	4	51	24	6	2	2.5	12
5	1	B	5	53	13	4	3	2.5	12
5	1	B	6	58	23	-2	5	3.5	13
6	2	NB	1	46	13	-10	2.5	1	9.5
6	2	NB	2	45	14	-6	2.5	1.5	9.5
6	2	NB	3	45	5	2	2.5	1.5	11
6	2	NB	4	46	-1	-2	4	1.5	12.5
6	2	NB	5	45	0	-2	4.5	2	13
6	2	NB	6	48	-3	-2	5	3	15
6	1	B	1	36	22	6	2	0.5	8
6	1	B	2	27	15	-3	2	1	9
6	1	B	3	31	12	10	2.5	1.5	11
6	1	B	4	31	29	21	2.5	1	12
6	1	B	5	41	40	17	3	2	13
6	1	B	6	36	48	48	4	2	15
7	1	NB	1	23	-3	-10	3	3	12
7	1	NB	2	18	12	-5	3	3	13
7	1	NB	3	20	2	-1	3.5	3.5	13
7	1	NB	4	19	5	-7	3.5	3.5	13
7	1	NB	5	15	9	-12	4	4	13
7	1	NB	6	21	10	-10	4	4	13
7	2	B	1	18	13	3	2	2	13
7	2	B	2	17	3	-14	2	2	13
7	2	B	3	15	4	-3	2	2	13
7	2	B	4	14	5	-2	2	2	13
7	2	B	5	17	11	-8	2	2	13
7	2	B	6	20	3	-19	2	2	13
8	1	NB	1	53	14	-7	7	3	17
8	1	NB	2	52	10	-14	5	2	15
8	1	NB	3	49	7	-9	4	2	14
8	1	NB	4	49	17	-5	3	1	12
8	1	NB	5	40	1	-12	2	0	11

```
8     1     NB     6     49     -5    -13     2     0     11
8     2     B      1     38     18      1     5     4     15
8     2     B      2     42     29     41     3     5     17
8     2     B      3     41     10     20     2     2     14
8     2     B      4     38     19     16     1     3     13
8     2     B      5     42     21     23     1     5     15
8     2     B      6     45     34     29   0.5     5     13;
```