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PHYSIOLOGICAL EFFECTS OF ABDOMINAL BELT USE DURING A SYMMETRIC LIFTING TASK

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PHYSIOLOGICAL EFFECTS OF ABDOMINAL BELT USE DURING A SYMMETRIC LIFTING TASK

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ABSTRACT

Abdominal belts are widely used by the manual material handling industry as a quick fix to work-related back injuries. The use of belts has increased despite the absence of definitive research findings that support belt use. NIOSH, in its review of scientific research, advises against the use of belts by workers with compromised cardiovascular systems. This conclusion was apparently based on the results of a single study that investigated the effects of a weight-lifting belt. The results of an earlier study (Madala et al., 1997) suggested that the effects of the flexible industrial-type belt were unlike those of the non-flexible weight-lifting belt. This study also indicated the existence of a threshold workload at which belt use may be physiologically beneficial.

The current study investigated the effects of belt use in a symmetric knuckle-to-shoulder lifting task at three workload levels. Workload levels were set as percentages (40%, 60%, and 75%) of the subject's individual peak oxygen consumption rate. Physiological measures observed in the study were oxygen consumption rate (VO_2), heart rate (HR), respiration rate (RR), ventilation rate (VE), and blood pressure (BP). The results of this study indicated that belt use results in lower physiological responses compared to the no-belt condition. These statistically significant results ($\alpha = 0.05$) were observed primarily at the 60% workload for VO_2, HR, and VE. The belt effect was also significant for the RR response at 75% but was not significant at any workload for blood pressure.

The results of this study illustrate the existence of workloads for which belt use may physiologically benefit the user. However, these results must be viewed cautiously since the workload required for positive belt effects is higher than what is normally recommended for repetitive manual material handling tasks.

PHYSIOLOGICAL EFFECTS OF ABDOMINAL BELT USE DURING A SYMMETRIC LIFTING TASK

CHAPTER 1

INTRODUCTION

The information available from the occupational health literature shows that back injuries are a major health problem in today's industrial setting. Compensation paid for these injuries is a good indicator of their incidence and severity and shows varying rates dependent on the industry (Kraus, Kathryn, McArthur, Peek-Asa, Samaniego, Kraus, and Zhou, 1996). Back injuries are believed to account for nearly 20 percent of workplace injuries and cost an estimated $20 billion to $50 billion annually to U.S. industry (Megan, 1996). The ever-increasing incidence and treatment costs, and limited success in prevention compound the seriousness of the problem.

Lower back injuries, or pain due to repetitive lifting, bending, and twisting, have been a safety and health issue for a long time with ever-increasing costs (LaBar, 1996). The majority of reported back injuries are associated with some kind of lifting activity. Such lifting injuries usually occur because of excessive stress on the spinal column, specifically on the lower back or lumbar spine. This may be the result of handling loads of excessive weight and/or from twisting and reaching while handling loads. These situations usually result from improper job design where the job requirements exceed the worker's capabilities, or from the use of improper lifting techniques.

A number of measures have been proposed to prevent work-related back injuries. The most often advocated approach to control work-related injuries is proper job design. While this approach has been shown to be the most effective method of reducing injuries

(Chaffin and Andersson, 1991), it is also expensive. Worker training, job screening, and ergonomic modifications are currently recommended by the National Institute for Occupational Safety and Health (NIOSH), but objective evidence of their effectiveness alone or in combination has been elusive and subject to many methodological problems (Kraus et al., 1996). The difficulties and costs involved in job redesign or modifications have made "personal protective devices" such as abdominal belts an inexpensive alternative. This approach has been very attractive for those organizations seeking a low cost, simple solution to reduce low-back injuries. The use of abdominal belts (also referred to as back belts, lifting belts, lifting supports, orthoses, ergogenic corsets, and braces) exploded in the early 1990's as American industry attempted to control a legitimate and serious problem.

Researchers from different fields comprising occupational health, human factors, and medicine have conducted dozens of studies over the past several years using various approaches to determine the effectiveness of abdominal belts. However, clear recommendations about the effectiveness of abdominal belts still elude the research community.

NIOSH has been developing manual lifting guidelines for over a decade, constantly improving the guidelines to include a greater variety of lifting tasks and the latest research findings. NIOSH lifting guidelines, first published in 1981, included calculation of a maximum permissible limit (MPL) and an action limit (AL) based on task parameters (NIOSH, 1981). These limits were then compared to the actual load to determine its acceptability. The limits were based on biomechanical, epidemiological, psychophysical and physiological research involving various MMH tasks. The MPL was set such that 25% of male U.S. workers and less than 1% of female U.S. workers were expected to have the muscle strength to safely accomplish the lift. Loads greater than the MPL significantly increased back injury incidence and severity. In addition, such loads resulted in intolerable compression forces on the L5/S1 disc and exceeded the recommended metabolic rates for most individuals. The action limit was established as the load which could be safely lifted by over 99% of male and over 75% of female U.S. workers. NIOSH suggested various approaches to task modification based on the level of the actual task load with respect to these limits.

NIOSH guidelines were updated in 1991 to include more parameters of the lifting task (NIOSH, 1994a). Significant additions in the most recent guidelines include lift asymmetry and load coupling between the object and the worker. The current guidelines also cover more tasks than originally covered in the 1981 guidelines. The MPL and AL were replaced by the calculation of a recommended weight of lift (RWL) based on the task parameters. The actual task load is then divided by the RWL to obtain a lifting index (LI) which is used to determine the acceptability of the task and approaches to task modification. The RWL and LI were based on the concept that the risk of lifting-related low-back injury increases as the demands of the lifting task increase. However, NIOSH admits that the relationship between task parameters and risk cannot be determined precisely. The 1991 NIOSH guidelines were again based on available information from biomechanical, physiological, and psychophysical studies. The guidelines recommend the approach of modifying the task when the load exceeds the limit, but the employer must make the final decision. The NIOSH lifting equation is one of several tools available to management in a comprehensive effort to prevent work-related low-back pain.

Recently, NIOSH was faced with an increased use of abdominal belts for a variety of lifting tasks in the manual material handling (MMH) industry. The increased use of abdominal belts lacked any scientific rationale. This led to the formation of a NIOSH (1994b) working group to review the scientific research conducted on back belt usage and to provide its own recommendations to industry. Due to limitations in the studies that examined the use of back belts in the workplace, NIOSH determined that the results cannot be used to support the effectiveness of back belts in workplace injury reduction. A similar conclusion was reported by Megan (1996) from a National Safety Council technical advisory report on the use of back belts, issued in September 1995 by the Ergonomics/Human Factors Standing Committee of the Industrial and Labor Divisions of the Council.

The NIOSH working group also reviewed the physiological effects of back belt usage. In this regard it concluded that "the use of back belts may produce temporary strain on the cardiovascular system" (NIOSH, 1994b). The working group's conclusion was apparently based on the results of a single study (Hunter, McGuirk, Mitrano, Pearman, Thomas, and Arrington, 1989) which identified significant increases in heart rate during aerobic activity and in systolic blood pressure during both aerobic and isometric exercise. Furthermore, the study used a rigid leather belt that is typically not used in the workplace.

No consensual standard currently exists with regard to the design and construction of belts. Belts used in industry may be fabric, leather, or rigid molded. They also vary in width, rigidity, closures, and the presence of suspenders. The wide variety of belts used in industry and in research studies hampers the ability to make generalizations about belt use. Many researchers have studied the effects of the weight training/lifting belt, which is usually a rigid belt as opposed to the industrial abdominal belt which is flexible and may or may not have a rigid support in the lumbar region. The belts used in weightlifting are almost always made of rigid non-elastic material such as leather.

The mechanism by which belts potentially aid users has not been determined. However, it has been hypothesized that belts increase intra-abdominal pressure (IAP) and provide protection to the spine while preventing improper lifting techniques. Many research studies have shown that the use of abdominal belts during a lifting task increases IAP (Lander, Simonton, and Giacobbe, 1990; McGill, Norman, and Sharratt, 1990). Increased IAP is theorized to help reduce the compressive forces on the lumbar spine. However, the relationship between increased IAP and reduction in low-back injuries or disorders has not been empirically verified. If increases in IAP reduce compressive forces on the spine, then abdominal musculature responses (as detected by electromyographic activity) should be lower with belt use. This was shown to be true under certain conditions (Hilgen, Smith, and Lander, 1991) while unfounded in other situations (Lander, Hundley, and Simonton, 1992; McGill et al., 1990). The differences may be attributable to differences in lifting parameters such as lifting style (stoop or squat), weight of the load, range of the lift (floor-to-knuckle, knuckle-to-shoulder, etc.), and frequency of lifting. Lander et al. (1990) reported elevated IAP for stoop lifts as the load approached the subject's maximal lifting capacity. Verification of these results and/or the benefits of increased IAP at loads of smaller magnitude and while using other lifting styles has not been performed.

Reduced range of motion has been cited as another mechanism through which belts benefit the user. It has been theorized that belts remind the user to use proper lifting techniques by restricting improper or unsafe lifting postures. Lavender, Thomas, Chang, and Andersson (1994) and McGill et al. (1990) reported such benefits. Restricted motion has also been reported as one of the major problems in non-compliance with belt use mandated by some companies. Therefore, the hypothesized benefit of belt use may also be responsible for its non-use in some situations. This also reduces the effectiveness of long-term studies conducted at the workplace. Non-compliance has also been associated with wearing tightly cinched belts over long periods and in hot and humid environments. This issue has been addressed by belt manufactures with the addition of a shoulder harness on the belt. The harness allows the user to loosen the belt while lifting activities are not being performed.

The current incidence of back injuries in industry is alarming. The best way to approach this problem would be to conduct a thorough job analysis leading to job redesign. When an industry is faced with limited resources for conducting such analyses, it searches for quick "fixes". Prescription of abdominal belts is at the top of the list of such quick "fixes". Current research findings neither support nor condemn the use of abdominal belts. Furthermore, few research studies have investigated the physiological effects of abdominal belts as measured by oxygen consumption, heart rate and blood pressure. The need for research on the physiological effects of belt use is heightened by

NIOSH's conclusion about the potentially negative effects of belt use for people with compromised cardiovascular systems.

The current research addresses the physiological effects of belt use in a simple sagittal plane lifting task. The lifting task was specifically intended to be simple in order to avoid research that produces more questions than answers. The approach was based on the current research literature which suggests multiple interactions among task parameters with respect to belt effectiveness. The selected task was also designed to address the effectiveness of belt use in moderate repetition activity rather than dedicated heavy MMH activity.

The following chapter discusses the objectives of the study based on the above premise. Chapter 3 discusses the literature relevant to the study. The different approaches for investigating belt effectiveness are discussed along with cardio-respiratory responses to physical activity. In the discussion on cardio-respiratory responses, a distinction is made between upper body and lower body activity. This distinction was critical, since the responses are dependent on the proportional involvement of the upper body and the lower body in the physical activity. Chapter 4 discusses the equipment used in the study and development of the study methodology via a pilot study. The pilot study was also used to answer the importance of relative loads. Chapter 5 discusses the main study and the protocol used in data collection. Chapter 6 presents the results and analyses for several response measures. Finally, Chapter 7 presents the conclusions and recommendations based on this research.

CHAPTER 2

OBJECTIVES

The controversy surrounding the effects of abdominal belts is partly due to a lack of focus on critical issues by researchers. The conflicting findings in the literature are partly due to the multiple parameters associated with manual material handling (MMH) tasks. The variety of MMH tasks leads to the inability to narrow the focus of back belt research to a few critical task parameters and specific levels within those parameters. Consider a simple lifting task such as the knuckle-to-shoulder lift. Some task parameters include lift duration, rest duration, lift frequency, load lifted, and asymmetry of the lift. The number of possible levels for each of these parameters renders any cross-comparison of studies extremely difficult.

The variety of belts used in industry and research adds to the difficulty in generalizing the effects of belt use. Industrial belts include elastic belts, non-elastic flexible belts, belts with rigid lumbar molds, belts with air bladders, belts with a shoulder harness, belts with Velcro® fasteners, and belts with buckles and rigid fastening material. The numerous combinations of belts, tasks, and task parameters makes the drawing of any comprehensive conclusions about belt use virtually impossible. Adding further to the confusion is the lack of agreement about the critical human response variables associated with MMH activity while using belts.

The development of abdominal belts for MMH can be traced to belts used by weightlifters. These weight lifting belts are usually rigid belts and are almost always tightly cinched. The short duration of lifting activity for weightlifters supports the use of high belt tension levels. In contrast, belts used in MMH activities are usually flexible belts made of either elastic or non-elastic material. Most industrial MMH tasks involve continuous lifting activity and less than favorable environmental conditions. Hence, industrial abdominal belts are usually flexible and often come with shoulder harnesses that allow the user to unfasten the belt during rest breaks.

Many research studies in the early 1990's have investigated the effects of weight lifting belts in exercise or sports-related activities and have tried to generalize the observed effects to the use of flexible belts in MMH activities. More recently, researchers have narrowed their focus to the specific effects of flexible belts on various human response variables. However, research studies that have investigated the physiological effects of belt use are still limited in their scope and objectives.

A NIOSH back belt working group conducted a review of the scientific literature on the use of belts and concluded that "the effectiveness of using back belts to lessen the risk of back injury among uninjured workers remains unproven" (NIOSH, 1994b). NIOSH also issued its recommendations and comments about the current state of research with respect to four different methodological approaches in the literature: biomechanical, epidemiological, psychophysical, and physiological. The current study addresses the conclusion reached by NIOSH regarding the physiological effects of the belt, specifically the cardiovascular effects of the belt.

Citing physiological research on back belt effects, NIOSH concluded that "the use of back belts can put a strain on the cardiovascular system and that individuals with a compromised cardiovascular system may be at a greater risk when exercising or working with back supports" (NIOSH, 1994b). NIOSH quoted the results of a single study that documented a significant increase in heart rate during aerobic exercise and increased systolic blood pressure during aerobic and isometric exercise. The belt used in the study (Hunter et al., 1989) was a rigid weight lifting belt. The participants in the study were six healthy weight lifters who performed three types of exercise, once with the belt and once without the belt. The three exercises were bicycling at 60% of peak VO_2 for six minutes, three sets of 10 repetition bench presses at 60% of 1 RM, and holding an isometric dead lift for two minutes at 40% of the maximal isometric dead lift. NIOSH extrapolated the findings of this single study to the effects of belt use in industrial MMH tasks.

Other researchers (Contreras, Rys, and Konz, 1995; Madala, Schlegel, and Purswell, 1997) have concluded that cardiovascular measures like heart rate and blood pressure are unaffected or only marginally affected by the use of a flexible belt in a simulated MMH task. Marley and Duggasani (1996) investigated a total of 17 physiological, kinematic, and psychophysical measures under two loads (7 and 14 kg) and three lifting frequencies (3, 6, and 9 lifts/min) while subjects (8 college-aged males) performed squat lifts in the sagittal plane for 15 minutes with and then without a belt. The authors concluded that, with the exception of blood pressure, there were no statistically significant differences in the observed measures during task performance with the belt vs. without the belt. Significant increases in blood pressure were reported during lifting with the belt. Although statistically significant, the blood pressure differences were physiologically irrelevant (4 mm Hg).

Soh, Parker, Crumpton, and Mealins (1997) investigated an asymmetric lift performed at a frequency of 10 lifts per minute with a 5.4 kg load for approximately six minutes. Three different types of belts were used: a non-elastic nylon belt, a belt with an expandable air chamber in the lower back area, and a flexible elastic belt with suspenders. The primary measure of interest was respiration rate. There was a statistically significant increase in the frequency of respiration when the task was performed with the non-elastic nylon belt. This result supports the notion that the use of a flexible elastic belt may not affect the respiration rate while the use of a non-flexible nylon or rigid weight lifting belt may lead to higher respiration rates.

Madala et al. (1997) investigated the effects of an elastic lifting belt on a knuckle-to-shoulder lifting task in the sagittal plane. The task was performed at a frequency of six lifts per minute with a load equivalent to 35% of one repeat maximum (maximum load a person can lift one time) for five 4-minute periods. The responses of interest were heart rate, systolic blood pressure, and heart rate recovery measured in the rest periods between the 4-minute work periods. There was a negative correlation of work pulse differences between the without belt and with belt conditions with the absolute weight lifted. The higher the absolute weight lifted, the less likely it was for belt wearing to have a differential effect on heart rate. Subjects with the highest one repeat maximum (1 RM) exhibited the smallest work pulse differences between the without belt and with belt conditions. The authors concluded that if the weight being lifted was low, then the belt itself may significantly increase work pulse. However, as the absolute weight lifted increased, the work pulse increased and the work pulse difference due to the belt was relatively small in comparison. In other words, at higher absolute loads, the belt effect was masked by the effect of the task itself.

The contradictory results of various studies raise a question regarding the importance of the magnitude of the load being lifted. Researchers have not yet directly addressed load magnitude, nor have they considered the implications of using absolute vs. relative loads. This variable requires careful consideration because cardiovascular responses usually depend on relative maximal capacities. It is essential that the subjects work under the same relative load conditions for external validity or generalizability of the study's conclusions. This would minimize the possibility of heterogeneity in subject physical condition affecting the responses.

Some research studies have addressed this issue by basing workloads on percentages of either static (maximal voluntary contraction, MVC) or dynamic (1 RM) strength capacities. The problem with using such variables while assessing cardiovascular responses is that these variables are a function of neuromuscular capability rather than cardiovascular capacity. Setting relative workload based on cardiovascular variables such as cardiac output, maximal oxygen uptake (VO_{2max}), or heart rate would be more appropriate in investigations of the physiological effects of belt use.

Another methodological problem associated with lifting studies is the neglect of task duration and related changes in physiological responses. The duration of the task is important since cardiovascular responses and response mechanisms can vary with the duration of the task and the onset of fatigue. Sampling time of the response measures is also an important factor. Studies that compare responses recorded at the end of the lifting task fail to consider the possibility of transient changes that might occur during the task.

Considering the current state of research, NIOSH's conclusion regarding the physiological effects of belt use, and the methodological limitations of past physiological studies, the current study investigated the following questions:

- Does belt use in a sagittal plane lifting task affect heart rate, blood pressure, oxygen uptake, ventilation, and respiration rate?
- How do the effects of belt use depend on task load level?
- Are there task load thresholds that determine the effectiveness of belt use?
- How are these load thresholds related to the NIOSH lifting guidelines?
- Are NIOSH cautions regarding the cardiovascular effects of belt use warranted for a flexible belt?

CHAPTER 3

LITERATURE REVIEW

Manual material handling presents a major industrial hazard in terms of causing low-back injuries during lifting. Snook (1988) reported that the risk of low-back injury in heavy manual lifting was eight times the risk associated with sedentary tasks. However, low-back injuries are not limited to industrial MMH activity. High injury rates also exist for employees in the health sector, primarily due to patient-handling tasks. Studies have shown that back injury incidence rates among licensed practical nurses, nurse aides, and registered nurses are higher than those in other health-related occupations (Jensen, 1987).

Due to the high costs associated with back injuries and back pain, numerous approaches have been used in attempts to reduce such injuries and the accompanying cost of workers compensation claims. Strategies include pre-employment screening, ergonomic workplace design, back schools, video demonstrations of proper lifting techniques, classroom training, general physical fitness, on-the-job training, and back belts (Alexander, Woolley, Bisesi, and Schaub, 1995).

Back belts or back supports have been used in sports-related activities, particularly in weightlifting, for many years. The early 1990's have seen an increased use of belts in MMH activities. Belts are manufactured in various sizes and styles. They can be flexible or rigid and made of elastic material or non-elastic material like nylon or leather. They may also have a rigid lumbar pad or inflatable lumbar sacs, and may sport other features like suspenders.

It is hypothesized that the belts work by promoting good posture, aiding the body's supporting structures, and reminding the wearer of proper body mechanics when lifting (Votel, 1993). The benefits of belt use are reportedly related to (1) increased intra-abdominal pressure (IAP), believed to increase support to the lower back and the abdominal region, and (2) the reinforcement of proper lifting techniques by restricting motion in non-sagittal planes (Grandjean, 1988). Hilgen (1992) reported that the belt compresses abdominal muscles to increase IAP, similar to how a person voluntarily tightens stomach muscles. Hilgen also suggested that the term "abdominal belt" is the proper name for this type of support rather than the misused "back belt" since the belt is worn around the abdomen rather than the back.

Evidence that abdominal belts aid manual lifting comes from studies of weightlifters using a highly tensioned, stiff leather belt for short periods. Weightlifters are able to lift higher loads with belt use. However, information is lacking on the long-term effects of moderately tensioned, flexible belts used in the workplace. Controversy exists over whether such belts might, in fact, harm users by causing disuse atrophy of the lumbar muscles.

McGill (1993) summarized the findings of clinical or laboratory studies conducted on abdominal belts by stating: "Difficulties in executing a clinical trial are well acknowledged: the Hawthorne effect is a concern, as it is difficult to present a true double-blind paradigm to workers since those who receive belts certainly know so; and there are logistical constraints on duration, diversity in occupations, and sample size." McGill also pointed out that many laboratory-based studies possess methodological problems such as the absence of a matched control group, no post-trial follow-up, and limited trial duration. Consequently, McGill concluded that data from well-conducted investigations fail to support belt use for all MMH workers in order to reduce low-back injury risk. However, McGill reported weak evidence supporting the notion that belt use may be beneficial for workers with previous low-back injury to reduce injury reoccurrence. It was also suggested that there may be an increased risk of injury following termination of belt use.

Several approaches have been used by researchers to evaluate the effectiveness of abdominal belts in reducing low-back injuries. These studies are usually classified as biomechanical, epidemiological, physiological, or psychophysical. Biomechanical studies investigate the physical behavior of the body and its anatomical components in mechanical terms such as displacement, velocity, and force. These studies essentially compare the mechanics of the body while the user performs a given task with the belt and without the belt.

Epidemiological studies are typically observational or post-hoc. These studies are often conducted in an occupational setting and involve analysis of injury statistics or subjective responses over extended periods. They involve monitoring changes in job performance due to belt use across time periods or between distinct time periods. The observed measures typically include injury incidence rates, time lost due to back pain, and costs associated with treating the injury.

Physiological studies investigate physiological responses such as heart rate, blood pressure, and oxygen consumption with belt use. Since most physiological measures require elaborate instrumentation, physiological studies are usually laboratory-based.

However, with advances in radio-telemetry, measures like heart rate are increasingly monitored in the workplace with minimal interference to the subject and the activity.

Psychophysical studies seek to determine what is psychologically acceptable to the subject. These studies involve presenting a subject with a physical stimulus (lifting task) and then observing the subject adjust the task (e.g., weight of the load, frequency of the lift) to an acceptable level. These investigations typically extrapolate the findings from a short-duration task to an eight-hour task. The application of psychophysics to abdominal belt investigations usually involves comparison of acceptable loads with and without belt use.

None of the four approaches has been able to conclusively demonstrate the effectiveness of belt use. However, the extensive research conducted using each approach helps narrow the focus of future research to a few critical issues. A multi-faceted approach incorporating all four research strategies may lead to a better understanding of the mechanisms associated with back belt use. Conclusive statements can only be made by developing and verfying mechanisms that can explain both the biomechanical and physiological effects of belt use. The following sections discuss the current state of research in each of the four areas.

3.1 Biomechanical Studies

Biomechanical measures of interest in belt use studies may be broadly classified as biological vs. body mechanics measures. Biological measures include electromyographic (EMG) activity of muscles, intra-abdominal pressure (IAP), and intradisc pressure (IDP). Biological measures often require invasive measurement techniques. Measures based on body mechanics include estimated compressive forces on body segments and joints, bending moments at various joints, force-time relationships, impulse, range of motion, displacement, velocity, and acceleration of body segments or joints. These measures are usually obtained by non-invasive techniques such as filming.

Biomechanical research has yielded some studies that support belt use and others that conclude that belts are not effective. The effects of intra-abdominal pressure (IAP) form one of the most widely discussed issues in biomechanical research studies. It has been theorized that an increase in IAP reduces spinal loads. The additional support that may be achieved by compressing the abdominal musculature surrounding the lumbar spine with an abdominal belt is expected to further reduce the spinal loading.

Lander et al. (1992) and Harman, Rosenstein, Frykman, and Nigro (1989) studied the intra-abdominal pressure (IAP) of subjects performing lifting tasks. The researchers assumed that IAP was a good indicator of spinal loading and that an increase in IAP indicated an increase in low-back support. Both research groups reported an increase in IAP when belts were worn. In their view, this justified wearing the belts. Spinal loads were not measured directly in either study but were assumed to correlate with the IAP values.

Several studies have questioned the hypothesized link between elevated IAP and a reduction in low-back loading. McGill and Norman (1987) noted that a build-up of IAP may be achieved via additional activation of the musculature in the abdominal wall resulting in a net increase in low-back compressive loading rather than a net reduction. In addition, Nachemson, Andersson, and Schultz (1986) published experimental results of direct measurement of intra-disc pressure during the performance of Valsalva maneuvers. The authors determined that an increase in IAP was accompanied by an increased rather than decreased low-back compressive load. Therefore, it may be erroneous to assume that the increase in IAP due to belt use reduces compressive loading on the spine.

McGill et al. (1990) studied IAP and myoelectric activity in the trunk musculature. Six subjects performed eight lifts each on a lifting machine. Two lifts were performed with breath holding and another two lifts with normal expiration. The four lifts were then repeated while the subject wore a belt. The task involved lifting a weight that the subject felt was heavy but could be lifted safely. No description of the range of the lift was given. However, it may be estimated that the lift started at approximately knee height. It was hypothesized that if belts were able to support some of the low-back extensor muscle activity, there would be a measured reduction in that activity. They found no change in the activation levels of the low-back extensors nor in any of the abdominal muscles when the task was performed with the belt compared with the no-belt lift.

Granata, Marras, and Davis (1997) studied the influence of different types of lifting belts on trunk kinetics, muscle activity, and predicted spinal loading during symmetric and asymmetric lifting exertions. Fifteen male subjects lifted boxes weighing 14 kg or 23 kg from sagittal plane symmetric or asymmetric (60 degrees clockwise) origins to an upright posture. From the study description, it is assumed that the task involved only lifting activity. In the symmetric lift, the initial height was the knee height of the subject. The final position was 10 cm above knee height and the box was placed 40 cm in front of the subject. From the description of the asymmetric lift, it may be assumed that the initial height of the box was 70 cm above the floor and offset by 60 degrees from the final location. The final location was identical to that of the symmetric lift. Since no subject descriptions were presented, it was assumed that the initial position of the box in the asymmetric lift (70 cm above floor) was lower than the final position (10 cm above knee height) for all subjects. The independent variables were belt type, lift symmetry, and box weight. The belts used were an elastic nylon belt, a leather weight lifting belt, and a fabric belt with a rigid lumbar support. The dependent variables included dynamic measures of trunk and pelvic motion, electromyographic activity, and predicted spinal loading. Belt tensions were adjusted to 4.5 kg for all subjects across all trials. The procedure for adjusting and measuring belt tension and the task duration were not mentioned by the authors.

The results of this study showed that the use of any of the three belts significantly reduced the peak trunk angles, velocities and accelerations in the sagittal, lateral and transverse planes. However, reduced range of motion in all three planes was only observed with the elastic belt. Use of the elastic belt affected trunk motion and the predicted spinal loading more than the other two belts. The authors reported that subjects typically flexed both the trunk and pelvis equally to perform a lift. With belt use there was reduced flexion, velocity, and acceleration of the trunk but increased pelvic flexion. The authors concluded that the use of elastic belts "transfers motion from the back to the pelvis, minimally affects muscle activity and significantly reduces trunk loading."

Hilgen et al. (1991) conducted a study to determine the weight of lift for which a belt becomes effective for the user. Dependent measures in the study were obtained via electromyography, kinematics, and a force platform. Two different belts, a flexible belt with an inflatable air sac and an elastic belt, were investigated along with a no-belt condition. The task involved lifting a wooden box (48.3 x 24.8 x 14.8 cm) from floor to knuckle height at a rate of one lift per minute. The task involved only lifting. Five physically active males with weight lifting experience performed a set of ten lifts with each belt and in the no-belt condition. The ten lifts involved two repetitions of five randomly chosen loads. Subjects performed the task in two sessions with a two-hour rest break between the sessions. The first session lasted 1 hour and 45 minutes, while the second session lasted 55 minutes. Belt tension for the air belt was adjusted to an air pressure of 190 mm Hg in the air sac while the elastic belt was tensioned as tightly as possible.

The measures used to determine the effectiveness of the belts were integrated EMG activity, spinal forces, moments, and spinal force and moment impulses at different stages of the lift. The air sac belt yielded the lowest integrated EMG activity, spinal force impulses, and moment impulses in the middle stage of the lift, while the elastic belt yielded the lowest values of these measures in the initial stage of the lift. In addition, the elastic belt also yielded lower moments and spinal forces in the initial stage of the lift. Based on these observations, the authors concluded that the abdominal belts were beneficial in stooped lifting tasks for task loads near or exceeding the NIOSH 1981 maximum permissible limit. This was the only study found by the author that attempted to find the base weight at which a belt was effective.

It has been hypothesized that abdominal belts benefit workers by increasing lifting capacity. Using a simulated lifting task, Woodhouse, Heiner, Shall, and Bragg (1990) compared the effects on isokinetic lifting capacity of two types of belts (a modified leather weight lifting belt with a rigid abdominal pad and an elastic belt). There were no statistically significant differences in the peak lifting force, total muscular work, or average muscular power between the two belts. Although there was a slight trend towards a small increase in peak lifting force and average muscular power for both belt conditions, the authors concluded that there was no statistical evidence that the lifting belts improved functional lifting capacity.

Many researchers have suggested that discontinuing the use of abdominal belts after a period of prolonged use may place workers at greater risk of back injury. A study by Holmstrom and Moritz (1992) found that after two months of belt wearing, trunk extensor muscle strength and endurance were unchanged while trunk flexor muscle strength increased, thus casting doubt on the muscle disuse atrophy hypothesis. Since abdominal belts are hypothesized to reduce the efforts of the abdominal musculature rather than the trunk extensors, this result should have been expected. In addition, McGill et al. (1990) found that the contraction level of abdominal muscles was so slight during experimental lifting both with and without a belt, that a detraining effect from belt use is highly unlikely. The hypothesis of disuse atrophy would be associated with the abdominal musculature since the activity of these muscles is hypothesized to be affected by abdominal belts. Since differences in contraction levels of these muscles between belt and no-belt conditions have been shown to be negligible, the theory of disuse atrophy with belt wearing may be discounted.

McGill, Seguin, and Bennet (1994) conducted an investigation of the passive bending properties of the human torso about its three principal axes of flexion/extension, lateral bending, and axial rotation. Passive bending in these axes was obtained with the subjects inside "floating" frictionless jigs. The jigs were configurable to measure sagittal, coronal, and transverse plane motions. The dependent measures in this study were the amount of torque that the subject was able to tolerate under different configurations and the EMG activity of the muscles. The resulting range of motion in each plane was also recorded. Three trials each of flexion, extension, right lateral bending, left lateral bending, clockwise rotation, and counterclockwise rotation were recorded. The trials were conducted under three conditions: normal, wearing an abdominal leather athletic belt (approximately 11 cm wide in the front and 6.5 cm wide in the rear), and holding one's breath after maximum voluntary inhalation.

The results for the maximum torque and muscle EMG activity showed that both belt wearing and breath holding appeared to stiffen the torso in the coronal and transverse planes but not in the sagittal plane. The authors concluded that since most lifting tasks involve torso extension, and to a lesser degree, lateral bending and rotation, the results of this study do not support the use of belts. In addition, restriction of motion or stiffness that is obtained from belt wearing is only one of the many biomechanical, physiological, and psychological factors that should be considered in the decision to use belts.

3.2 Epidemiological Studies

Epidemiological studies are usually retrospective studies. The effects of specific variables are studied in a real world situation with limited control over extraneous variables. Epidemiological studies avoid the need to generalize laboratory results to the "real world." In addition, the larger number of subjects and longer time-period of analysis or observation provide higher validity. Variables observed in epidemiological back-belt studies include job performance measures and back-injury incidence measures. Job performance measures assess the ability of the worker to meet the job requirements and may include productivity-based measures. Back-injury incidence measures include observation of the frequency of incidents, the workload intensity of the associated job, lost time, incurred compensation costs, previous injury history, and first report of back pain in chronic cases.

Another epidemiological approach is to observe changes in factors that may modify the risk of back injury. These factors may be broadly classified into personal risk factors and job-related risk factors. Personal risk factors include age, gender, anthropometry, training, strength, lifting techniques, and worker attitude towards the job. Job-related characteristics that are known to modify risk of injuries include weight lifted, the size of the load, and the frequency of lifting

Most epidemiological studies involve a one-time analysis of specific measures across a particular time period. Typically, the time period of interest has passed prior to conception of the study. Of late, more real world studies are meticulously planned to take place over extended periods of time with periodic data collection. Some of these longitudinal studies investigating low-back injuries and belt use last as along as five years with multiple data collection periods. The primary disadvantages of epidemiological studies include the number of extraneous variables that may affect the data and the changes in these extraneous variables over time. These disadvantages may be reduced to a certain extent by planning frequent data collection periods and measuring all possible extraneous variables.

Walsh and Schwartz (1990) conducted a six-month study involving abdominal belts containing hard plates molded in the shape of the low-back region of each participant. Male warehouse workers were randomly divided into three groups of 27 subjects each. The first group was a control group and received no training and no belt. The second group did not receive a belt but participated in a one-hour training session on lifting mechanics and back injury prevention. The third group received both training and the custom-made abdominal belt. The workers performed their regular job activity which involved handling various loads in a warehouse. The dependent measures in the study were abdominal flexion strength, injury rate, and productivity. The abdominal flexion strength of the workers was measured before and after the study. The results showed no difference in abdominal flexion strength or accident rate but did show a decrease in lost time for the third group of workers who were both trained and used a belt. However, it appeared that within the third group of workers the benefit was apparent only for those participants who had injured their lower back previously.

Reddell, Congleton, Huchinson, and Montgomery (1992) studied baggage handlers for an airline. They examined the effects of wearing an abdominal belt on lumbar injury incidence and severity. The belt was a fabric weight lifting belt, 15 cm wide in the front and approximately 10 cm wide in the rear. This belt was more flexible than a leather weight lifting belt but less flexible than the typical elastic belt currently used in MMH tasks. The study began with 896 baggage handlers divided randomly into four groups as follows: belt only, belt and training, training only, and a control group with no belt and no training. The study lasted eight months and the authors were able to trace 642 of the original 896 subjects. No significant differences were found among the treatment groups in terms of total lumbar injury incident rate, lost work days, or workers compensation rates. However, lack of compliance with the given instructions was a problem. Furthermore, injury incident rates were self-reported which implies a potential for recall bias. The authors also noted that an eight-month investigation may be too short to detect any potential impact of belt use.

In a retrospective study of 1,316 workers routinely involved in manual lifting activities, Mitchell, Lawler, Bowen, Mote, Asundi, and Purswell (1994) investigated the effectiveness of back belts in reducing back injuries and their associated costs. A self-administered questionnaire was used to determine exposure information during the period from 1985 to 1991. The questionnaire recorded information on lift frequency, weight of lift, proportion of the work day spent lifting, belt use, history of back problems, and medical treatment. During the six-year period, leather belts were used from 1985 to 1986 and flexible non-elastic canvas belts with suspenders were used after 1986. The workers were involved in warehousing jobs.

Belt use was implemented at two levels. The first level was voluntary. Any worker who lifted, pushed or pulled items weighing at least 20 lb for more than 50% of the time was provided a belt on request. The second level of implementation was mandatory. Any worker performing a similar job as the level 1 worker but who had sustained a back injury or strain within the past two years was required to wear a belt. All workers who joined the organization during the six-year period also received back injury prevention training. The results indicated that back belts were minimally effective in preventing low-back injuries. When the data were adjusted for factors associated with heavy lifting (weight lifted per day, previous training, and previous back injury), belts were marginally effective in injury prevention. The results suggested that certain work-related factors, namely the history of previous back problems and the daily amount of weight lifted, significantly affected the risk of back injuries independent of belt use.

Kraus et al. (1996) reported findings from one of the longest and largest epidemiological studies on the effects of abdominal belts. The study was conducted at a national chain of home improvement stores and analyzed the records of nearly 36,000 employees over 101 million working hours. Working hours of exposure, back belt use policy, and intensity of material handling were analyzed from 1989 through 1994. A mandatory belt-use policy was introduced for all store employees in 1990. Therefore, belt effects were compared between 1989 and the period 1990 to 1994.

Incidence rates were calculated for individuals wearing and for individuals not wearing the belt, and all documented injuries to the lower back were analyzed. The intensity of manual material handling varied widely based on job title. The authors divided the various job titles into low, moderate, and high based on the intensity of the lifting/carrying activity (frequency, weight, and distance carried). Before the implementation of the back belt policy, employees had a rate of acute low-back injuries of 30.6 per million working hours. After implementation of the policy, this rate fell nearly 34% to 20.2 low-back injuries per million working hours. This effect was reported for both genders, in younger workers and in those over 55 years of age, under both low and high intensity lifting/carrying, and for individuals with as little as one to two years of employment with the company. The authors concluded that "uniform mandatory implementation of a back-support-use policy significantly reduces the incidence of acute low-back injuries incurred in the workplace."

3.3 Psychophysical Studies

Psychophysical studies investigate the psychological response to a physical stimulus. The physical stimulus in most lifting studies is the physical lifting or lowering task under specific conditions. The psychological response is the set of conditions that the subject perceives to be comfortable. The experimenter can choose to vary any task parameter, but in many cases task frequency and load travel parameters are held constant. For example, a psychophysical approach to studying the effects of belt use on a lifting task would involve the subject performing the identical task with and without a belt. Once the experimenter sets the task parameters, the subject would be asked to vary the lifted load until it was comfortable. The load thus depends on the subject's perception of a comfortable load for a typical eight-hour shift.

The psychophysical approach to determining maximum loads was originally developed by Snook and Irvine (1967) for slow, intermittent tasks. Ciriello, Snook, and Blick (1990) concluded from their study of lifting that "psychophysics appears to provide valid and reliable results for intermittent tasks with frequencies up to 4.3 cycles/min. For tasks greater than 4.3 cycles/min, physiological measurements of heart rate and oxygen consumption are needed to establish limits in performance." This conclusion was based on the finding that the weights and forces established during a 40-minute test were maintained for a four-hour test with no evidence of excessive heart rate or oxygen consumption.

McCoy, Congleton, Johnston, and Jiang (1988) conducted a psychophysical study using a floor-to-knuckle lift performed at the rate of three lifts per minute for 45 minutes. Two different belts were used. One belt was an elastic stretch belt while the other had a pump and a posterior air bladder for supporting the lumbar region. Twelve adult male college students with no prior back problems participated in the study. The dependent measures were maximum acceptable weight of lift (MAWL), external pressure on the abdomen during belt use, and subjective comfort response. External pressure on the abdomen was recorded using pressure changes measured by an air bladder inserted under the belt. Maximum acceptable workload was calculated as the combined product of maximum acceptable weight of lift, height of lift, and task frequency. Wearing the belts increased the maximum acceptable workload that the subjects were willing to lift by 19%. However, no difference in maximum acceptable workload between the two belts was reported. There was no difference in external abdominal pressure between the two belts. Subjective responses showed that 58% of the subjects preferred the elastic belt, 33% preferred no-belt, and only 9% preferred the air belt.

Lavender and Kenyeri (1995) hypothesized that if abdominal belts provide a biomechanical or motivational advantage, then participants in a psychophysical lift test with a belt should select a higher MAWL. Eleven male and five female subjects wore an elastic belt while lifting a box from 30 cm above the floor to elbow height. The box was initially loaded to a randomly selected weight between 4.5 and 31.8 kg. A task frequency of two lifts per minute was used and the task was performed for 40 minutes while the subject adjusted the weight in the box to a level that could be sustained for eight hours. There was no significant difference in the MAWL achieved with vs. without the belt.

Bowen, Purswell, Schlegel, and Purswell (1995) conducted a psychophysical investigation of floor-to-knuckle (FK) and knuckle-to-shoulder (KS) lifting and lowering in the sagittal plane under belt and no-belt conditions. The abdominal belt used was made from elastic material. Thirty-one subjects, nineteen females and twelve males participated in the study. Eighteen subjects performed only the FK lift while thirteen subjects performed only the KS lift. Initially, the preferred belt tension was obtained for each subject in either the FK or the KS task. The load that the subject lifted in this stage was selected by the subject and ranged from 11.3 to 13.6 kg. Task frequency was two lifts and lowers per minute.

Once the preferred belt tension was obtained for each subject, a psychophysical approach was used to determine the MAWL. The dependent variable was the MAWL that the subject preferred. The independent variables were the belt condition, type of lift, and gender. The authors reported a significant increase of 13% to 18% in the MAWL with belt wearing. An average preferred belt tension of 6.8 kg was reported, with subjects in the KS task preferring higher tension. Furthermore, female subjects tended to prefer lower belt tensions than male subjects.

3.4 Physiological Studies

A broad definition of physiological responses would include IAP, electromyographic activity of muscles, blood pressure, heart rate, oxygen consumption, ventilation, energy substrates, breathing rate, and a number of derived measures. However, a more common definition applicable to belt effect research would include only effects on the circulatory and respiratory systems.

The primary disadvantages of the physiological approach are the cost of instrumentation and the often associated confinement to a laboratory environment. The quick response nature of the cardio-respiratory system often makes it difficult to monitor responses in a timely fashion without affecting the task under investigation. Continuous monitoring of physiological responses often requires intrusive equipment although not necessarily invasive procedures. Certain physiological measures such as blood pressure often cannot be measured without task interference. This leads to situations where the task must be designed around the capabilities of current technology and instrumentation.

Hunter et al. (1989) monitored blood pressure and heart rate while subjects performed various tasks with and without an abdominal belt. The belt was a 10 cm wide rigid leather weight lifting belt. Six healthy subjects performed three different exercise tasks. Each task was performed once with the belt and once without the belt. The three tasks were bicycling at 60% of peak VO_2 for six minutes (aerobic), three sets of 10 repetition bench presses with 60% of 1 RM (aerobic), and holding a dead lift for two minutes at 40% of the maximal dead lift (isometric). The primary dependent measures were heart rate and blood pressure. Heart rate was measured continuously using a single bipolar EKG lead. Blood pressure was measured every minute using the auscultation method on the non-dominant arm.

Mean systolic blood pressure was significantly higher with belt use for the aerobic and isometric activities. A significant heart rate increase was also associated with belt use during aerobic exercise. With belt use, the rate-pressure product (product of heart rate and systolic blood pressure) was significantly higher (6% to 15%) for all three exercise tasks. These results led the authors to conclude that individuals with compromised cardiovascular systems are probably at greater risk while wearing back supports when lifting or performing physical exercise.

Contreras et al. (1995) studied the effects of three types of abdominal belts on two lifting and lowering tasks. Belt A, made of semi-rigid synthetic material, was 10 cm wide and 0.5 cm thick. A 2 cm thick rigid lumbar pad was permanently attached to belt A. Belt B was available in two designs, male and female. The design for females had a maximum width of 14 cm around the lumbar region and tapered to 10 cm at each end. The upper edge had more curvature than the belt designed for males. The belt for males had a maximum width of 16 cm in the lumbar region and tapered to 10 cm at each end. Both belts were designed to be positioned over the pelvic region and were made of sections of rubber and synthetic mesh. Belt C measured 20 cm in the lumbar region and tapered to 10 cm at each end. Belt C was made of an elastic synthetic material and was available with suspenders.

The dependent measures in this study were blood pressure, heart rate, body part discomfort ratings and subjective rating. Nine male subjects and seven female subjects lifted a wooden box without handles. The box measured 38 x 20 x 15 cm and weighed 6.5 kg. The task involved either lifting or lowering at the rate of 4 lifts/lowers per minute. Two vertical lift distances were used, floor to 86 cm and floor to 175 cm. Each of the four possible tasks lasted eight minutes. Belt tension was set to 25 mm Hg as measured by an air bladder worn under the belt. The air bladder was removed once the necessary tension was achieved.

There were no significant differences in blood pressure (systolic or diastolic) or heart rate due to belt condition. Also, there was no significant difference in body part discomfort ratings, although discomfort increased significantly with time, and females experienced higher discomfort than males. Belt C was the preferred belt among subjects.

Marley and Duggasani (1996) investigated the effects of abdominal belts on several physiological, kinematic, and psychophysical variables. Eight male college students performed sagittal plane lifting of a box from the floor to a height of 76 cm for a duration of 15 minutes. Three task frequencies (3, 6, and 9 lifts per minute) and two loads (7 and

14 kg) were used. The measured physiological responses were heart rate, oxygen consumption, carbon dioxide expiration, tidal volume, respiration rate, rate of energy expenditure, and systolic and diastolic blood pressure. Kinematic data included displacement angles, peak positive velocities, average positive velocities, and peak positive accelerations of the hip joint and knee joint. Belt tension was controlled across trials for each subject. However, the authors do not report the specific procedures used to control and measure belt tension. With the exception of significantly higher systolic and diastolic blood pressures with belt use, the physiological responses were not significantly affected. The practical significance of the blood pressure differences was questionable. The kinematic measures also failed to exhibit any significant changes with belt use.

Soh et al. (1997) investigated changes in respiration parameters while subjects performed a repetitive lifting task with and without an abdominal belt. Eleven male college students lifted a load of 5.4 kg from a height of 13.8 cm above the floor to a table 60 cm above the floor. The final position of the load was horizontally displaced 37.5 cm away from the subject compared to the initial position. The lift also involved an asymmetry of 45 degrees in the counter-clockwise direction from the initial to the final position. The task was performed at a rate of ten lifts per minute for approximately six minutes. Three types of belts were investigated: a 10.2 cm wide non-elastic nylon belt, a 12.7 cm wide air belt with an inflatable lumbar sac, and a 22.9 cm wide elastic belt with adjustable suspenders. A pneumograph strain gauge across the subject's chest was used to measure respiration rate. The belt tension was not described.

Compared to a no-belt condition, a significant increase in respiration rate was observed for the non-elastic belt while similar but non-significant increases were observed for the other belts. The authors attributed the higher respiration rates to a reduction in abdominal distensibility and an increase in IAP. The proposed mechanism involves increased pressure on the diaphragm and reduced lung volume via abdominal mass with belt use. In the absence of the belt, abdominal mass moves downward and forward due to gravity. This in turn nullifies the reduction in mean vital capacity and end reserve volume observed with belt use. The use of a rigid belt amplifies this effect, whereas the elastic belt allows a certain degree of abdominal distension. These results support the notion that rigid belts are not effective in an MMH task since they result in higher respiration rates. Rigid belts are therefore more appropriate for short-duration weightlifting activity where the effects of higher respiration rates are not critical and are more than offset by the positive effects. Although the authors reported similar trends with the elastic and air belt, the lack of any data on belt tension precludes any comparisons.

Madala et al. (1997) investigated the physiological effects of an abdominal belt in a material handling task that involved lifting and lowering a box from knuckle height to shoulder height for five 4-minute periods interspersed by rest periods determined by the subject's heart rate (HR). During each work period, cycles of lifting and lowering were performed every ten seconds. Each rest period lasted until the subject's heart rate dropped to 35 bpm above his resting level. The weight lifted was 35% of the subject's one repeat maximum. The dependent measures were heart rate, systolic blood pressure and heart rate recovery time. The independent variables were belt condition and work period. Belt tension was psychophysically determined for each subject.

The average belt tension obtained for the lifting task was 8.6 kg (S.D. = 1.29 kg), and the average weight lifted was 10.79 kg (S.D. = 2.15 kg). Bowen et al. (1995) reported a belt tension between 6.3 and 6.8 kg while performing a knuckle-to-shoulder lift of 10.6 kg every 30 seconds. The higher belt tension preferred by the subjects in the Madala et al. may be due to the higher task load.

Belt use had a minimal effect on the physiological measures in this study, although there was a negative correlation of work pulse differences between the no-belt and belt conditions with the actual weight lifted. The higher the 1 RM value (and the corresponding weight lifted), the less likely it was to observe a significant effect of the belt on heart rate. If the weight being lifted was low, the belt itself seemed to produce a significant work pulse difference. As the weight being lifted increased, the work pulse increased accordingly, and the additional work pulse increase due to the belt was relatively small in comparison. In other words, the belt effect was masked by the effect of the task itself.

According to the authors, if the lifted weight is very high, the belt may have an augmentative effect. This conclusion was based on the fact that lower mean heart rates, lower mean SBP, and shorter recovery times were observed when lifting was aided by the belt. However, these differences were not statistically significant. These observations led the authors to hypothesize the existence of a critical weight (possibly within NIOSH limits) above which belts benefit lifting from a physiological standpoint.

Whitney (1997) investigated belt use effects on physiological and perceived strain during a high frequency, long-duration asymmetric stoop lifting and lowering task. The dependent measures were heart rate, blood pressure, lower left back discomfort, lower right back discomfort, perceived exertion, and static lift strength. Heart rate was expressed as work pulse, and systolic and diastolic blood pressure observations were converted to changes in systolic blood pressure and diastolic blood pressure from work to rest. The author conducted three experiments while varying the task parameters. The number of participants in each experiment varied.

The participants in the first experiment were two male subjects of average fitness. A lower work pulse was reported with belt use (belt tension of 5.6 kg) while performing the task at 5%, 15%, and 25% of the maximum static lift strength (SLS). The work pulse difference between the belt and no-belt conditions during the 25% SLS workload was significantly lower than for 5% and 15% SLS workloads. The second experiment examined the psychophysical adjustment of belt tension. The participants were four male subjects with no prior lifting experience. Belt tension preference was repeatable for low (5% SLS) and high (25% SLS) workloads but not for the moderate workload.

Eight male subjects participated in the third experiment. Individual differences in physiological responses were attributed by the author to subject characteristics such as body weight, static lift strength, abdominal girth, and physical task conditioning. Consequently, the author reported that the weight lifted, and the abdominal girth, body weight, and fitness of the participant were the four most important determinants of belt use effects in a high-intensity asymmetric stoop lifting-lowering task. Belt use resulted in higher physiological strain in this study.

3.5 NIOSH Working Group Conclusions

NIOSH formed a back belt working group in 1994 to address the increased use of abdominal belts in MMH tasks. The primary objective of this group was to review the scientific literature to assess the effectiveness of abdominal belt use in the workplace. The NIOSH group addressed the lack of conclusive evidence for belt use by conducting its own review of the literature and providing recommendations based on its interpretation of the state of research and the research methodologies used.

Based on its review of biomechanical studies of belt use, NIOSH concluded that "there are insufficient data to indicate that typical industrial-type back belts significantly reduce the biomechanical loading of the trunk during lifting." In addition, "there is no conclusive evidence that actual trunk muscle forces, predicted spinal compression, or shear forces are significantly reduced by wearing a back belt." NIOSH recommended using alternate intervention strategies instead of back belts to reduce spinal loading in MMH tasks.

From its review of biomechanical and physiological studies, NIOSH reported that no conclusive scientific evidence currently exists that belt use is protective to industrial workers based on changes in IAP and trunk muscle EMG. This conclusion was based on the observation that the exact nature of the biomechanical and physiological mechanisms that may provide the hypothesized protection are still unknown. NIOSH also cautioned against the possible hazards of prolonged belt use to back and abdominal muscle tone and cardiovascular health. NIOSH specifically mentioned the possibility of back belts causing temporary strain on the cardiovascular system. With respect to disuse atrophy, NIOSH concluded that there are insufficient data to demonstrate a relationship between the prevalence of back injury in healthy workers and discontinuation of back belt use.

NIOSH's main criticism of the psychophysical approach to back belt use was the absence of any study that evaluated the relationship between the user's perception of maximum acceptable workload and low-back injury. In addition, psychophysical studies have not adequately addressed the possibility of biased results from pre-study subject assumptions regarding back belt effectiveness. The use of a back belt may foster an increased sense of security, which may or may not be warranted or substantiated. NIOSH also raised the possibility of a "Hawthorne effect" in studies reporting higher acceptable loads with belt use.

NIOSH listed several critical problems with existing epidemiological studies. The problems included low participation rates, inadequate observation periods, small sample sizes, relatively low-back-injury rates, inclusion of individuals with previous back injuries, and recall and reporting biases of current and previous injuries and exposures.

NIOSH's review of research studies and methodologies showed that there was no consensus in either the methodologies or the results within each of the four broad approaches. Shortcomings and gaps in the research were identified. Nevertheless, NIOSH presented its recommendations for belt use based on the available research. NIOSH concluded that "the working group does not recommend the use of back belts to prevent injuries among uninjured workers, and does not consider back belts to be personal protective equipment." Furthermore, NIOSH emphasized that the use of back belts does not mitigate the hazards posed by repeated lifting, pushing, pulling, twisting, or bending.

3.6 Cardiovascular Responses to Physical Activity

The current study focused on the physiological effects of belt use in an upper body task. This section reviews the physiological responses normally associated with an upper body task. Cardiovascular responses to physical activity have been investigated primarily by exercise physiologists. Hence, most research findings are based on exercise activities. Although most of these findings may be applied to occupational activities, precise responses and their underlying mechanisms in occupational settings cannot be generalized from exercise activities.

Cardiovascular responses (CV) have been primarily investigated for lower body activity using treadmills and bicycle ergometers. Exercise physiologists have also investigated upper body activity such as arm-cranking exercise using arm ergometers. Occupational lifting predominantly involves the upper body with contributions from the lower body. Therefore, conclusions drawn from isolated upper body or lower body exercise activity may not be directly applicable to MMH activity.

MMH activity such as the knuckle-to-shoulder lift involves a large static component in terms of grasping and holding the load that is lifted in comparison with the dynamic resistance load in arm cranking. All upper body activity involves further static loading in the form of stabilizing the torso. However, the cost of stabilizing the upper body is significantly reduced when the arm-crank test is performed with the subject seated. Such reduction in static loading is difficult to achieve in MMH activity since most MMH activity requires mobility. Increasing the relative proportion of lower body involvement in lifting helps reduce static loading in MMH activity, but such alterations are highly task dependent.

Heart rate and blood pressure increases during upper body exercise reflect a greater circulatory strain than lower body activity at the same sub-maximal level. Although the physiological factors that lead to this differential response have not been adequately identified, several hypotheses have been proposed. These hypotheses are based on factors such as smaller muscle mass, a larger static exercise component, smaller venous return due to less muscle pump activity, and an increased neural drive.

The onset of static exercise is typically accompanied by increases in mean arterial pressure (MAP) while dynamic exercise produces a transient decrease in MAP. Researchers have attributed this marked difference in MAP response to differences in the relative responses of cardiac output and total peripheral vascular resistance (PVR). Cardiac output (CO) is the product of heart rate (HR) and stroke volume (SV). Stroke volume is the volume of blood ejected in each beat or stroke. Therefore, CO increases are achieved via higher heart rates or higher stroke volumes.

Regardless of the type of exercise, HR increases in the transition from rest to exercise. This produces a concomitant increase in cardiac output. The extent to which HR is responsible for the increase in CO depends on a number of factors such as the muscle mass involved in the exercise, the type of exercise, and the physical conditioning of the subject. HR increases with the start of exercise and results in CO and MAP increases. In dynamic exercise, MAP increases brought about by increased CO via increases in HR are offset by a decrease in peripheral vascular resistance via neural activity. However, in static exercise the decline in PVR is not sufficient to compensate for the increase in CO via HR and there is a resultant increase in MAP. Furthermore, higher MAP may also result from occlusion of the active muscle vasculature due to static loading. Therefore, static activity is almost always accompanied by immediate increases in MAP.

Normal MAP response beyond 50% sub-maximal dynamic activity (with respect to oxygen uptake) cannot be offset by drops in PVR. Therefore, above this level, MAP increases regardless of the nature of the activity. These results have important implications in the explanation and control of CV response to sub-maximal activities involving either dynamic or static activity.

In studies involving isometric contraction of finger extensors, stroke volume changes neither increased nor decreased (Smith, Misner, Bloomfield, and Essandoh, 1993; Misner, Going, Massey, Ball, Bemben, and Essandoh, 1990). These findings were hypothesized to result from the variation in the proportion of maximal voluntary contraction (MVC) force exerted by the subjects. Furthermore, isometric efforts increase sympathetic nervous activity, which may increase heart rate and affect stroke volume. The contributions of preload, afterload, and ventricle contractility in determining the stroke volume response have not been conclusively determined. Preload and afterload refer to the blood volume in the heart chambers before and after a heart stroke. Ventricle contractility refers to the contractility of the heart chambers, which affects the volume of blood that can be ejected with each stroke.

Toner, Glickman, and McArdle (1990) studied the cardiovascular adjustments to exercise distributed between the upper and lower body. A comparison of upper and lower body sub-maximal exercise showed that differences in HR, SV, and rate pressure product (RPP) responses exist for the same sub-maximal levels of oxygen uptake. In low-intensity exercise, the differences between upper and lower body responses are smaller if the lower body is involved to a certain extent during the upper body exercise. Exercise performed with only the upper body results in higher HR and RPP and lower SV when compared to strictly lower body exercise. The contribution of this research to real life is that it is wise to incorporate the lower body in upper body activities in order to reduce strain on the CV system.

Keteyian, Marks, Levine, Kataoka, Fedel, and Levine (1994) investigated cardiovascular responses to sub-maximal arm and leg exercise. The authors reported that in dynamic, upright arm or leg exercise, both SV and HR increase during the progression from rest to moderate work. As exercise is increased to maximum, SV continues to increase and then plateaus. The plateau in SV during exercise generally occurs when oxygen uptake or power output is 40% to 50% of maximum. The oxygen uptake (VO_2) values observed during leg exercise at a power output (PO) equivalent to 50% and 75% of maximum PO were 52% and 70% of VO_{2max}, respectively. Similarly, during arm exercise at the same PO percentages, VO_2 was 54% and 71% of VO_{2max}, respectively. HR increased steadily with power output in both arm and leg exercises. However, SV increased from rest to 50% PO and then remained constant for PO increases beyond 50% for both arm and leg exercise. The authors concluded that cardiac output increased from rest to 50% of the maximum power output through an increase in HR and SV. As exercise progressed to the 75% level, HR increased with no further increase in SV.

McArdle, Katch, and Katch (1996), from their review of the literature, reported that the peak oxygen uptake, heart rate, and pulmonary ventilation achieved during maximal exercise with the arms is generally 20% to 30% *lower* than with leg exercise. The authors further summarized that "during sub-maximal exercise, the response pattern for oxygen uptake between upper and lower body exercise is reversed." The bases for this conclusion were reports of ***higher*** oxygen uptake in upper body or arm exercise compared to lower body or leg exercise at the same absolute power output or load level. The difference in oxygen uptake is relatively small during light exercise. However, with an increase in the intensity of exercise (set in terms of absolute power output), the difference increases rapidly. This response has been attributed primarily to lower mechanical efficiency in upper body exercise due to the additional energy cost of stabilizing the torso. Similar differences in sub-maximal heart rate, pulmonary ventilation and perception of effort responses are reported between upper and lower body activity.

Hagen, Hallen, and Harms-Ringdahl (1993) investigated the relationship between traditional maximal VO_2 tests and an occupational lifting task. The authors compared a sagittal plane symmetric floor-to-knuckle lifting/lowering task (employing both squat and stoop techniques) to a treadmill test. The investigation examined the important issue of establishing safe levels of physical strain for occupational lifting activity based on traditional laboratory-based stress tests or maximal VO_2 tests. The subjects were healthy individuals who performed repetitive lifting tasks in the course of their occupation. The treadmill protocol to obtain peak VO_2 (assumed by the authors to be the best estimate of VO_{2max}) used a stepwise, continuous protocol with grade increments of 2% every two minutes until volitional termination. The speed of the treadmill was chosen to elicit a heart rate response of 140-160 bpm in the initial stage (0% grade). Heart rate increased by 5 to 15 bpm during each two-minute period. Peak VO_2 was estimated as the highest 60-second average value of VO_2 observed during the test. Peak VO_2 during repetitive lifting was also tested using a stepwise, continuous protocol. The pace of the task was 20 lifts/min and the mass was increased by 2.5 kg at two-minute intervals. The initial weight of the lifting task was determined based on HR responses during sub-maximal tests and treadmill tests with a view toward optimizing between the time to exhaustion and achieving true VO_2 peak. The maximum mass of the lifting task was restricted to 24 kg, and the pace of the task was increased by 4 lifts/min if the subject had not reached exhaustion at this load.

Hagen et al. (1993) reported higher peak HR, VO_2, and ventilation (VE) values for the treadmill task compared with either squat lifting or stoop lifting. Squat lifting resulted in significantly higher peak HR, VO_2, and VE values compared with stoop lifting. These results can be explained by the amount of muscle mass involved in each task. Treadmill running involves the most muscle mass and hence results in higher peak CV responses. Squat lifting utilizes the muscle mass of the legs as opposed to stoop lifting which utilizes the trunk muscles. Therefore, squat lifting, which involves greater muscle mass than stoop lifting, generates higher peak CV responses. Differences in peak cardiovascular responses among tasks are driven by the amount of muscle mass involved in the task.

The results of this research may also be extended to an analogy involving arm-cranking exercise and knuckle-to-shoulder lifting. The amount of muscle mass involved and the static component of the task differentiate the arm-cranking task from the knuckle-to-shoulder lifting/lowering task. An arm-crank test involves no static component other than the weight of the arms. A lifting task includes a static component in the form of the load being handled. In addition, it should be noted that a knuckle-to-shoulder task would not tax the cardiovascular system to as great an extent as arm cranking or treadmill exercise. Arm cranking and treadmill exercise involve greater muscle mass than a simple lifting task. The neuromuscular system's response to the task and to the resulting muscle fatigue in the knuckle-to-shoulder task usually confound the determination of true peak cardiovascular responses due to the static component of the task.

The following are additional conclusions that can be drawn from a review of the literature on cardiovascular responses:

(1) The respiratory system reacts faster than HR and blood pressure (BP), independent of the intensity of static muscle contraction. This has implications in explanations of respiratory effects vs. HR and BP response to belt use. Furthermore, it is necessary to consider the data collection time intervals while comparing responses and belt use effects.

(2) The peripheral drive from the contracting muscles plays an important role in determining the CV and respiratory responses. The active musculature in a lifting task is less than the musculature involved in a typical arm-crank test. Therefore, the peripheral drive and associated responses would be of lower magnitude, and CV responses for the lifting task would involve more input from other mechanisms.

(3) Skeletal muscle characteristics play an important role in influencing cardiovascular responses to exercise. A sprinter's response to dynamic exercise may be elevated compared to an endurance athlete's response, and vice-versa for static exercise. The basic mechanisms responsible for control of

CV responses may be the same for both athletes, but the actual modality of maintaining CV responses may be quite different. Muscle fiber type and the resultant micro-vessel density are thus important in influencing the CV response to exercise. Therefore, the fitness of the subject and the training condition of the active musculature in the lifting task play an important role.

The study reported here investigated the effects of belt use on short-duration lifting activity. Therefore, untrained college-aged subjects were used. The use of trained MMH workers might result in different CV responses and response mechanisms. This has important implications in comparing results across different subject groups.

CHAPTER 4

EXPERIMENTAL METHODOLOGY

4.1 Overview

An important issue in the experimental design of research involving human subjects is to ensure that the subjects tested are as homogenous as possible so that any observed differences are due solely to the independent variables. This is achieved largely through the use of repeated measures designs, where the heterogeneity in subjects is addressed by using subjects as their own control. While homogeneity among test subjects is desirable for demonstrating an effect, it is equally important that the subjects be representative of the general population to which research results are applicable. This requirement is normally satisfied by random selection of test subjects from the general population.

Another issue in experimental design is selecting independent variables and levels within each independent variable. This selection is usually based on the research hypothesis, which itself may reflect prior research, pilot studies or the scientific literature. Response measures assess human performance on an experimental task in order to detect the effects of varying the independent variables. Response measures are usually selected based on their relevance to the research hypothesis, expected strength of the cause-effect relationship with the independent variable, and the ability to be measured. Once the independent variables and response measures have been defined, the next step is to conduct the experiment under set levels of the independent variable(s) while minimizing changes in the experimental conditions. This procedure emphasizes control of extraneous variables in the study.

The current study was divided into two experimental data collection periods. A pilot study was conducted to develop a protocol for determining relative workloads. The pilot study is described in this chapter, whereas Chapter 5 presents the methodology for the main study. The response measures used in both studies were similar, although the main study employed more response measures. These are discussed in detail in their respective chapters. The independent variables differed between the studies and are discussed in their respective chapters. The equipment used in the pilot study was similar to that used in the main study with minor exceptions due to the additional measures in the main study. The following section describes the equipment used in the studies. Section 4.3 presents the objectives, variables, measures, and results of the pilot study.

4.2 Equipment

This section describes the equipment used in the main study. Equipment not used in the pilot study will be noted in the discussion. The equipment used in this research can be broadly divided into two classes, equipment for observing the cardio-respiratory responses and equipment for structuring the task.

4.2.1 Cardio-Respiratory Equipment

A MedGraphics Model CPX/D cardiopulmonary system was used to collect cardio-respiratory data. Cardio-respiratory monitoring systems are often referred to as metabolic carts. The system used in this study is shown in Figure 4.1. The metabolic cart comprised a gas analysis module, a flow analysis module, a pneumotach, a mouthpiece, and a computer. This system acquired cardio-respiratory data from sampling the gases expired by the subject via the pneumotach. Two sampling lines were attached to a clip mounted on the pneumotach. In operation, one line sampled the exhaled air for gas analysis and the other line, a dual conduit line, measured the differential pressure between two points to determine air flow rate. Figure 4.2 illustrates the pneumotach and the sampling lines on a clip. One end of the pneumotach is attached to a mouthpiece with a saliva trap (Figure 4.3) while the other end fits in the subject's mouth (Figure 4.4). A nose clip is worn by the subject during testing to ensure breathing only through the mouthpiece.

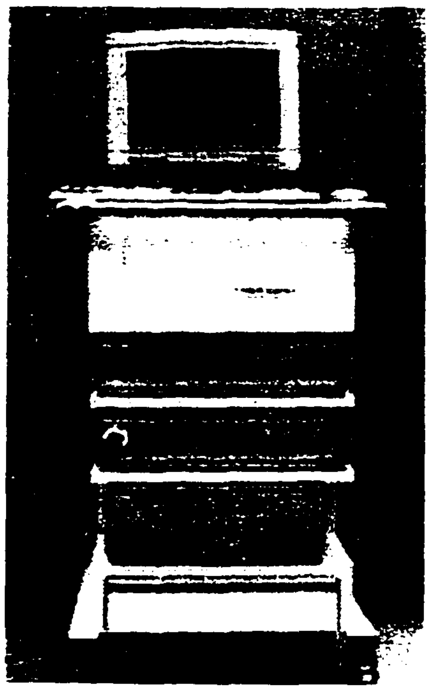

Figure 4.1. Metabolic Cart.

Figure 4.2. Pneumotach with Sampling Lines.

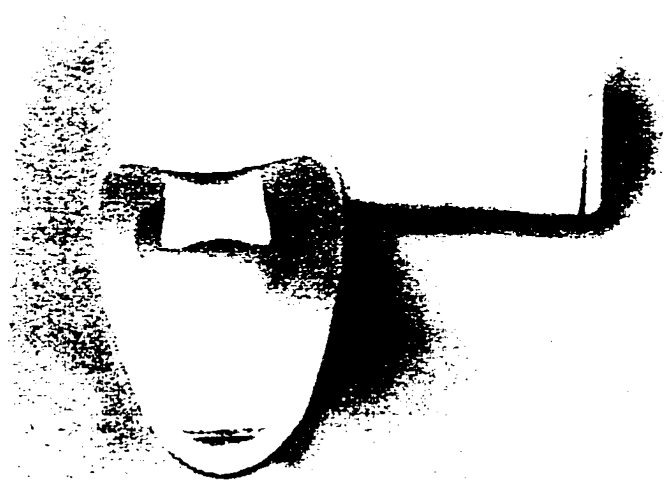

Figure 4.3. Mouthpiece.

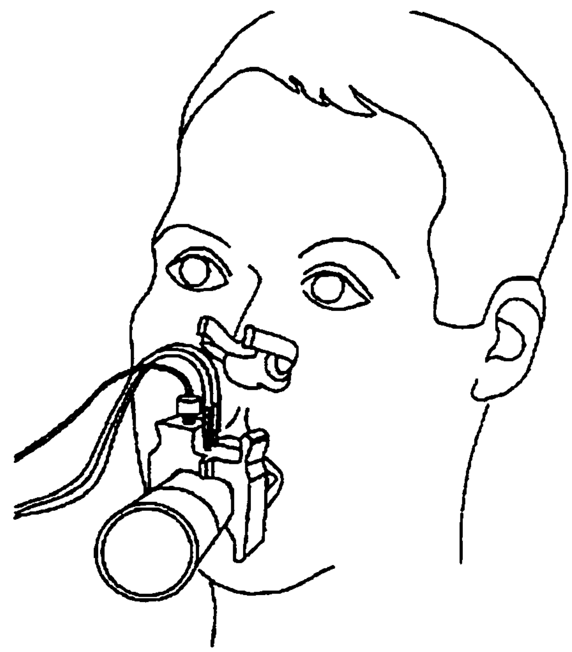

Figure 4.4. Subject with Mouthpiece.

The metabolic cart was calibrated before each test session as recommended by the manufacturer. The system required at least 30 minutes warm-up time for the analyzers to stabilize before calibration could be performed. System calibration involved two steps. The first step involved calibrating the pneumotach and the flow module. This was to ensure that the flow module accurately measured the volume of expired air. The pneumotach with the sampling lines was attached to a three-liter calibration syringe. Air was drawn into and ejected from the syringe through the pneumotach. This process was guided by the system software which also recorded the flow volume. Based on acceptable parameters defined by the system, the software determined whether the flow module calibration was successful. The volume of air recorded by the system was also displayed for manual verification.

The next step in system calibration involved gas analyzer calibration. The system software guided this process through on-screen instructions. This step involved measuring the oxygen and carbon dioxide contents in a calibration gas mixture containing known percentages of oxygen and carbon dioxide. Again, the system determined if the gas analyzer calibration was successful. The gas analysis results were simultaneously displayed to facilitate manual verification of the calibration process.

The metabolic cart recorded four fundamental measures, the volume of oxygen consumed, volume of carbon dioxide produced, volume of expired air in each breath, and respiration rate. The data sampling rate of the system was fixed at the breath-by-breath interval. The system software (BreezeE$_X$) allowed calculation of several other measures that were a function of the four fundamental measures. The software allowed flexible, user-selectable units of measurement. Data recorded by the system were viewable as data tables or in graphical form in real time. The real-time and subsequent data presentation were highly customizable. The metabolic cart was designed to be interfaced with other external systems such as an ECG monitor. Such additional interfaces would automatically increase the number of response measures that could be recorded by the system.

A Quinton ECG monitor (Model Q4000) was used to obtain heart rate data. The ECG monitor is shown in Figure 4.5. QuickPrep® electrodes (Quinton) were used to acquire the ECG signal. A modified six-electrode setup was used for heart rate acquisition. This involved four limb electrodes, a V2 electrode (on the fourth intercostal space to the left of the sternal border), and a V5 electrode (on the horizontal line from the fifth intercostal space along the midclavicular line to the anterior axillary line). The

Quinton system was interfaced with the MedGraphics system, which enabled the metabolic system to record heart rate data and other cardio-respiratory measures simultaneously. The metabolic cart acquired data on each breath, yielding a variable number of data points in a given time interval based on the respiration rate of the subject. Heart rate signals during each breath were averaged, providing an average heart rate across each breath interval.

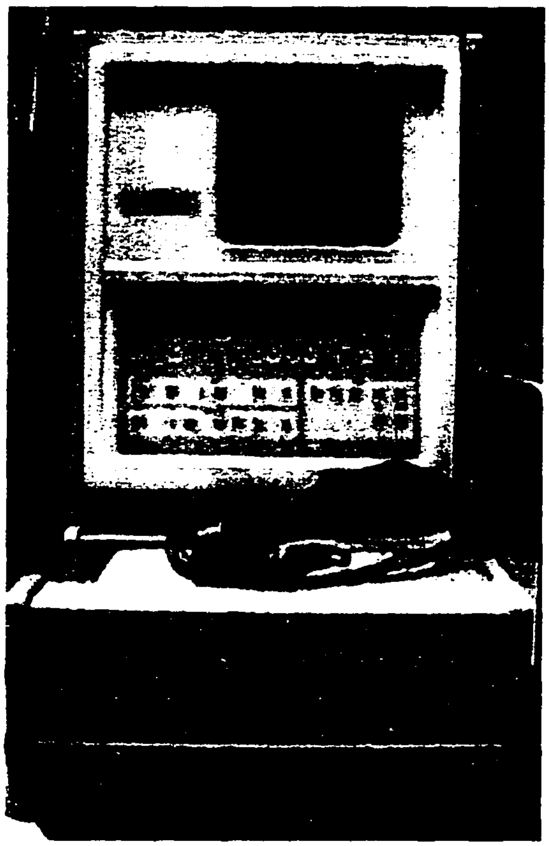

Figure 4.5. ECG Monitor.

Blood pressure data were collected in the main study using a computer-based blood pressure monitoring system by Pulse Metric®, Inc. (DynaPulse® DP-2000A). Systolic and diastolic blood pressures were estimated from oscillometric and pressure pulse form data using an algorithm developed by Pulse Metric®, Inc. A sample waveform recorded by this system is shown in Figure 4.6. The lower part of the figure displays the main pressure waveform along with a time line. The waveform in the upper left corner is a zoomed-in display of the main pressure waveform. The main pressure waveform display reads from left to right and shows the changes in pressure as the cuff pressure decreases during the measurement.

The three triangles at the bottom of the main waveform graphically display the locations of the systolic, mean arterial, and diastolic points in the pressure waveform. The first triangle along the axis of the graph represents the systolic blood pressure. This is detected by both the phase shift and the increases in pressure due to the Bernoulli effect when blood spurts through the artery at high velocity. As the cuff pressure continues to drop, the forces developed by the blood flow equal the cuff pressure. Cuff pressure at this point is equivalent to the mean arterial pressure and is represented by the second triangle. Cuff pressure ultimately decreases to a point where it is no longer able to occlude blood flow. This is reflected in the decreasing magnitude of the waveform, and the third triangle marking this point represents the diastolic pressure.

The vertical bar on the main pressure waveform is used to develop the zoomed display in the top-left corner of the figure. The "boxed" pressure value displayed to the right of the main pressure waveform represents the blood pressure at the instant denoted by the location of the vertical bar. The vertical bar shows a pressure of 98 mm Hg as it is located at the instant where the mean arterial blood pressure was detected. The upper right portion of the figure shows numerical values obtained for systolic blood pressure, diastolic blood pressure, mean arterial blood pressure, heart pulse, date and time of the data recording.

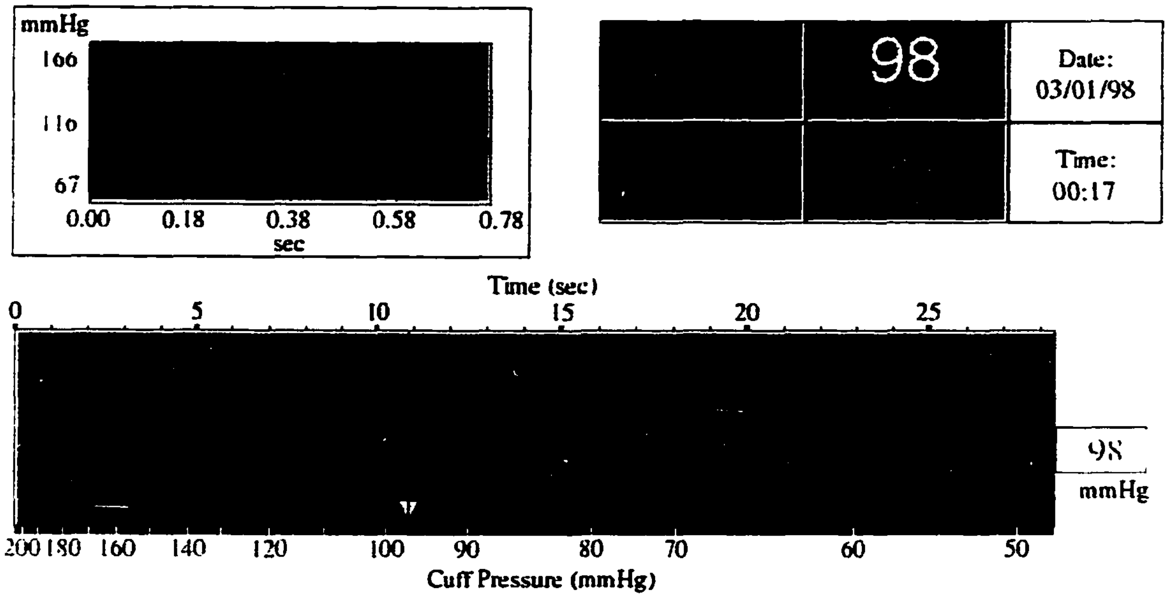

Figure 4.6. Blood Pressure Waveform.

4.2.2 Task Equipment

A shelving system was built in-house to accommodate different knuckle and shoulder heights of the subjects. A VWR timer-beeper (Model 62374-000) was used to set subject working pace. Sachets containing steel grit, each weighing approximately 0.22 kg (0.48 lb), were used to load the box that the subject lifted and lowered. The box is shown in Figure 4.7. The box dimensions were 26 x 26 x 17 cm. The handles were set 37 cm apart along the length of the box. The grip length of the handles was 15 cm. The bare handle grips were flat and measured 4 cm wide and 2 cm thick. The handles were wrapped with 1 cm thick foam padding and subtended an angle of 17 degrees with the horizontal. Tare weight of the box was 6.47 kg (14.23 lb).

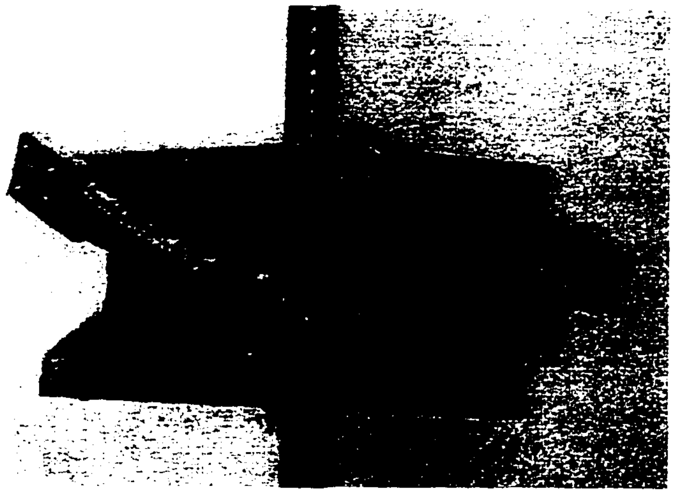

Figure 4.7. Lifting Task Weight Box.

The abdominal belt used in the study (OK-1, Model 505) was a typical industrial flexible belt made of elastic material. Figure 4.8 illustrates the belt. The inner straps were made of lightweight material and were used to adjust the belt position over the abdominal region. The tension achievable through these straps was negligible. The outer straps were made of elastic material and were used to tension the belt. Velcro® material sewn into the inner straps was used to adjust the position of the belt. Velcro® material sewn into the outer straps was used to adjust the belt tension. Fasteners to affix suspenders were present on the top outer edge of the inner straps, although the belts used in this study were not fitted with suspenders. Three belt sizes were available based on subject waist size. The dimensions of the belt are given in Appendix A.

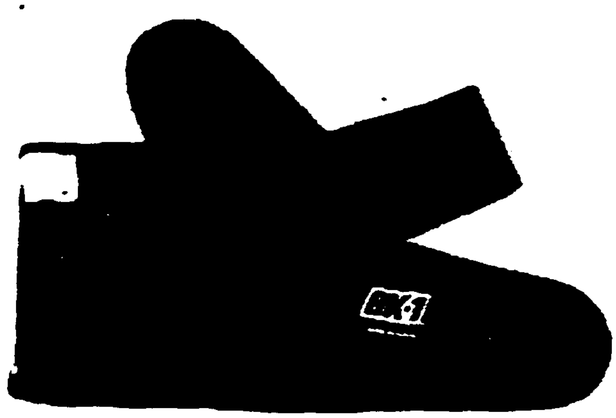

Figure 4.8. Abdominal belt

The preferred belt tension for each subject was measured using a device consisting of a load cell (Omega LCCB-50) and a fixture that clasped the belt-tensioning strap. The device used was similar to that developed by Whitney (1997). The fixture was used to clasp one end of the tensioning strap while the other end of the strap was affixed to the load cell. The load cell glided over rails built into the device. The free end of the load cell was attached to a handle which was used to stretch the tensioning strap to a specific length. The length to which the strap was stretched was obtained from measurements made after each subject adjusted the belt tension to his preference. The force required to stretch the tensioning strap was then determined by the load cell. Load cell data were acquired by data acquisition software (Labtech Notebookpro Ver. 9.03) via an analog-to-digital conditioning board (Omega DAS-08 PGA) implemented on a personal computer (Dell XPS-P100C). Force data recorded in pounds represented a "linear" estimate of the preferred belt tension for each subject.

4.3 Pilot Study

A pilot study was conducted to help establish the appropriate levels of the variables of interest. The pilot study was also used to establish the methodology for determining relative workloads based on individual peak VO_2 capacity such that all subjects worked under the same relative cardiovascular strain. Cardio-respiratory measures were observed in order to establish this methodology. Ensuring that the subjects worked under a similar relative physical strain was important since heterogeneity in subject physical fitness or other characteristics was expected to affect the response measures. Such heterogeneity could result in significant individual differences (subject by independent variable interactions).

Ensuring that the subjects performed tasks based on individualized workloads would improve the generalizability since results could be discussed relative to individual capacities irrespective of differences in individual characteristics. However, this approach requires that the maximal VO_2 capacity of the subject be determined in order to establish sub-maximal workloads. Since the determination of VO_2 capacity is not feasible in industry, other easily performed tests or existing measures are needed. This, in turn, requires quantification of the relationship between peak VO_2 capacity and these existing or easily determined measures. Determination of such measures is beyond the scope of the current study. However, the methodologies developed by exercise physiologists to estimate VO_2 capacity based on heart rate response and anthropometric measures form a good starting point.

There were two main objectives to the pilot study: (1) obtain task-specific peak oxygen consumption values for each subject, and (2) determine workload levels that could be used to elicit desired sub-peak VO_2 responses. The pilot study was also used as a means of improving the data collection procedure and subject tolerance of the monitoring equipment.

4.3.1 Subjects

Four male college students participated in the pilot study. All four subjects were volunteers and did not receive monetary compensation. Subject characteristics are summarized in Table 4.1. None of the subjects reported any history of back injury. The physical conditioning of the subjects was fair as reflected by their resting cardio-respiratory data (Table 4.1). The average knuckle and axilla height for the subjects were 74.5 cm and 133.5 cm respectively, resulting in an average travel distance of 59 cm for the weight box.

Table 4.1. Descriptive Data for the Pilot Study Subjects.

Subjects	Age	Height (cm)	Weight (kg)	Resting Heart Rate	Resting VO_2 (ml/kg/min)
1	27	181.0	76.9	83	4.86
2	31	175.9	74.5	78	3.94
3	22	173.0	76.9	70	5.24
4	24	186.0	79.4	77	5.60

4.3.2 Procedure

The pilot study involved two distinct experimental phases. The first phase involved determination of the peak VO_2 capacity while the second phase addressed determination of the specific load required to evoke a desired oxygen uptake.

The peak test involved knuckle-to-shoulder lifting and lowering of a weight box at a frequency of 6 cycles per minute. The actual height to which the weight box was lifted was set to each subject's axilla height (armpit height) to ensure that the loss of mechanical advantage at the end of the range-of-motion did not result in an underestimation of true peak capacities.

The initial load was the weight of the box (6.47 kg) plus 2.27 kg. Each subject performed the task at this load for two minutes. At the end of the second minute, and every minute thereafter until the end of the tenth minute, the load was increased by 2.27 kg. At the end of the tenth minute, and every minute thereafter until exhaustion, the load was increased by 1.14 kg. Each subject was allowed to terminate the test when he could no longer lift the current load in compliance with the task requirements. Each subject was also free to terminate the task whenever he felt there was a risk of injury. The experimenter closely monitored the subject's vital signs and visible stress levels to minimize the risk of injury. No pilot study trial was terminated prematurely either by the subject or the experimenter for any reason.

The metabolic cart recorded four fundamental dependent measures during the peak test: volume of oxygen consumption (VO_2), heart rate (HR), respiration rate (RR), and ventilation rate (VE). The volume of carbon dioxide produced (VCO_2) and the respiratory exchange ratio (RER defined as VCO_2/VO_2) were estimated using the fundamental measures. Data were continuously recorded and monitored in real-time throughout the pilot study test periods.

Since the goal of the peak test was to determine the task-specific peak VO_2 uptake, it was important to ensure that the subject reached his true peak capacity. However, considering that task termination was at the discretion of the subject, other criteria were monitored to ensure that peak oxygen uptake was reached. These criteria included the condition that the respiratory exchange ratio be greater than 1.0 and that HR exceed 80%

of the age-predicted maximum. If these criteria were not satisfied, then the peak test was discarded and repeated at a later time. To determine the validity and repeatability of the peak test protocol, the tests were performed twice by each subject.

The second phase of the pilot study involved determination of customized loads that would elicit similar VO_2 uptakes for all subjects (expressed as a percentage of individual peak VO_2). Individual loads to elicit VO_2 uptake equivalent to 40%, 60%, and 75% of the peak VO_2 were desired for the main study. Madala et al. (1997) indicated that physiological effects associated with belt use may be related to the amount of weight lifted. The authors used 35% of 1 RM as the load that each subject lifted. At this load the authors did not report any significant belt effects. Therefore, workload levels neighboring the absolute weight used by Madala et al. (1997) were investigated. The relative percentage workload based on 1 RM would be higher in terms of absolute weight than the load based on a continuous dynamic test as used in this study. The highest and lowest workloads investigated in the current study were selected to detect the possibility of belt effects dependent on the load. Further discussion of rationale for selection of these specific workload levels is discussed in the independent variables section of the next chapter.

Different methods were examined to obtain loads that would reliably elicit the target VO_2 responses. These approaches are presented in the next section, since they were developed in an iterative fashion based on the results obtained at each step.

4.3.3 Results and Analyses

The results of the first peak test for each subject are summarized in Table 4.2. As mentioned earlier, the metabolic cart recorded cardio-respiratory data at every breath. Therefore, data representative of peak performance were obtained by averaging the data recorded in the last 60 seconds of the peak test. The values in parentheses show the test-retest differences obtained by subtracting the response of the first test from that of the second test.

Table 4.2. Peak Test Cardio-Respiratory Data.

Sub	Peak Test Duration (min)	Peak Load (kg)	Peak VO_2 (ml/kg/min)	Peak RER	Peak HR (% of max)	Peak RR (breaths/ min)	Peak VE (L/breath)
1	13.66 (0.16)	30.0 (0)	19.1 (0.84)	1.01 (0.09)	91.2 (7.0)	31 (0.73)	1.47 (0.14)
2	19.16 (3.0)	35.7 (3.4)	20.6 (-0.49)	1.11 (0.02)	82.0 (8.2)	25 (-5.87)	1.63 (0.06)
3	14.82 (2.13)	32.3 (2.3)	24.3 (-0.73)	1.03 (-0.08)	86.4 (-8.2)	36 (3.64)	1.59 (-0.26)
4	15.00 (1.0)	32.3 (1.1)	23.8 (-3.03)	1.06 (0.05)	83.7 (2.5)	21 (1.53)	2.11 (-0.09)

Correlations between the VO_2 data sets from the two peak tests were calculated for each subject. The data used in the calculations were one-minute averages of the observed data across the duration of the peak test. The correlations obtained were 0.99, 0.98, 0.99, and 0.97 for the four subjects. The high correlations indicate that a similar VO_2 trend over time was observed in both test and retest. A two-dependent-sample t-test was performed on the peak VO_2 values obtained from the two tests. This involved performing the test on the set of four data points comprising the test-retest VO_2 differences. The results showed that there were no significant differences between the two peak tests [$t(3) = -1.06$, $Pr > |T| = 0.3667$]. Based on these analyses, the peak test protocol was assumed reasonably successful.

The next objective was to establish a VO_2 prediction method based on the VO_2 response and the load lifted in the course of the peak test. The least-squares method was used to fit linear prediction equations to the VO_2 and load data from the peak test for each subject. The resulting equations are given in Table 4.3. These equations were used to estimate the load required to elicit the desired VO_2 response which was 40%, 60%, or 75% of the peak VO_2. These loads were then used in sub-peak tests to validate the VO_2 prediction methodology.

Table 4.3. VO_2 Estimation as a Function of Load.

			Std Error of Estimates	
Subjects	**Linear Equation**	**R^2**	**Slope**	**Intercept**
1	$Y = 0.5077X + 3.3056$	0.99	0.0137	0.2999
2	$Y = 0.4498X + 2.5211$	0.96	0.0108	0.5835
3	$Y = 0.5883X + 4.2131$	0.99	0.0135	0.3079
4	$Y = 0.4998X + 4.0564$	0.98	0.0176	0.4133

Legend: Y: VO_2 (ml/kg/min), X: load (kg).

Each subject performed three sub-peak tests designed to evoke 40%, 60%, or 75% of the peak VO_2 response. Two randomly chosen sub-peak tests were performed on one day with at least one hour between tests. The lifting task was similar to the peak test except that the load remained constant. Subjects performed the task for five minutes and then rested for two minutes. Three such cycles of work and rest were performed by each subject using the weight estimated by the prediction equations. Cardio-respiratory measures were recorded continuously during each test session, including the rest periods within each cycle.

The VO_2 data recorded during these sub-peak test sessions were averaged over the last minute for each work period. These data indicated that the weights were underestimated; recorded VO_2 responses were lower than the target responses for all three predicted levels. On average, the observed VO_2 response was 18% lower than the estimated value.

It was hypothesized that the underestimation was due to the difference between the structures of the peak test and the sub-peak tests. The peak test was a continuous test with no rest-periods, thereby leading to fatigue accumulation, while the sub-peak tests involved three cycles of work and rest. To examine the effect of work duration on VO_2 response, Subject 1 was asked to repeat two tests with longer work periods. Sub-peak tests for 40% and 60% were repeated with an eight-minute work period. Data were again averaged over the last minute of each of the three work periods. Although statistical analysis showed that the VO_2 response did not vary significantly between the fifth and the eighth minute, a statistical conclusion based on three data points from two out of three workload levels may not be warranted.

Based on the subject's feedback regarding the use of the mouthpiece and general discomfort, it was felt that performing four eight-minute work periods would be very stressful for the subject. Long work periods would increase the total duration (nearly 60 minutes) of each session and create excessive discomfort for the subjects from wearing the mouthpiece. The cumulative effect of the workload, particularly at the 75% level, could potentially affect the later work periods since two-minute rest periods would be insufficient for reasonable recovery. In addition, one of the objectives of the main study was to examine the effects of belt use on short-duration lifting, simulating occasional lifting activity rather than dedicated manual material handling. Based on these concerns and the desire to collect data from more short work periods rather than fewer long work periods, it was decided that the work period duration would remain at five minutes.

Since the problem of VO_2 underestimation was not resolved by increasing the duration of the task, various adjustments to the loads were examined. The loads predicted by the linear equations to elicit the target VO_2 responses underestimated the responses to a large extent. The estimation of load based on the corresponding peak load and VO_2 values was re-evaluated and an alternate methodology was employed. The load required to elicit a given percentage of peak VO_2 response was estimated as the equivalent percentage of the maximum load lifted by the subject in the peak test. In other words, the estimated load to elicit 40% of the peak VO_2 response was 40% of the load corresponding to the peak VO_2 response.

Sub-peak tests were performed by each subject using these new load estimates. Three cycles of five minutes of work and two minutes of rest were observed at each workload level. The VO_2 response data during the last minute of each five-minute work period were averaged and used to represent that particular work period. These VO_2 averages were then compared to each subject's peak VO_2 to obtain the percentage of peak VO_2 response evoked by each load in each work period.

Table 4.4 presents the averaged VO_2 responses obtained from the sub-peak tests using loads determined as percentages of the peak load. Comparison of the data with the target values showed that the VO_2 responses were much closer to the targets than with the original approach. However, there were still individual differences between the observed and target responses. Examination of the data on a case-by-case basis identified both over-estimations and under-estimations relative to the target. On average, the prediction procedure was on target for the 60% and 75% loads, whereas the 40% level was overestimated and produced higher response than desired.

Table 4.4. Sub-Peak Test VO_2 Responses.

	Desired Percentage of VO_2 Peak											
	40%				60%				75%			
Sub	**WP1**	**WP2**	**WP3**	***Ave***	**WP1**	**WP2**	**WP3**	***Ave***	**WP1**	**WP2**	**WP3**	***Ave***
1	52.9	54.5	50.8	*52.7*	57.6	63.4	61.8	*60.9*	81.2	83.8	83.2	*82.7*
2	52.4	51.9	53.4	*52.6*	64.6	62.6	64.1	*63.8*	79.6	80.1	79.1	*79.6*
3	47.3	45.3	48.1	*46.9*	53.1	54.7	52.7	*53.5*	64.6	67.5	63.8	*65.3*
4	43.7	45.4	45.0	*44.7*	54.2	55.9	57.6	*55.9*	69.3	71.8	73.5	*71.6*
Ave	49.1	49.3	49.3	49.2	57.4	59.1	59.0	58.5	73.7	75.8	74.9	74.8
SD	4.4	4.7	3.6	4.1	5.2	4.5	5.0	4.7	8.0	7.5	8.4	7.9

All values are percentages of corresponding peak VO_2 responses.
Legend: WP: work period, Ave: average, SD: standard deviation

Although the predictions were not as close as desired, the relatively small magnitude of the differences and the inherent inability to precisely control human physiological responses led to the decision to accept the current method for load estimation. Fine tuning of the load to achieve responses closer to the target may have been possible, but the resources required to develop a universal formula for estimating the loads for any subject was beyond the scope of the current study. In addition, load estimation was used as a means to control differences in VO_2 responses between subjects and was not the main objective of the study. Furthermore, VO_2 response was only one of five response variables that were measured in the main study. Estimating the load to elicit the required VO_2 responses would not necessarily control differences among subjects with respect to the other response measures. Controlling response measure differences among subjects for all response variables was again beyond the scope and objective of this study. Statistical experimental design techniques were used to control such differences given the current resource constraints. These techniques essentially involved data normalization, a repeated-measures experimental design, and the measurement of covariates that were potential sources of response differences among subjects.

The results of the pilot study validated the peak test protocol and led to the development of a load estimation methodology to evoke desired VO_2 responses. The peak test protocol successfully evoked similar peak responses when the peak tests were repeated. Therefore, it was decided that a single peak test would be adequate for obtaining individual peak capacities in the main study. In addition, the load estimation procedure used in the pilot study was reasonably accurate, considering the inherent limitations of such estimations. The accuracy obtained was deemed sufficient for the current study. Therefore, the protocol was established for the main study to determine the peak load for each subject and set workload levels based on a percentage of each subject's peak load. The pilot study also helped establish a data collection procedure which caused minimal interference to the subject or to the data recording process.

CHAPTER 5

MAIN STUDY: METHODOLOGY

5.1 Overview

The goal of the main study was to determine the effects on selected cardio-respiratory responses of wearing an abdominal belt while performing a lifting/lowering task. The task parameters were selected to represent users involved in occasional lifting activity. Dedicated manual material handling activity is too varied and strenuous to be successfully simulated under laboratory conditions by untrained subjects. Material handlers involved in such strenuous activity are usually well trained and use prudent caution. The proportion of workers who perform MMH activity similar to the task in this study is believed to be greater than the proportion involved in high frequency, multi-load, and multi-profile handling activity. Untrained manual material handlers are also more likely to perform lifting with a low task frequency but a high variety of loads and profiles. This study aimed at investigating the effects of belt use by this group of people.

The next section describes characteristics of the participants in the main study. Experimental variables are discussed in Section 5.3. The independent variables, response measures, and control variables are discussed in detail with emphasis on the bases for selection. Section 5.4 discusses the experimental procedure of the main study, including the data collection protocol for each of the five experimental sessions. The last section of this chapter discusses the statistical design of the experiment and pertinent statistical issues associated with the selected design.

5.2 Subjects

Participants were primarily students from the University of Oklahoma, Norman Campus. The rationale behind using untrained subjects was based on the attempt to investigate the effect of belt use on occasional lifting activity. Twelve male subjects participated in the study. Each participant was paid $64 upon completion of the study. All participants were required to read and sign an informed consent form approved by the University of Oklahoma's Institutional Review Board, Norman Campus for the use of human subjects for research purposes. The subjects also answered a health status questionnaire that screened for any contraindications to their participation in the study. In addition, information on prior use and opinions about abdominal belts were recorded via a questionnaire. The informed consent, health status questionnaire, and pre-study impressions questionnaire were required reading material by all subjects. A sample of this material is presented in Appendix B. Descriptive characteristics of the participants are summarized in Table 5.1.

Table 5.1. Descriptive Data.

Subjects	Age (years)	Height (cm)	Weight (kg)	Resting HR (bpm)	Resting VO_2 (ml/kg/min)
4	26	194	69.9	57	4.9
5	24	182	80.1	69	3.6
6	26	164	53.7	73	4.8
7	24	183	77.7	57	4.1
8	23	180	78.2	95	5.9
9	23	166	63.3	63	3.6
10	21	176	82.0	72	3.9
11	24	185	82.9	80	5.5
12	23	174	77.2	54	5.1
13	23	175	71.1	75	5.5
14	20	169	67.4	69	3.8
15	25	183	71.8	88	4.4
Mean	23.5	177.6	72.9	71.0	4.6
SD	1.8	8.6	8.6	12.5	0.8

Legend: SD: standard deviation

5.3 Experimental Variables

The study employed three independent variables and five response measures. The independent variables were belt condition, workload, and work period. Belt condition was examined at two levels, with-belt (WB) and no-belt (NB). Workload was manipulated at three different levels to elicit VO_2 responses equivalent to 40%, 60%, and 75% of peak VO_2 capacities. Four work periods were observed. The primary response measures were oxygen consumption, heart rate, respiration rate, ventilation rate, and blood pressure. Control variables included constant belt tension for each subject across trials, environmental conditions, and the time between sub-sessions. In addition, static strength and the dynamic one-repeat maximum (1 RM) were also measured for each subject at the completion of the study. These measures were recorded for use as covariates in statistical analyses and for comparisons with other studies using these measures to establish workload levels.

5.3.1 Independent Variables

The independent variables selected for the study were based on the literature review and objectives of the current study. Belt condition was observed at two levels, with-belt and no-belt. Only one type of belt was used since the literature review revealed that differences between belts were primarily between rigid belts and flexible belts. Furthermore, one of the goals of this study was to investigate the effects of the flexible belt which is predominantly used in MMH activity. The belt model employed in this study was previously used by Madala et al. (1997) and Bowen et al. (1996). The research objectives of the current study were developed from the results of these studies, and it was therefore appropriate to test the hypotheses using the same belt.

Workload levels were manipulated to elicit 40%, 60%, and 75% of the peak VO_2 level. Workload levels were based on each subject's peak VO_2 level to achieve better control of the task-related responses. Required workload levels were achieved by loading the weight box with loads equivalent to 40%, 60%, or 75% of the load associated with the peak VO_2. Controlling workload in this manner was hypothesized to reduce the influence of subject-to-subject variation in cardio-respiratory responses to a given task.

Madala et al. (1997) demonstrated that it was less likely to observe physiologically detrimental belt effects at higher workloads. Lower workloads were associated with larger differences in physiological response while using the belt relative to the responses observed while not using the belt. Although this result was obtained using weights based on 1 RM capacities, the reported load-related belt effect may be expected to hold in other situations. The peak loads lifted in the pilot study were compared to those used by Madala et al. In order to use absolute loads that bracketed those used by Madala et al., the three workload levels of 40%, 60%, and 75% were selected.

Multiple work periods were used to simulate occasional lifting activity. This approach also avoided task termination due to subject fatigue and provided more data. A minimum rest period duration of two minutes was required to acquire blood pressure data and to provide adequate VO_2 recovery. A single blood pressure measurement took approximately 45 seconds. Two minutes allowed for a second blood pressure measurement if the first attempt failed due to motion artifacts. Blood pressure instrumentation was very sensitive to subject motion and required the subject to be very still while data were being acquired. In addition, VO_2 response recovery was approximately 80% complete within two minutes, that is, following the work period the VO_2 response was very close to the resting VO_2 value within two minutes.

5.3.2 Response Measures

The response measures were essentially cardio-respiratory measures. Oxygen consumption, respiration rate, and ventilation rate were measured by the metabolic cart based on sampling of the exhaled air. Heart rate was measured by the ECG monitoring device interfaced to the metabolic cart using a modified six-electrode setup.

The total amount of energy required to perform a specific physical task should remain constant whenever the task is repeated with sufficient time for recovery. However, the physiological cost of performing a specific task varies by individual since individual mechanical and physiological efficiencies vary. This difference may also be observed for the same individual and task under different conditions. It is hypothesized that by observing the oxygen consumption patterns under a well-controlled task for two belt conditions, the impact of belt use on physiological cost can be determined. To further investigate the mechanism of belt effects, other measures such as respiration rate, ventilation rate, heart rate, and blood pressure were recorded. These simultaneously measured variables were hypothesized to shed light on probable mechanisms for belt effects or the lack of belt effects.

Oxygen consumption, heart rate, respiration rate, and ventilation rate were recorded for each breath. Limitations of non-invasive blood pressure instrumentation allowed a single blood pressure measurement per work period. This limitation prevented observation of blood pressure effects during the actual work period. Systolic blood pressure recovery progresses rapidly during the rest period. Blood pressure data could only be obtained during the first 40 seconds after the work period ended. These data may not have been a true representation of the work period and any belt effect may have been missed early in the rest period. Blood pressure effects may be more effectively studied for longer duration tasks where theoretically residual effects following task termination last longer. Such studies would still not be able to eliminate the disadvantage of having a single data point representing the entire work period.

Static strength and a dynamic one-repeat maximum lift were measured at the completion of the study. These measures were recorded to enable comparisons with studies where workloads were a function of one of these measures. These measures were also hypothesized to be reasonable covariates to explain variation among subjects. Static strength was measured as a maximum voluntary contraction lift while the subject lifted a box attached to the load cell. The box was placed at knuckle-height for each subject. The one-repeat maximum was the maximum load that the subject could lift and lower once. The one-repeat maximum test was performed under the same task conditions as those used in the main study with the exception of repetitions. The current study did not use either of these measures in determination of workload levels. Since cardio-respiratory measures were used as response measures, it was reasoned that workload levels should also be based on these measures. Static strength would form an appropriate basis for workload levels if the response measure was some measure of static strength or directly correlated to static strength. A similar rationale exists for not using the one-repeat maximum.

5.3.3 Control Variables

Belt tension was controlled for each subject. Each subject established a comfortable belt tension which was then used for all sessions involving belt use. The heights of the shelves to which the subject lifted and lowered were controlled individually. The height to which the subject lifted the load was fixed at the subject's axilla height. The height to which the subject lowered the load was fixed at the subject's knuckle height.

Environmental conditions were maintained at approximately the same levels for all sessions. Temperature was maintained at 23°C, humidity was between 40% and 55%, and illumination levels were maintained at 860 lux. Sessions were at least 12 hours apart. Rest periods between sub-sessions were 25 minutes.

5.4 Experimental Procedure

The study was conducted in five sessions. Each subject wore shorts and a lightweight T-shirt in all sessions. The shorts worn by the subject had an elastic waistband instead of buttons or zippers to ensure ease in determining belt tension and to provide comfort while wearing the belt.

5.4.1 Session 1

The first session was used to screen subjects for contraindications, and to determine the subject's peak VO_2 value and comfortable belt tension. Subject screening for contraindications to testing was a two-step process. In the first step, the subject read the informed consent form and completed a health status questionnaire. Pre-study impressions based on prior belt use were also recorded. The informed consent form, health status questionnaire, and pre-study belt use impressions questionnaire are presented in Appendix B. Step two followed after the subject signed the informed consent form, provided there were no contraindicative data from the health status questionnaire. The second step involved recording the subject's resting cardio-respiratory data. Any subject with an abnormal resting heart rate (> 95 bpm) or resting systolic blood pressure (> 160 mm Hg) was eliminated from further participation in the study.

The subject's abdominal girth, knuckle height, shoulder height, axilla height, biceps circumference (relaxed), weight, and standing height were recorded. These anthropometric measures were recorded as per the definitions given in the NASA (1978) anthropometric source book.

The subject's skin was prepared for ECG electrode placement by cleaning the skin surface with alcohol to remove residue. The electrode sites were identical to those used in the pilot study. After electrode placement, the subject was asked to rest in a chair for ten minutes prior to data recording. The ten-minute pre-test rest period was used to reduce the effects of pre-session activity. In addition, pre-session activity was limited by instructing the subjects via a pre-study information document given to all subjects recruited for the study (Appendix C). The subject read an instruction sheet (Appendix D) that detailed the objectives of Session 1 during the ten-minute rest period.

Next, resting cardio-respiratory data were collected for five minutes while the subject stood on a platform. The subject wore the mouthpiece and nose clip shown in Figure 4.4. Data were collected with the subject standing in order to reduce the impact of postural metabolic changes that may occur when the subject moved from a sitting posture to a standing posture immediately prior to the test.

The subject began the peak VO_2 task after the five-minute resting data collection period. The task involved repeated lifting and lowering of a box at a pace of six cycles per minute. Within each cycle, lifting or lowering activity was performed every five seconds. Each cycle involved lifting the box to shoulder height and waiting for completion of a five-second interval, and returning the box to knuckle height and waiting for the completion of a five-second interval. The box was placed on shelves adjusted such that the position of the box handles was either at knuckle height or shoulder height. The experimenter increased the load in the box at regular intervals. The timer-beeper was set to beep at five-second intervals and was placed close to the subject within his auditory and visual range. These auditory and visual stimuli were used by the subject to synchronize his lift or lower every five seconds. The protocol used in determining peak VO_2 was identical to that used in the pilot study.

Each subject was allowed to terminate the test when he could no longer lift the current load in compliance with the task requirements. Each subject was also free to terminate the task whenever he felt there was a risk of injury. The experimenter closely monitored the subject's vital signs and visible stress levels to minimize the risk of injury. None of the peak tests was terminated prematurely either by the subject or the experimenter. Considering that task termination was at the discretion of the subject, other criteria were monitored as in the pilot study to ensure that peak oxygen uptake was reached. These criteria included the condition that the respiratory exchange ratio be greater than 1.0, that HR exceed 80% of the age-predicted maximum, and that a subjective rating of perceived exertion greater than 9 be obtained.

Subjective ratings of effort were obtained at least three times during the peak test using Borg's 10-point rating of perceived exertion (Noble, Borg, Jacobs, Ceci, and Kaiser, 1983). The main objective of recording ratings of perceived exertion (RPE) during the peak test was to ensure that each subject was familiar with the rating procedure. This was assumed to lead to more accurate responses of perceived exertion during the sub-peak sessions. The ratings were recorded while the subject rested between the lifting and lowering activity. The subject was asked to point with his finger to the appropriate rating on the RPE chart (Appendix E).

The subject rested for 25 minutes following termination of the peak test. The rest duration of 25 minutes was established based on the recovery responses observed during the pilot study peak tests.

The next stage of data collection in Session 1 involved determination of the comfortable belt tension. For this purpose, the subject performed the task with a load equivalent to 75% of the maximum load attained in his peak test. There were three belt sizes available. The belt manufacturer suggests using waist size to determine the appropriate belt size. This recommendation was used to select the correct belt size for each subject.

Cardio-respiratory data were not recorded in this phase, although heart rate was monitored for subject safety. The subject was instructed to begin the task with the maximum possible belt tension. The subject performed the task for eight minutes, while continuously adjusting belt tension to a level that was comfortable. Following termination of the task, the lengths of the left and right tensioning straps were measured using a flexible tape. Belt tension was determined using the device described in Section 4.2.2. The belt tension determined for each subject was then used for that subject in all sub-sessions that required the use of the belt. The results are presented in Table 5.2.

Table 5.2. Belt Tension Data.

	Belt	Left Strap		Right Strap	
Sub	**Size**	**Length (cm)**	**Tension (kg)**	**Length (cm)**	**Tension (kg)**
4	small	40.4	7.6	39.0	7.7
5	medium	48.5	7.5	50.5	7.9
6	small	40.0	7.5	38.0	7.5
7	small	44.0	8.0	40.0	7.8
8	small	44.0	8.0	44.0	8.6
9	small	44.0	8.0	38.0	7.5
10	medium	46.0	7.3	45.0	7.2
11	small	42.0	7.8	43.0	8.3
12	small	43.0	7.9	40.0	7.8
13	small	45.0	8.1	42.0	8.0
14	small	43.0	7.9	39.0	7.7
15	small	43.0	7.9	38.0	7.5
Mean		43.6	7.8	41.4	7.8
SD		2.3	0.3	3.8	0.4

Legend: SD: standard deviation

5.4.2 Sessions 2 through 4

In Sessions 2 through 4, the subject performed the lifting/lowering task with the three different loads and two belt conditions (with-belt and no-belt). The sessions occurred on three days separated by at least twelve hours. Each session consisted of two sub-sessions, thus allowing one sub-session for each load-belt combination. Using the same lifting/lowering heights and rate, the task was performed repeatedly for four cycles of five minutes of work followed by two minutes of rest.

Certain restrictions were followed in the assignment of workload and belt conditions to sub-sessions. No session could include two instances of the same workload, and no session could include two with-belt sub-sessions. First, the two 75% workload conditions were randomly assigned to the three sessions, followed by random assignment of the two 40% and the two 60% workloads. After the assignment of workloads to sub-sessions, a coin toss was used to determine the belt condition sequence within each session. At the end of this assignment procedure, a sequence of six sub-sessions with specific workload and belt conditions was obtained. This sequence of three sessions was rotated systematically to obtain three different test sequences. The sub-session sequence within each session was reversed in each of the three test sequences to obtain another three test sequences. This process resulted in six sequences of the six workload-belt conditions. The twelve subjects were then randomly assigned a test sequence, ensuring two subjects per sequence. The final testing sequence for each subject is presented in Table 5.3.

The data collection procedures for Sessions 2 through 4 were identical. As soon as the subject reported for testing, the ECG electrodes were attached and the subject was asked to relax in a chair for ten minutes. The blood pressure cuff was placed over the subject's brachial artery on his right upper-arm. During this pre-test rest period, the subject was given an instruction sheet which detailed the objectives of the session

Table 5.3. Testing Sequence.

	Session 2		Session 3		Session 4	
Subjects	**SS-1**	**SS-2**	**SS-3**	**SS-4**	**SS-5**	**SS-6**
7, 15	60 NB	75 WB	40 NB	60 WB	40 WB	75 NB
9, 10	40 NB	60 WB	40 WB	75 NB	60 NB	75 WB
6, 12	40 WB	75 NB	60 NB	75 WB	40 NB	60 WB
8, 14	75 WB	60 NB	60 WB	40 NB	75 NB	40 WB
4, 5	60 WB	40 NB	75 NB	40 WB	75 WB	60 NB
11, 13	75 NB	40 WB	75 WB	60 NB	60 WB	40 NB

Legend: SS: sub-session, WB: with-belt, NB: no-belt

(Appendix F). Resting blood pressure was recorded at the fourth and ninth minute of the ten-minute rest period.

At the end of the ten-minute rest period, the subject was asked to don the mouthpiece and the nose clip. Cardio-respiratory resting data were collected for five minutes while the subject stood on the test platform ready to perform the task. After five minutes of data collection, the subject was instructed to begin the lifting/lowering task. The subject used the beeps and the visual stimulus of the timer-beeper to maintain the work pace. Blood pressure and subjective effort on the RPE scale were recorded following each five-minute work period. Response measures were continuously recorded for four such work and rest cycles. Recovery data were collected for five minutes following the last work period. After task termination, the subject completed a questionnaire soliciting subjective responses to the task (Appendix G). The subject relaxed for 25 minutes before the second sub-session started. The data collection procedure for the second sub-session was identical to the procedure for the first sub-session.

For the sub-sessions using the belt, data collection was paused after the five-minute cardio-respiratory resting data collection period. The experimenter helped the subject don the abdominal belt and ensured that the belt tension was identical to the comfortable tension determined by the subject in Session 1. Data collection resumed and resting cardio-respiratory data with the belt were recorded for four minutes. At the end of this four-minute period, the subject was instructed to perform the lifting/lowering task. The subjective questionnaire at the end of the WB sub-session included additional questions related to belt use. At the end of the final sub-session, subjective impressions of belt use and of the task were recorded (Appendix H).

5.4.3 Session 5

Towards the end of the study Session 5 was conducted to collect static and dynamic strength data. The subjects were asked to report for a 45-minute test session. Static strength measurements were performed first. The subject was asked to lift the weight box attached to 300 lb load cell fixed to the platform on which the subject stood. The load cell was interfaced to the computer in the same manner as the load cell for determining belt tension. The test was performed at least four times following at least two familiarization trials. The time between trials was at least two minutes.

Dynamic strength was measured in the form of a one repeat maximum. The subject was asked to perform the experimental task with no restriction on the time taken for the lift and lower. The box weighed 57.7 kg. The load was varied by 2.27 kg until the subject could not perform or could perform the task. The final load was fine-tuned by increasing and decreasing the load in multiples of 1.14 kg. A three-minute rest break was provided between trials. On average, each subject achieved his 1 RM within five trials.

5.5 Statistical Model

The statistical model used for analysis of each response measure was:

$Y = \mu + B_i + L_j + P_k + S_l + BL_{ij} + BP_{ik} + BS_{il} + LP_{jk} + LS_{jl} + PS_{kl} + BLP_{ijk} + BLS_{ijl} + BPS_{ikl} + LPS_{jkl} + BLPS_{ijkl} + \varepsilon_{ijkl},$

where,

Y = response measure

μ = overall mean

B_i = effect of the belt ($i = 1$ represents no-belt NB, $i = 2$ represents with-belt WB)

L_j = effect of the workload level ($j = 1$ to 3 for 40%, 60%, and 75%)

P_k = effect of the work period ($k = 1$ to 4) and

S_l = effect of the subject ($l = 1$ to 12).

The expected mean squares for the statistical model and the appropriate F-tests are presented in Table 5.4.

Table 5.4. Expected Mean Squares for a Four-Factor Mixed-Effects Model.

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	EXPECTED MEAN SQUARE	F STATISTIC
Belt (B)	SS_B	*a-1*	$\sigma^2 + bcd\phi_B + bc\sigma^2_{BS}$	MS_B/MS_{BS}
Workload (L)	SS_L	*b-1*	$\sigma^2 + acd\phi_B + ac\sigma^2_{BS}$	MS_L/MS_{LS}
Work Period (P)	SS_P	*c-1*	$\sigma^2 + abd\phi_P + ab\sigma^2_{PS}$	MS_P/MS_{PS}
Subject (S)	SS_S	*d-1*	$\sigma^2 + abc\sigma^2_S$	-
B × L	SS_{BL}	*(a-1)(b-1)*	$\sigma^2 + cd\phi_{BL} + abd\sigma^2_{BLS}$	MS_{BL}/ MS_{BLS}
B × P	SS_{BP}	*(a-1)(c-1)*	$\sigma^2 + bd\phi_{BP} + acd\sigma^2_{BPS}$	MS_{BP}/ MS_{BPS}
B × S	SS_{BS}	*(a-1)(d-1)*	$\sigma^2 + bc\sigma^2_{BS}$	-
L × P	SS_{LP}	*(b-1)(c-1)*	$\sigma^2 + ad\phi_{LP} + bcd\sigma^2_{LPS}$	MS_{LP}/ MS_{LPS}
L × S	SS_{LS}	*(b-1)(d-1)*	$\sigma^2 + ac\sigma^2_{LS}$	-
P × S	SS_{PS}	*(c-1)(d-1)*	$\sigma^2 + ab\sigma^2_{PS}$	-
B × L × P	SS_{BLP}	*(a-1)(b-1)(c-1)*	$\sigma^2 + abc\phi_{BLP}$	MS_{BLP}/MS_{BLPS}
B × L × S	SS_{BLS}	*(a-1)(b-1)(d-1)*	$\sigma^2 + abd\sigma^2_{BLS}$	-
B × P × S	SS_{BPS}	*(a-1)(c-1)(d-1)*	$\sigma^2 + acd\sigma^2_{BPS}$	-
L × P × S	SS_{LPS}	*(b-1)(c-1)(d-1)*	$\sigma^2 + bcd\sigma^2_{LPS}$	-
B × L × P × S	SS_{BLPS}	*(a-1)(b-1)(c-1)(d-1)*	$\sigma^2 + abcd\sigma^2_{BLPS}$	-
Error	-	-	σ^2	-

In Table 5.3, *a* refers to the number of belt conditions, *b* refers to the number of load levels, *c* refers to the number of work periods, and *d* refers to the number of subjects. The F statistic for any interaction involving subjects cannot be computed since there is no estimate of true error due to the absence of replications. The same situation was encountered for the main effect of subjects.

The Statistical Analysis System (SAS) was used for all statistical analyses. Analysis of variance tests were conducted on all response measures. The usual sphericity problems associated with mixed models/repeated measures designs can be ignored for the main factor of interest, since there are only two levels of the repeated factor (with-belt and no-belt). However, sphericity is an issue with respect to workload and work period.

Therefore, upon detection of significant results from the ANOVA tests susceptible to sphericity problems, the Greenhouse-Geisser conservative F-test critical value was used ($F_{0.05,1,11} = 4.84$). The degrees of freedom for this critical value were obtained by dividing the numerator and denominator degrees of freedom by the numerator degrees of freedom. All main effects F-value calculations include a subject interaction term as the denominator. Therefore, the degrees of freedom for the denominator after the necessary division leaves only the subject term. The degrees of freedom for subjects is $d-1$ or 11.

Two-dependent-sample t-tests were used in certain cases instead of standard multiple comparison procedures which are sensitive to violation of the sphericity assumption. T-tests were performed on cell means. In some cases, marginal cell means were used based on the independent variable and overall statistical results.

CHAPTER 6

RESULTS AND ANALYSES

6.1 Overview

The results of the study have been summarized by response measure. Raw data from each response measure were first analyzed using exploratory data analysis techniques. This procedure involved plotting the raw data in a variety of ways to visually identify trends. As can be seen from the sample data in Appendix I, the data for one subject for a single task condition were quite extensive. Various methods of data reduction were explored to consolidate the number of data points for the purpose of statistical analysis, while ensuring that none of the inherent trends were lost in the process.

The number of data points for a response measure in a given time interval varied with the breathing rate of the subject. This meant that there were more data points when the subject was working vigorously compared with rest or the initial stage of a sub-session. This pattern held for all the cardio-respiratory data recorded by the metabolic cart.

Descriptive data for each subject included several anthropometric measures, health status, and subjective impressions of belt use. Table 6.1 presents the anthropometric data. Data about each subject's health status and pre-test impressions about belt use are presented in Appendix J. Cardio-respiratory data collected during the peak VO_2 test are presented in Table 6.2. Resting data collected at the beginning of each session are presented in Table 6.3.

Table 6.1. Anthropometric Data.

Sub	Knuckle Height (cm)	Axilla Height (cm)	Shoulder Height (cm)	Abdominal Girth(cm)	Unflexed Biceps (cm)
4	81.5	145.5	156.4	80.0	26.4
5	77.8	138.7	147.4	92.5	31.0
6	64.0	124.4	133.3	77.8	27.0
7	75.4	135.0	143.3	87.5	34.0
8	74.5	133.5	141.0	91.0	32.5
9	64.9	121.0	129.1	79.0	28.5
10	68.0	125.0	136.0	92.0	30.0
11	77.4	138.8	147.6	84.0	34.0
12	73.0	130.0	136.2	81.0	32.0
13	68.8	130.7	139.6	85.0	30.0
14	66.9	125.2	132.6	80.0	27.0
15	77.0	134.6	146.0	83.5	29.5
Mean	72.4	131.9	140.7	84.4	30.2
SD	5.7	7.2	7.8	5.2	2.6

Legend: SD: standard deviation

Table 6.2. Peak Test Cardio-Respiratory Data.

Sub	Test Duration (min)	RER	VO_2 (ml/kg/min)	HR (beats/min)	RR (breaths/min)	VE (L/min)
4	19.00	1.0	24.2	175.8	34.6	1.6896
5	15.67	1.0	19.4	146.0	34.8	1.2830
6	9.00	0.9	24.3	148.8	20.6	1.5654
7	17.00	1.1	19.8	146.2	29.1	1.4858
8	15.33	1.1	25.9	200.1	33.9	2.0281
9	13.67	1.0	30.4	164.6	32.3	1.3889
10	14.83	1.0	25.8	178.5	25.0	2.2500
11	16.33	1.0	29.1	144.2	31.3	1.9826
12	20.17	1.0	23.1	147.5	45.3	1.4522
13	15.00	1.0	30.2	197.9	43.6	1.4391
14	9.17	1.0	19.7	163.9	26.3	1.1374
15	13.33	1.1	19.9	176.8	26.3	1.7996
Mean	14.45	1.0	24.3	165.9	31.9	1.6251
SD	3.09	0.04	4.1	20.1	7.3	0.3321

Legend: SD: standard deviation

Table 6.3. Pre-Session Resting Cardio-Respiratory Data.

	VO2 (ml/kg/min)			HR (beat/min)			RR (breaths/min)			VE (L/breath)		
Sub	**S-2**	**S-3**	**S-4**	**S-2**	**S-3**	**S-4**	**S-2**	**S-3**	**S-4**	**S-2**	**S-3**	**S-4**
4	3.7	5.2	5.5	62.8	77.0	71.7	12.5	11.5	16.3	0.9596	1.0239	0.7293
5	4.5	4.2	3.5	72.6	81.5	64.8	19.5	17.1	15.8	0.6544	0.6802	0.7022
6	5.6	5.0	4.9	80.1	84.8	88.5	14.6	13.0	16.2	0.6269	0.6383	0.5457
7	3.6	3.5	4.3	74.2	77.8	79.1	13.2	17.1	14.2	0.5813	0.4921	0.7123
8	5.2	5.2	4.6	94.4	99.2	91.2	21.0	19.5	17.7	0.6868	0.6623	0.8461
9	4.3	3.6	4.3	74.4	80.0	78.4	11.3	10.0	12.3	0.5658	0.5196	0.5294
10	3.8	3.8	4.0	82.9	70.7	82.4	9.8	12.7	10.9	0.8443	0.7537	0.8918
11	5.0	5.0	5.1	89.2	72.0	67.6	8.8	12.0	13.2	1.0361	0.9871	0.9854
12	4.4	5.3	5.3	65.2	63.4	71.5	15.5	20.8	20.2	0.6518	0.6800	0.6923
13	6.5	5.7	5.3	82.7	89.0	74.3	21.3	19.4	17.0	0.6949	0.6553	0.6394
14	4.4	3.8	3.3	89.6	86.7	76.5	18.0	14.1	16.9	0.4370	0.5302	0.4351
15	4.1	4.5	3.9	90.8	112.3	86.9	14.9	16.2	16.7	0.6255	0.6726	0.5847
Mean	4.6	4.6	4.5	79.9	82.9	77.7	15.0	15.3	15.6	0.6970	0.6913	0.6911
SD	0.8	0.8	0.7	10.2	13.2	8.3	4.2	3.6	2.6	0.1700	0.1659	0.1595

Legend: S: session, SD: standard deviation

Table 6.4 presents the peak test loads, and measures of task-related static strength and dynamic 1 RM. Table 6.5 presents the acquisition time for each blood pressure observation. The time recorded was the total time taken from the moment the cuff was inflated (which was the moment the subject started the last lower of a work period) to the moment when the computer displayed the blood pressure data.

Table 6.4. Peak Test Load and Measures of Strength in kg.

Sub	Peak Load	Static Strength	Dynamic 1-RM
4	31.5	75.1	69.0
5	33.7	-	-
6	24.6	31.6	46.2
7	33.7	38.5	59.9
8	32.6	-	-
9	31.5	40.0	54.2
10	32.6	38.8	54.2
11	33.7	49.6	61.0
12	38.3	56.7	61.0
13	32.6	36.8	61.0
14	24.6	47.1	39.4
15	30.3	44.9	59.9
Mean	31.6	38.3	47.1
SD	3.8	21.2	23.3

Legend: SD: standard deviation, "-" missing value

Table 6.5. Blood Pressure Data Acquisition Time (seconds).

	WP 1	WP 2	WP 3	WP 4	Mean	SD
Subject 4						
40 NB	35	35	35	35	35.0	0.0
40 WB	97	37	37	37	52.0	30.0
60 NB	39	39	39	39	39.0	0.0
60 WB	38	38	38	38	38.0	0.0
75 NB	37	37	37	37	37.0	0.0
75 WB	37	43	41	41	40.5	2.5
Subject 5	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	58	58	58	58	58.0	0.0
40 WB	57	57	57	57	57.0	0.0
60 NB	55	55	55	55	55.0	0.0
60 WB	58	58	58	58	58.0	0.0
75 NB	57	57	57	57	57.0	0.0
75 WB	51	51	51	51	51.0	0.0
Subject 6	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	44	44	48	48	46.0	2.3
40 WB	39	39	39	39	39.0	0.0
60 NB	47	47	47	47	47.0	0.0
60 WB	39	39	39	39	39.0	0.0
75 NB	39	39	39	39	39.0	0.0
75 WB	37	37	37	37	37.0	0.0
Subject 7	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	48	48	48	48	48.0	0.0
40 WB	49	49	49	49	49.0	0.0
60 NB	49	109	49	49	64.0	30.0
60 WB	49	49	49	49	49.0	0.0
75 NB	49	55	55	67	56.5	7.5
75 WB	50	50	50	50	50.0	0.0
Subject 8	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	52	52	52	52	52.0	0.0
40 WB	47	47	47	47	47.0	0.0
60 NB	50	50	50	50	50.0	0.0
60 WB	53	53	53	53	53.0	0.0
75 NB	46	46	101	46	59.8	27.5
75 WB	52	52	52	52	52.0	0.0
Subject 9	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	103	38	38	38	54.3	32.5
40 WB	40	40	40	40	40.0	0.0
60 NB	37	37	37	37	37.0	0.0
60 WB	39	39	39	39	39.0	0.0
75 NB	37	37	37	37	37.0	0.0
75 WB	37	37	37	37	37.0	0.0
Mean (all subjects)	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	51.2	46.3	46.9	45.3	47.4	10.8
40 WB	50.6	45.0	45.0	45.0	46.4	9.8
60 NB	46.6	51.6	46.8	46.4	47.8	10.6
60 WB	45.7	44.4	45.3	45.3	45.1	7.1
75 NB	49.0	44.5	49.1	45.5	47.0	14.0
75 WB	45.3	46.3	45.6	45.6	45.7	5.7

	WP 1	WP 2	WP 3	WP 4	Mean	SD
Subject 10						
40 NB	40	40	40	40	40.0	0.0
40 WB	41	41	41	41	41.0	0.0
60 NB	41	41	41	41	41.0	0.0
60 WB	55	40	40	40	43.8	7.5
75 NB	43	43	43	43	43.0	0.0
75 WB	41	41	41	41	41.0	0.0
Subject 11	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	49	49	49	49	49.0	0.0
40 WB	62	55	55	55	56.8	3.5
60 NB	54	54	54	54	54.0	0.0
60 WB	51	51	51	51	51.0	0.0
75 NB	48	48	48	48	48.0	0.0
75 WB	49	49	49	49	49.0	0.0
Subject 12	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	45	45	45	45	45.0	0.0
40 WB	47	47	47	47	47.0	0.0
60 NB	51	51	53	49	51.0	1.6
60 WB	49	49	49	49	49.0	0.0
75 NB	49	49	49	49	49.0	0.0
75 WB	48	48	48	48	48.0	0.0
Subject 13	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	46	46	46	46	46.0	0.0
40 WB	47	47	47	47	47.0	0.0
60 NB	48	48	48	48	48.0	0.0
60 WB	45	45	45	45	45.0	0.0
75 NB	107	47	47	47	62.0	30.0
75 WB	43	49	43	43	44.5	3.0
Subject 14	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	40	40	40	40	40.0	0.0
40 WB	40	40	40	40	40.0	0.0
60 NB	42	42	42	42	42.0	0.0
60 WB	41	41	41	41	41.0	0.0
75 NB	38	38	38	38	38.0	0.0
75 WB	-	45	45	45	45.0	0.0
Subject 15	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	54	60	64	45	55.8	8.3
40 WB	41	41	41	41	41.0	0.0
60 NB	46	46	46	46	46.0	0.0
60 WB	31	31	41	41	36.0	5.8
75 NB	38	38	38	38	38.0	0.0
75 WB	53	53	53	53	53.0	0.0
Grand Mean	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
Ave NB	48.9	47.4	47.6	45.7	47.4	11.8
SD NB	15.1	12.5	11.5	7.0		
Ave WB	47.3	45.2	45.3	45.3	45.7	7.7
SD WB	11.2	6.5	6.1	6.1		

Legend: WP: work period, NB: no-belt, WB: with-belt, Ave: mean, SD: standard deviation

The data reduction approach was similar for all response measures except for blood pressure since there was only a single blood pressure measurement for each work period. For some response measures, data normalization was also applied to account for inter-subject and intra-subject variability. Data normalization techniques are discussed in detail for each response measure.

To ensure that information was not lost in the data reduction, the raw data were examined graphically for a limited number of runs. All response measures for four randomly selected subjects, two workloads (40% and 75%), two work periods (first and fourth), and both belt conditions were examined. The goal of data reduction was to generate composite data truly representative of each work period.

6.2 Oxygen Consumption

The following figures illustrate the development of the data reduction procedure for oxygen consumption based on the responses for Subject 12. A subset of the data for Subject 12 is provided in Appendix I.

Figure 6.1 presents the data for all work and rest periods for the 75% workload and no-belt task condition. The variation in response within each work period is illustrated as a function of time. The figure emphasizes the necessity for data reduction as it reflects the number of data points within each work period. As observed in Figure 6.1, there are fewer data points during the initial five-minute rest period compared with the fourth work period (between the 26th and 31st minute).

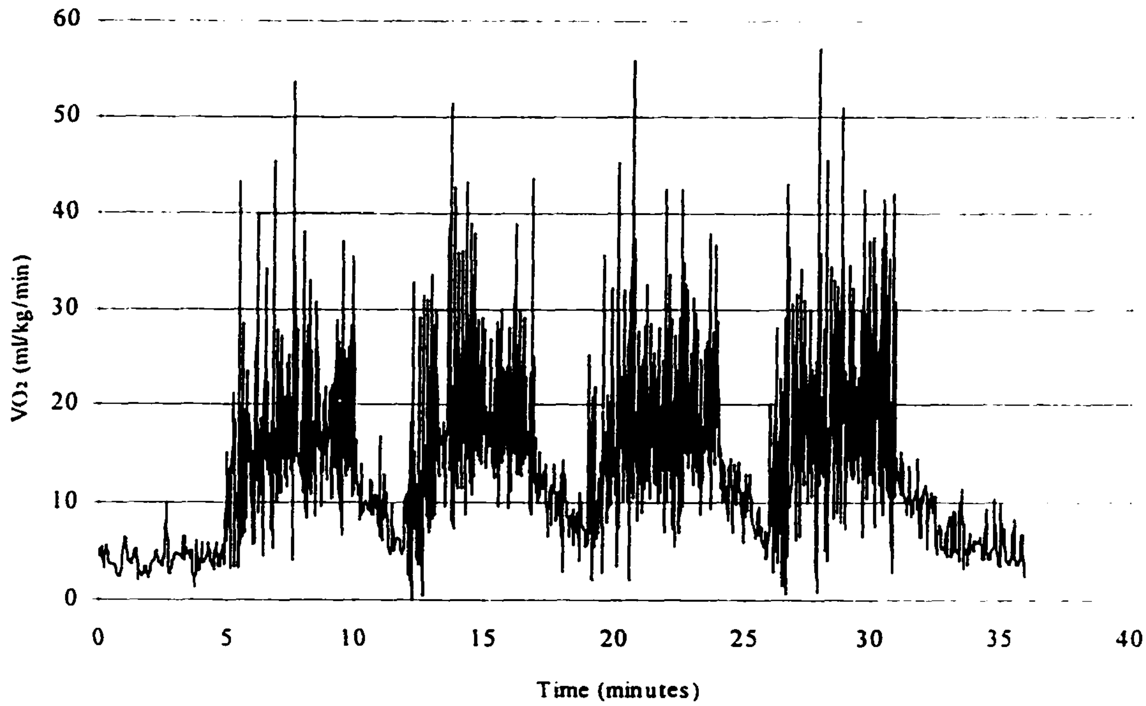

Figure 6.1. Oxygen Consumption Data for Subject 12 at 75% Workload and No-Belt.

At this stage, it was necessary to determine representative data for each work period. It was logical to assume that the responses in the latter part of the work period formed a better representation of the work period and better reflected the stress on the subject's cardiovascular system. Therefore, data from the last two minutes of each work period were examined. The subject's cardio-respiratory fitness level and the respiration rate pattern at different workloads affected the number of data points in a given time period. This is because the data collection rate was equivalent to the respiration rate. So if the subject breathed at a faster rate, there were more data points, as was the case in the last minute of the fourth work period (Figure 6.1). In consideration of this measurement artifact, a shorter representative time duration such as the last 20 or 40 seconds of each work period was not considered. A shorter duration would include too few data points if the respiration rate were low, in which case the average may be easily affected by response artifacts. The response artifacts are discussed in the next paragraph.

Figure 6.2 provides an expanded view of a subset of Figure 6.1 representing the last minute of the fourth work period. The five-second increments on the X-axis in Figure 6.2 correspond to a lift or lower in the task performance cycle. The subject began a lift at time equals 30 minutes and initiated a lower at time equals 30.08 minutes, etc. The time required to complete a lift or a lower was approximately three seconds.

The metabolic cart measured the volume of air in each exhalation and simultaneously measured the breath-to-breath interval. The volume of oxygen consumed was obtained by comparing the oxygen present in the exhaled air with that of the standard concentration of oxygen in the environment. The rate of oxygen consumption was obtained by extrapolating the oxygen consumed in a specific breath-to-breath interval (which is variable) to a standard time interval such as one minute. The variation in VO_2 values originating from typical measurement variation and human response variation becomes amplified when the volume of oxygen consumed is converted to a rate of consumption per minute.

Considering the data collection artifact (i.e., the inability to record responses that are representative of only the effort), all data points recorded in the last minute were averaged to reasonably represent the response for each work period. Although, an average calculated over the last two minutes of each work period would have included more data points, it would also have included a stage at which the subject's response had not necessarily achieved the true task representation. Hence, it was believed that an average of data from the last minute of each work period would be a reasonable representation of the subject's response to the task.

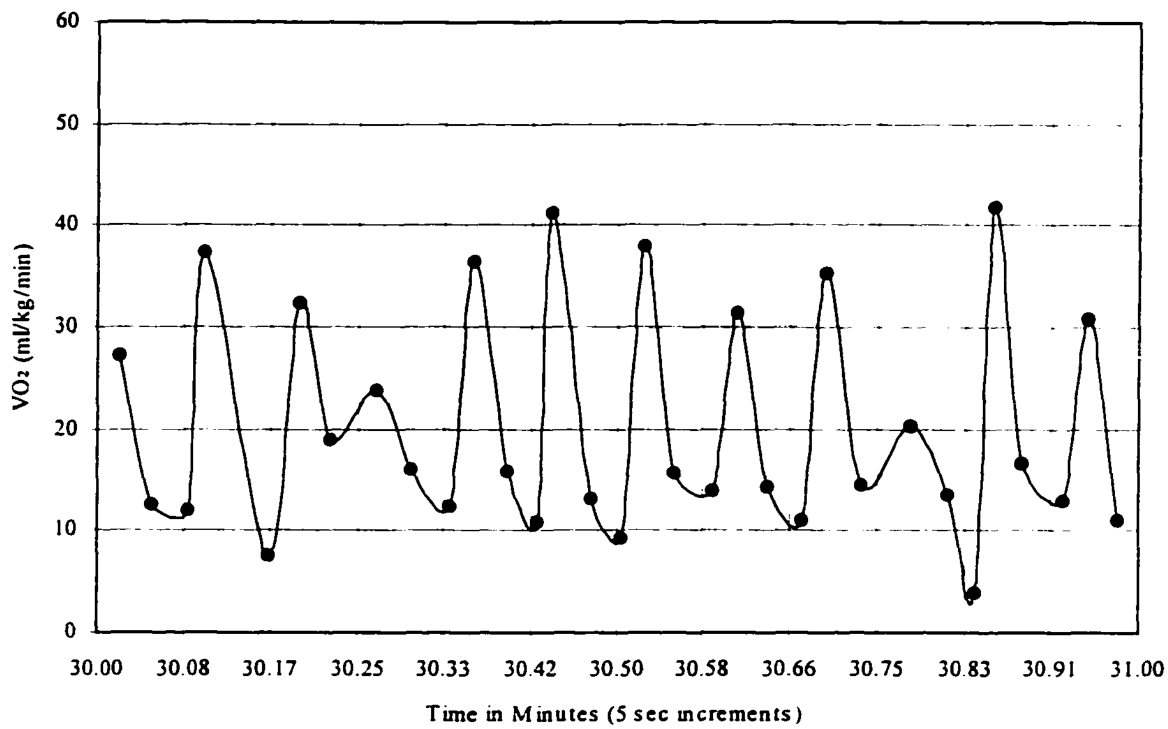

Figure 6.2. Oxygen Consumption Data for Subject 12 in the Last Minute of Work Period 4 at 75% Workload and No-Belt.

Oxygen consumption data reduced in this manner are presented in Table 6.6. The data in Table 6.6 were further examined using graphical methods. Figure 6.3 presents the VO_2 response data for the 40% workload averaged across the four work periods. The with-belt and no-belt conditions do not provide a consistent response, since there is no clear trend of either lower or higher VO_2 responses with the belt. Subjects 4, 5, 6, 7, 11, and 12 displayed a higher WB response whereas the rest of the subjects displayed a lower WB response compared to the NB response.

Table 6.6. Oxygen Consumption Data (ml/kg/min).

Subject 4	**WP 1**	**WP 2**	**WP 3**	**WP 4**	**Mean**	**SD**	**Subject 10**	**WP 1**	**WP 2**	**WP 3**	**WP 4**	**Mean**	**SD**
40 NB	13.0	12.2	12.1	14.5	13.0	1.1	**40 NB**	12.3	11.1	11.3	12.1	11.7	0.6
40 WB	15.6	13.1	13.1	13.0	13.7	1.3	**40 WB**	10.1	9.6	9.8	10.8	10.1	0.5
60 NB	17.9	16.3	16.6	16.0	16.7	0.8	**60 NB**	12.4	13.1	13.1	11.6	12.6	0.7
60 WB	14.0	14.0	13.2	13.5	13.7	0.4	**60 WB**	13.4	15.8	16.9	16.9	15.8	1.7
75 NB	18.9	19.3	19.3	19.1	19.2	0.2	**75 NB**	15.3	15.7	15.7	16.5	15.8	0.5
75 WB	18.3	18.8	19.4	21.0	19.4	1.2	**75 WB**	14.6	15.1	16.0	16.5	15.6	0.9
Subject 5							**Subject 11**						
	WP 1	**WP 2**	**WP 3**	**WP 4**				**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	8.6	8.5	8.4	9.1	8.7	0.3	**40 NB**	12.4	11.5	12.2	12.4	12.1	0.4
40 WB	9.2	9.0	10.2	10.3	9.7	0.7	**40 WB**	11.7	12.6	12.8	12.1	12.3	0.5
60 NB	9.4	10.3	10.3	11.2	10.3	0.7	**60 NB**	16.9	16.2	15.7	16.4	16.3	0.5
60 WB	12.9	12.5	11.9	12.0	12.3	0.5	**60 WB**	15.9	14.5	16.4	17.0	15.9	1.1
75 NB	14.7	14.3	14.7	14.7	14.6	0.2	**75 NB**	18.4	19.4	19.0	19.3	19.0	0.4
75 WB	13.0	13.2	13.8	12.5	13.1	0.5	**75 WB**	17.0	17.5	17.5	18.7	17.7	0.7
Subject 6							**Subject 12**						
	WP 1	**WP 2**	**WP 3**	**WP 4**				**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	9.2	8.4	8.7	8.5	8.7	0.3	**40 NB**	11.1	12.3	12.3	10.9	11.7	0.7
40 WB	10.7	10.4	12.3	13.0	11.6	1.3	**40 WB**	12.3	12.6	11.9	11.3	12.0	0.6
60 NB	11.5	11.8	11.7	10.6	11.4	0.5	**60 NB**	15.4	15.2	16.8	14.7	15.5	0.9
60 WB	10.3	10.3	11.8	10.8	10.8	0.7	**60 WB**	15.2	14.8	14.5	14.8	14.8	0.3
75 NB	13.8	14.7	15.7	15.1	14.8	0.8	**75 NB**	18.7	19.0	19.8	20.4	19.5	0.8
75 WB	12.6	11.7	11.0	11.9	11.8	0.7	**75 WB**	16.5	17.1	17.0	16.7	16.8	0.3
Subject 7							**Subject 13**						
	WP 1	**WP 2**	**WP 3**	**WP 4**				**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	9.8	8.9	7.7	9.6	9.0	1.0	**40 NB**	16.3	13.4	14.4	13.2	14.3	1.4
40 WB	10.6	10.2	10.1	9.3	10.0	0.5	**40 WB**	13.6	14.5	14.9	14.2	14.3	0.5
60 NB	13.0	13.6	13.5	12.8	13.2	0.4	**60 NB**	19.8	20.1	19.5	18.4	19.4	0.7
60 WB	13.2	13.0	12.2	13.2	12.9	0.5	**60 WB**	16.8	15.9	15.7	16.6	16.2	0.5
75 NB	13.5	13.5	13.4	13.9	13.5	0.2	**75 NB**	21.7	25.1	24.3	22.5	23.4	1.6
75 WB	13.1	13.9	14.1	14.5	13.9	0.6	**75 WB**	22.3	22.5	21.4	22.0	22.1	0.5
Subject 8							**Subject 14**						
	WP 1	**WP 2**	**WP 3**	**WP 4**				**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	11.8	11.5	11.7	12.1	11.8	0.3	**40 NB**	10.3	10.2	10.3	11.0	10.4	0.4
40 WB	11.5	11.4	11.5	10.4	11.2	0.5	**40 WB**	9.8	9.9	10.0	9.4	9.8	0.2
60 NB	17.0	16.9	16.8	17.3	17.0	0.2	**60 NB**	13.5	13.9	13.4	14.2	13.7	0.4
60 WB	11.0	10.0	9.1	9.3	9.8	0.9	**60 WB**	12.2	12.6	12.0	12.3	12.3	0.2
75 NB	17.4	18.1	18.3	18.6	18.1	0.5	**75 NB**	13.5	13.8	14.3	14.9	14.1	0.6
75 WB	18.8	18.1	19.5	20.1	19.1	0.9	**75 WB**	15.4	15.5	15.3	15.6	15.4	0.1
Subject 9							**Subject 15**						
	WP 1	**WP 2**	**WP 3**	**WP 4**				**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	14.0	13.7	14.6	16.5	14.7	1.2	**40 NB**	9.8	10.9	10.2	10.5	10.3	0.5
40 WB	13.1	12.0	12.3	12.0	12.3	0.5	**40 WB**	9.7	8.7	9.6	9.8	9.4	0.5
60 NB	15.3	15.0	15.5	15.4	15.3	0.2	**60 NB**	14.2	15.0	14.5	14.2	14.5	0.4
60 WB	15.4	15.2	14.9	14.8	15.1	0.3	**60 WB**	12.2	13.0	11.5	13.0	12.4	0.7
75 NB	18.8	18.4	20.0	18.8	19.0	0.7	**75 NB**	15.1	15.4	15.6	15.5	15.4	0.2
75 WB	15.6	16.3	16.8	17.1	16.4	0.7	**75 WB**	15.6	16.2	16.9	16.6	16.3	0.6
Mean (all subjects)							**Grand Mean**						
	WP 1	**WP 2**	**WP 3**	**WP 4**				**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	11.6	11.1	11.1	11.7	11.4	2.1	**Ave NB**	14.29	14.35	14.48	14.51	14.41	3.48
40 WB	11.5	11.2	11.5	11.3	11.4	1.7	**SD NB**	3.32	3.63	3.61	3.39		
60 NB	14.7	14.8	14.8	14.4	14.7	2.5	**Ave WB**	13.7	13.65	13.81	13.97	13.78	3.07
60 WB	13.5	13.5	13.3	13.7	13.5	2.1	**SD WB**	2.90	3.05	3.08	3.35		
75 NB	16.7	17.2	17.5	17.4	17.2	2.9							
75 WB	16.1	16.3	16.5	16.9	16.5	2.8							

Legend: WP: work period, NB: no-belt, WB: with-belt, Ave: mean, SD: standard deviation

Figures 6.4 and 6.5 show the VO_2 response for the 60% and 75% workloads, respectively. Visual examination of these figures resulted in a similar conclusion. There is no discernible trend at either workload. Compared to the 40% workload, the relative difference between the NB and WB responses at the 60% workload was reversed for Subjects 4, 6, 7, 10, 11, 12, and 13. Similar reversals were observed between 40% and 75% and between 60% and 75%.

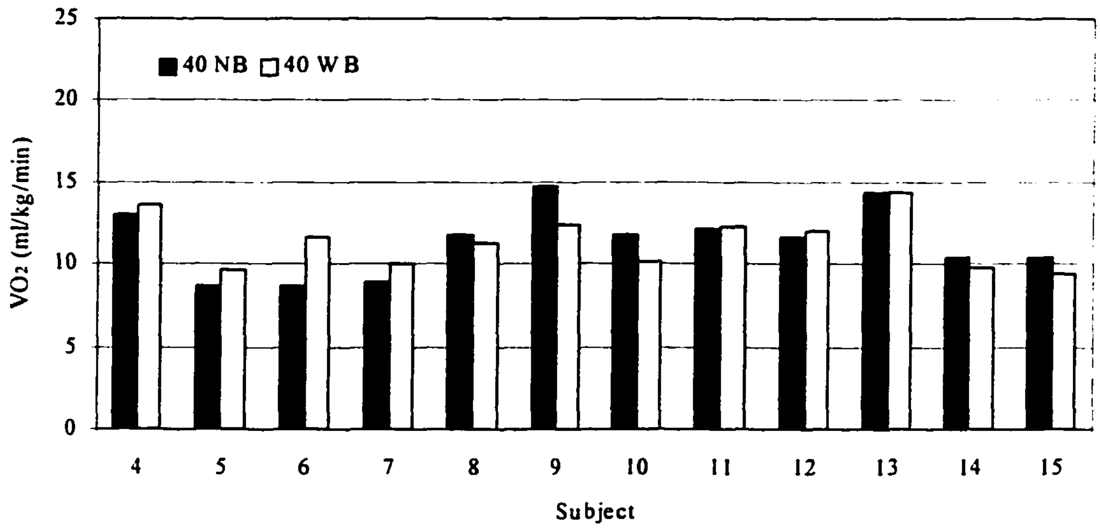

Figure 6.3. Oxygen Consumption Response to 40% Workload.

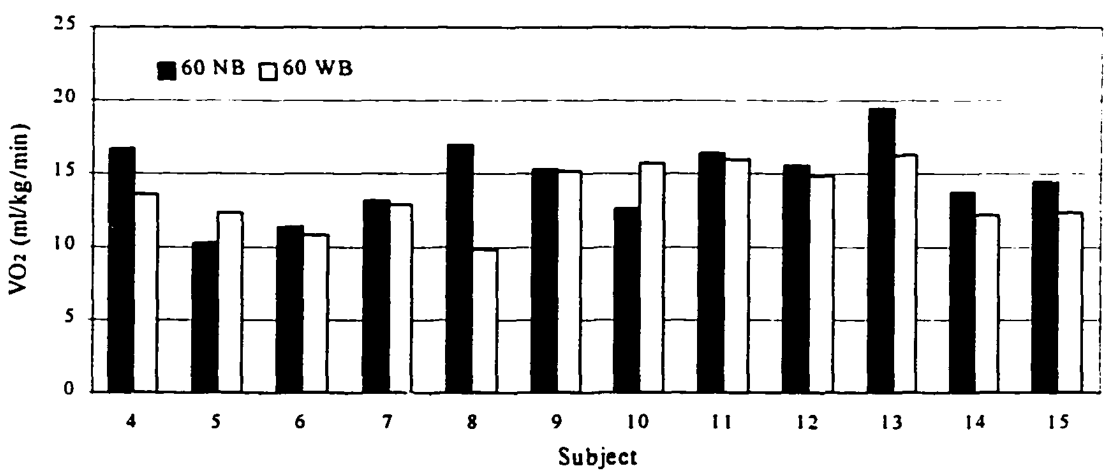

Figure 6.4. Oxygen Consumption Response to 60% Workload.

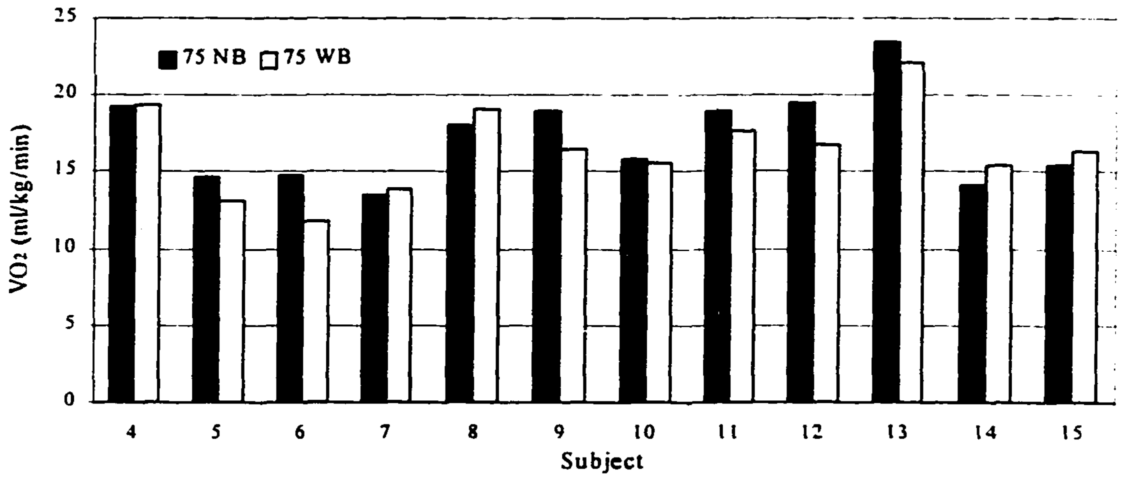

Figure 6.5. Oxygen Consumption Response to 75% Workload.

The oxygen consumption data in Table 6.6 reflect the individual differences in cardiovascular response to various task loads. Data normalization using either individual resting values or peak VO_2 values was necessary to facilitate the comparison of responses across subjects. Peak VO_2 values were chosen for normalization since these values were more reliable within subjects compared to resting values which were easily affected by day-to-day variations and pre-test activities. The reliability of peak VO_2 values was demonstrated in the pilot study where the data of the peak tests suggested that the peak VO_2 values did not differ statistically from test to retest. The resting VO_2 values in Table 6.3 show a large within-subject variation.

The data in Table 6.7 represent VO_2 responses normalized as a percentage of the peak VO_2 for each subject. Table 6.7 also presents averages and standard deviations calculated across subjects, belt conditions, workloads, and work periods.

Table 6.7. Oxygen Consumption Data as a Percentage of Individual Peak VO_2.

Subject 4							Subject 10						
	WP 1	WP 2	WP 3	WP 4	Mean	SD		WP 1	WP 2	WP 3	WP 4	Mean	SD
40 NB	53.9	50.6	49.9	60.1	53.6	4.6	40 NB	47.6	43.2	43.9	47.1	45.4	2.2
40 WB	64.4	54.0	54.2	53.6	56.6	5.2	40 WB	39.0	37.3	38.1	42.0	39.1	2.0
60 NB	74.1	67.7	68.6	66.3	69.2	3.4	60 NB	48.0	51.0	51.0	45.1	48.8	2.8
60 WB	57.9	57.8	54.5	55.8	56.5	1.7	60 WB	51.9	61.4	65.7	65.4	61.1	6.4
75 NB	78.4	80.1	80.0	79.1	79.4	0.8	75 NB	59.4	61.0	61.0	64.0	61.4	1.9
75 WB	75.7	77.7	80.3	86.8	80.1	4.9	75 WB	56.6	58.6	61.9	64.2	60.3	3.4
Subject 5							**Subject 11**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	44.4	43.5	43.2	47.1	44.6	1.8	40 NB	42.6	39.6	42.0	42.5	41.7	1.4
40 WB	47.3	46.3	52.6	52.9	49.8	3.5	40 WB	40.2	43.4	44.0	41.7	42.3	1.7
60 NB	48.6	53.2	52.8	57.6	53.1	3.7	60 NB	58.1	55.7	54.1	56.5	56.1	1.7
60 WB	66.3	64.5	61.3	61.6	63.4	2.4	60 WB	54.6	49.7	56.5	58.4	54.8	3.7
75 NB	75.6	73.6	75.9	75.9	75.3	1.1	75 NB	63.4	66.7	65.3	66.3	65.4	1.5
75 WB	66.8	67.8	70.9	64.6	67.5	2.6	75 WB	58.4	60.3	60.1	64.2	60.7	2.5
Subject 6							**Subject 12**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	37.7	34.6	35.6	35.1	35.7	1.4	40 NB	48.4	53.3	53.3	47.4	50.6	3.2
40 WB	44.0	42.8	50.5	53.5	47.7	5.2	40 WB	53.5	54.6	51.6	48.9	52.1	2.5
60 NB	47.2	48.5	47.9	43.6	46.8	2.2	60 NB	66.7	65.8	72.8	63.9	67.3	3.9
60 WB	42.4	42.3	48.5	44.3	44.4	2.9	60 WB	65.8	64.2	62.7	64.2	64.2	1.3
75 NB	56.9	60.4	64.6	62.0	61.0	3.2	75 NB	80.9	82.4	86.0	88.3	84.4	3.4
75 WB	51.9	48.0	45.3	48.9	48.5	2.7	75 WB	71.4	74.0	73.8	72.4	72.9	1.2
Subject 7							**Subject 13**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	49.5	44.7	38.7	48.3	45.3	4.9	40 NB	53.9	44.6	47.7	43.7	47.5	4.6
40 WB	53.3	51.5	50.7	47.1	50.7	2.6	40 WB	45.2	48.2	49.3	47.0	47.4	1.7
60 NB	65.5	68.6	67.9	64.7	66.7	1.9	60 NB	65.6	66.5	64.5	60.9	64.4	2.5
60 WB	66.6	65.8	61.7	66.4	65.1	2.3	60 WB	55.8	52.7	52.0	55.0	53.9	1.8
75 NB	67.9	68.0	67.5	70.1	68.4	1.1	75 NB	71.8	83.3	80.6	74.6	77.6	5.3
75 WB	66.1	70.3	71.1	73.4	70.2	3.1	75 WB	74.0	74.7	70.9	73.0	73.2	1.7
Subject 8							**Subject 14**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	45.6	44.5	45.1	46.9	45.5	1.0	40 NB	52.4	51.7	52.4	55.7	53.1	1.8
40 WB	44.3	44.0	44.5	40.4	43.3	2.0	40 WB	49.7	50.1	50.7	48.0	49.6	1.1
60 NB	65.8	65.4	65.0	66.7	65.7	0.7	60 NB	68.5	70.4	68.2	72.3	69.9	1.9
60 WB	42.6	38.6	35.1	35.9	38.1	3.4	60 WB	62.1	63.9	60.9	62.5	62.4	1.2
75 NB	67.3	70.0	70.8	71.9	70.0	2.0	75 NB	68.7	70.2	72.7	75.8	71.8	3.1
75 WB	72.6	69.8	75.2	77.7	73.8	3.4	75 WB	78.5	78.8	77.7	79.4	78.6	0.7
Subject 9							**Subject 15**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	46.2	45.2	48.2	54.4	48.5	4.1	40 NB	49.4	54.7	51.1	53.0	52.1	2.3
40 WB	43.2	39.4	40.6	39.4	40.6	1.8	40 WB	48.8	44.0	48.1	49.2	47.5	2.4
60 NB	50.3	49.4	51.0	50.6	50.3	0.7	60 NB	71.4	75.4	73.0	71.5	72.8	1.9
60 WB	50.7	49.9	49.2	48.7	49.6	0.9	60 WB	61.4	65.4	57.9	65.2	62.5	3.6
75 NB	62.0	60.6	65.7	61.9	62.6	2.2	75 NB	76.0	77.5	78.5	78.0	77.5	1.1
75 WB	51.3	53.6	55.4	56.3	54.1	2.2	75 WB	78.6	81.4	85.2	83.5	82.2	2.9
Mean (all subjects)							**Grand Mean**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	47.6	45.8	45.9	48.4	47.0	5.7	Ave NB	59.16	59.49	59.90	60.25	59.69	12.57
40 WB	47.7	46.3	47.9	47.0	47.2	5.5	SD NB	11.67	13.09	13.31	12.65		
60 NB	60.8	61.5	61.4	60.0	60.9	9.2	Ave WB	57.02	56.86	57.46	58.09	57.36	12.17
60 WB	56.5	56.3	55.5	57.0	56.3	8.8	SD WB	11.48	12.39	12.19	13.06		
75 NB	69.0	71.2	72.4	72.3	71.2	7.8							
75 WB	66.8	67.9	69.0	70.4	68.5	10.5							

Legend: WP: work period, NB: no-belt, WB: with-belt, Ave: mean, SD: standard deviation

Figures 6.6 through 6.8 present the normalized VO_2 data from Table 6.7 averaged across work periods. The response for the 40% workload no-belt condition averaged across all subjects was 47.0% (SD = 5.7%). However, an examination of the VO_2 uptake achieved by each subject in the fourth work period showed that, with the exception of Subject 6, all subjects exceeded the target response (40% of the peak capacity). The observed VO_2 values ranged from 35.1% to 60.1% across all work periods. Figure 6.6 shows these wide variations in individual subject response, implying that subject-related factors influenced individual responses at this workload.

Figures 6.7 and 6.8 show that the target responses for the 60% and 75% workload condition were not achieved by most subjects. The observed VO_2 values at 60% workload in the fourth work period ranged from 43.6% to 72.3%. In the NB condition, Subjects 5, 6, 9, 10, and 11 recorded uptake values that were below the targeted 60%, while the rest of the subjects exceeded the target. The average no-belt response was 60.9% (SD = 9.2%) for the 60% workload.

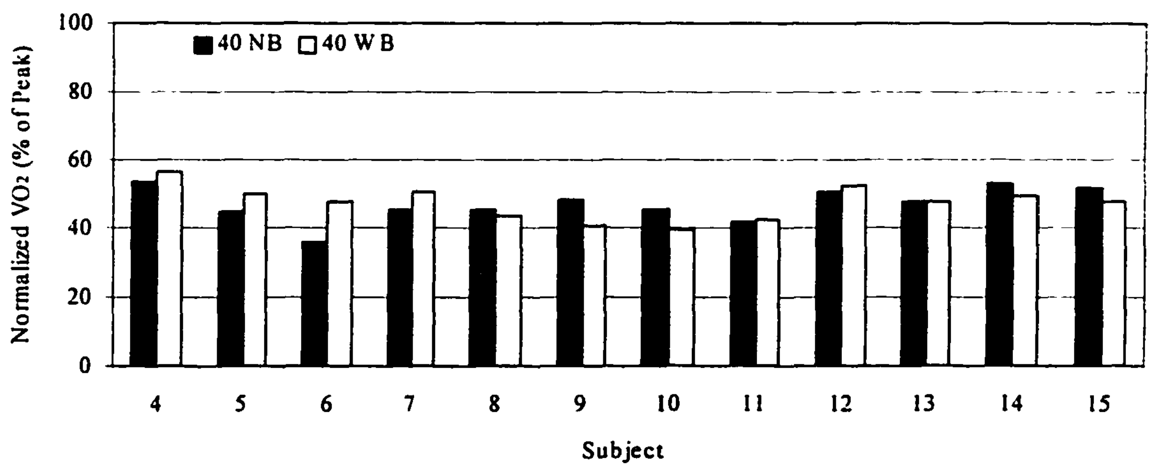

Figure 6.6. Normalized Oxygen Consumption Response to 40% Workload.

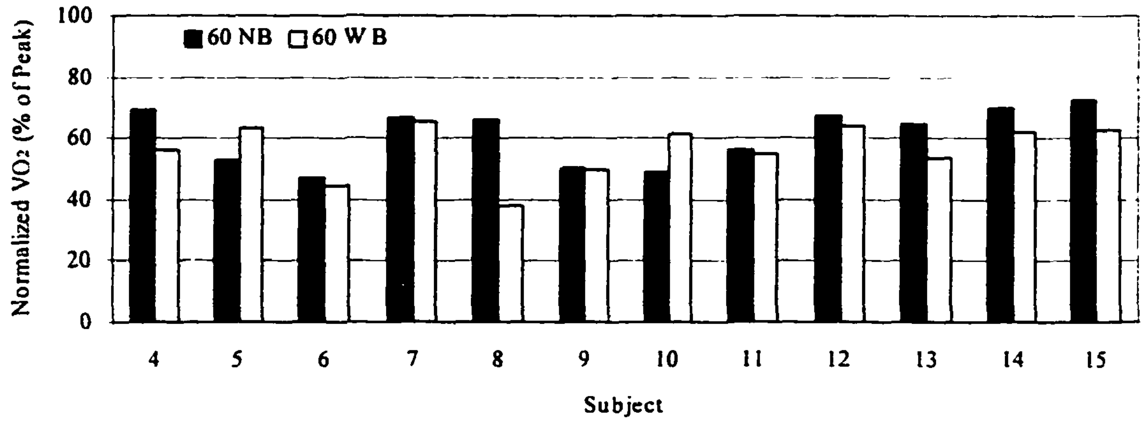

Figure 6.7. Normalized Oxygen Consumption Response to 60% Workload.

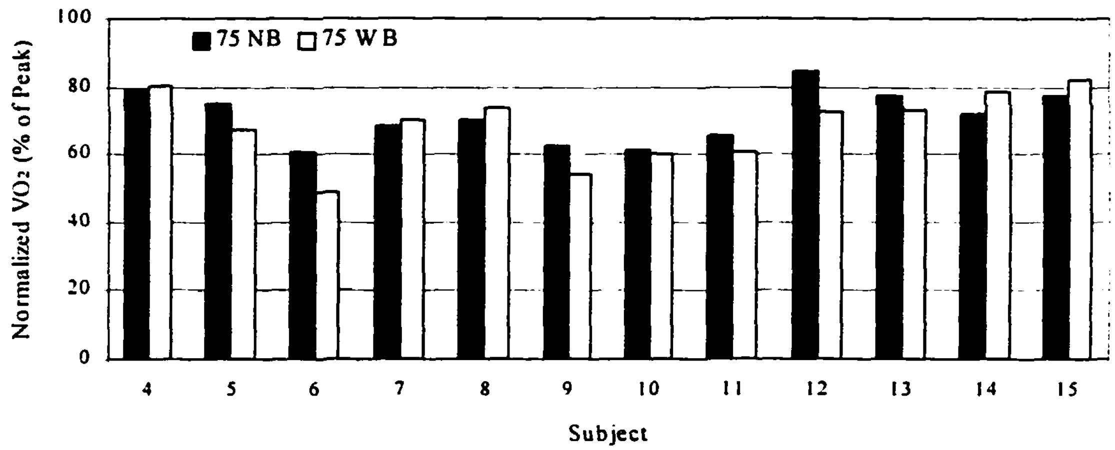

Figure 6.8. Normalized Oxygen Consumption Response to 75% Workload.

Oxygen uptake values recorded at the 75% workload in the fourth work period ranged from 62.0% to 88.3%. Subjects 6, 7, 8, 9, 10, and 11 were short of the target while the rest of the subjects were either on target (Subjects 5, 13, and 14) or exceeded the target (Subjects 4 and 12). The average response observed for the 75% workload was 71.2% (SD = 7.8%).

Examination of Figures 6.6 through 6.8 shows that the with-belt and no-belt responses differed by workload and subject. This leads to the hypothesis that there are unknown factors (either subject-based or instrument-based) that affected responses to the belt and workload conditions. However, the likelihood of instrument-based variation is low considering the precautions taken and extensive validation of the equipment by independent researchers. Therefore, it was believed that individual subject characteristics (as discussed in relation to the variation in the last-minute data) were likely to cause the wide variation in response relative to the variation caused by the workload and belt conditions.

Statistical verification of these observations was provided by analysis of variance. Table 6.8 provides a summary of the ANOVA results.

Table 6.8. ANOVA Summary for Normalized VO_2 Response Data.

Source	**DF**	**Mean Square**	**F Value**	**Pr > F**
Belt (B)	1	393.87	5.76	0.0353
Workload (L)	2	12449.41	125.07	0.0001
Work Period (P)	3	18.15	2.55	0.0723
Subject (S)	11	966.00	-	-
B * L	2	143.82	0.95	0.4005
B * P	3	1.05	0.15	0.9292
B * S	11	68.39	-	-
L * P	6	25.62	4.20	0.0012
L * S	22	99.54	-	-
P * S	33	7.11	-	-
B * L * P	6	11.58	1.35	0.2492
B * L * S	22	150.71	-	-
B * P * S	33	231.00	-	-
L * P * S	66	402.61	-	-
B * L * P * S	66	8.59	-	-

Legend: DF: degrees of freedom

At a 0.05 level of significance, the two belt conditions produced statistically different VO_2 responses. On average, the no-belt condition resulted in a higher VO_2 response than the with-belt condition. Work periods also differed significantly, and there was a significant Workload × Work Period interaction. This implied that the VO_2

response was not consistent across work periods for different loads (Figure 6.9). Data for Figure 6.9 were obtained by averaging across all subjects.

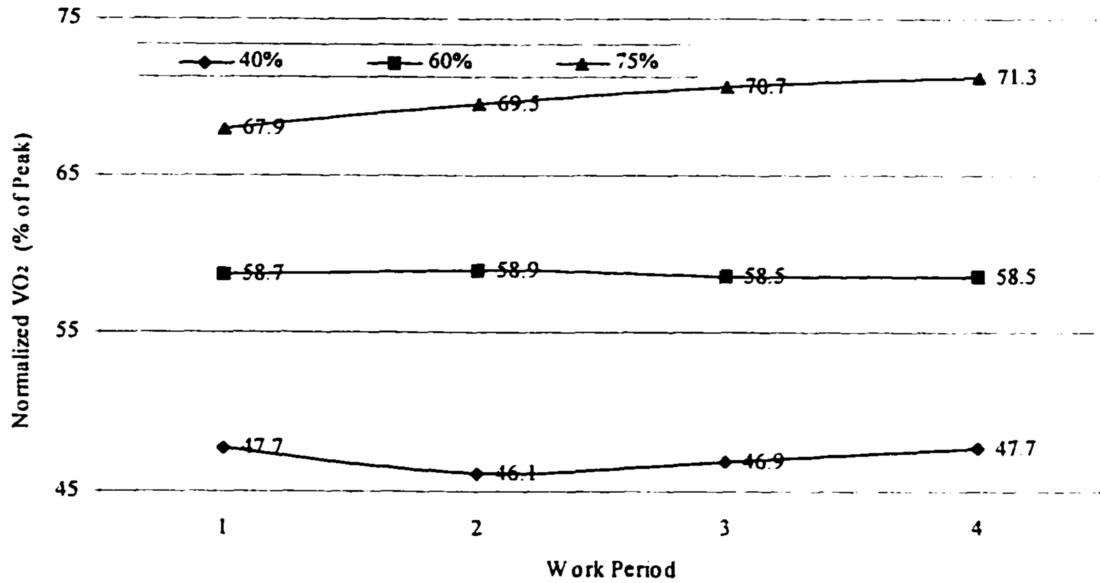

Figure 6.9. Workload by Work Period Interaction in Normalized VO_2 Response Data.

VO_2 response across work periods would be expected to increase or remain stable due to accumulated fatigue or achievement of steady state, respectively. Figure 6.9 shows that the rate of accumulation of fatigue or increase in response across work periods is affected by the workload. The change in response from Work Period 1 to Work Period 2 was -1.6% for the 40% workload, while it was 0.2% and 1.6% for the 60% and 75% workloads, respectively. Similar differences were observed for the change in response from Work Period 2 to Work Period 3, and from Work Period 3 to Work Period 4 among the workload levels. By themselves, these differences do not explain the observed significant interaction. The response trend from Work Period 1 to Work Period 4 for the workload levels is different. There is essentially no change in response with respect to work periods for the 40% and 60% workload levels compared to the increased response with increasing work period at the 75% workload.

Variation in the VO_2 response pattern due to subject-related characteristics would be reflected in the three-way interactions of Belt × Workload × Subject or Belt × Work Period × Subject. The Belt × Workload × Subject interaction was considered more important than the latter since work period was merely an observed condition rather than a manipulated independent variable. There was no legitimate F-test available for this interaction. Figure 6.10 shows the three-way interaction of belt, workload, and subject. The data were obtained by averaging across all work periods and subtracting the WB responses from the corresponding NB responses.

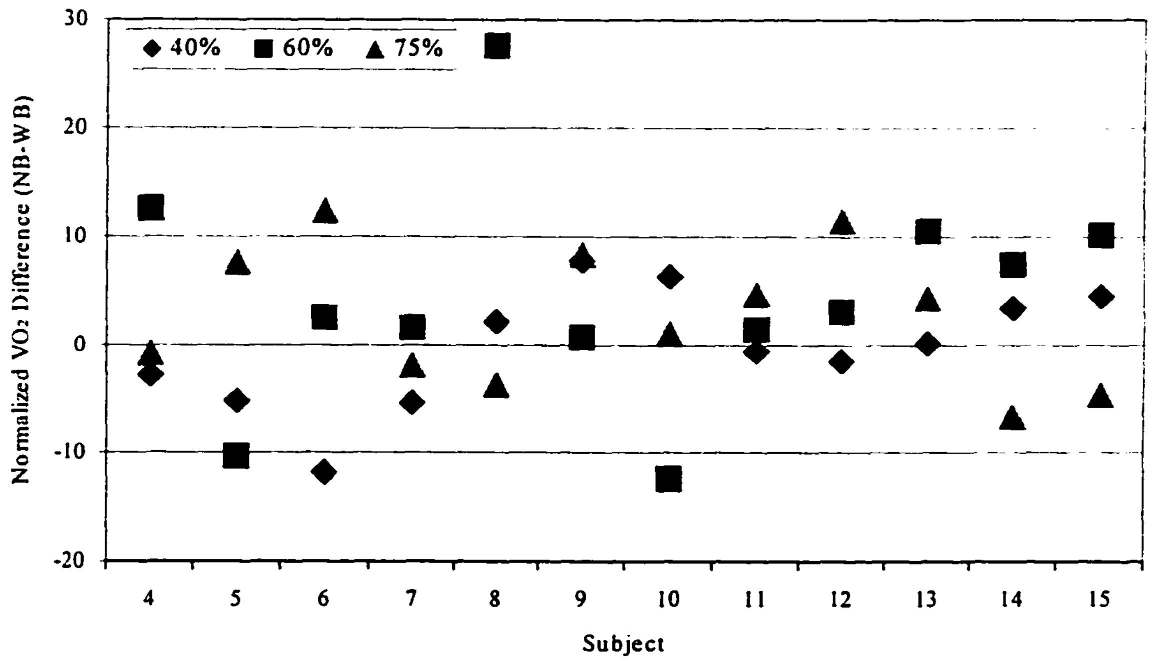

Figure 6.10. Belt by Workload by Subject Interaction for Normalized VO_2 Data.

Examining the response for belt condition at the 40% workload shows that Subjects 4, 5, 6, and 7 had a lower NB response compared to the WB response. The rest of the subjects had either a similar response (Subjects 11, 12, and 13) for both belt conditions or a lower WB response compared to the NB response (Subjects 8, 9, 10, 14, and 15). Similar examination of the response at the 60% workload shows that Subjects 5 and 10 had a lower NB response compared to the WB response, while the rest of the subjects had a lower WB response compared to the NB response. At the 75% workload, Subjects 4, 7, 8, 14, and 15 had a lower NB response than the WB response, while the rest of the subjects had a lower WB response compared to the NB response. The largest positive difference between belt conditions (NB > WB) was observed at different load conditions for different subjects. Subject 10 had the largest positive difference at the 40% workload. Subjects 4, 7, 8, 13, 14, and 15 had the largest positive difference at the 60% workload and the remaining subjects (5, 6, 9, 11, and 12) had the largest difference at the 75% workload.

The magnitude of differences between belt conditions varied with workload levels and also across subjects to a certain extent. However, in spite of these variations, the overall with-belt VO_2 response was statistically lower than the no-belt VO_2 response. The variations discussed in the previous paragraph may be attributed to the variation typically associated with human responses.

The main effect of workload was statistically significant. To determine the relative differences, a multiple comparison procedure was required. As discussed in Section 5.5, multiple comparison procedures are affected by violations of sphericity assumptions. Therefore, comparisons involving averages across the independent variables would be in error. Two-dependent-sample t-tests on cell means or marginal cell means (averaged across one of the independent variables) would be appropriate. However, performing such comparisons on all possible pairings would be a tedious task. Furthermore, differences in VO_2 response due to load were not critical to the study and were expected to be a part of the natural physiological response. A significant Workload × Belt interaction would have required further analyses along these lines. However, the Workload × Belt interaction was not significant. Hence, it may be assumed that the response to load reflected the normal physiological trend with the 75% load evoking the largest response.

ANCOVA tests were also conducted on the VO_2 data. The data set used in this analysis was the same set used in the rest of the analyses. All three covariates (peak test load, static strength, and 1 RM) were included in the statistical model. The results did not uncover any new facts. The F-ratios and p-values remained the same as those associated with the original statistical model.

6.3 Heart Rate

Heart rate (HR) data from the same four subjects under the same conditions were analyzed in a manner similar to that described for oxygen consumption. A subset of the data for Subject 12 is provided in Appendix I. Heart rate responses for Subject 12 are used to illustrate the data reduction procedure. Figure 6.11 shows the raw heart rate data for Subject 12 performing the task without the belt at the 75% workload.

The metabolic cart recorded heart rate data received from the ECG monitor at the same rate as the other cardio-respiratory data. Heart rate signals received within each breath were averaged by the metabolic cart. Therefore, the number of data points within a given time period for heart rate was the same as for the other cardio-respiratory data.

This also meant that there were fewer data points during the initial five-minute rest period compared to the fourth work period (between the 26th and 31st minute). However, this observation is not as easy to make as it was for the oxygen consumption data because the breath-to-breath variability was lower for heart rate.

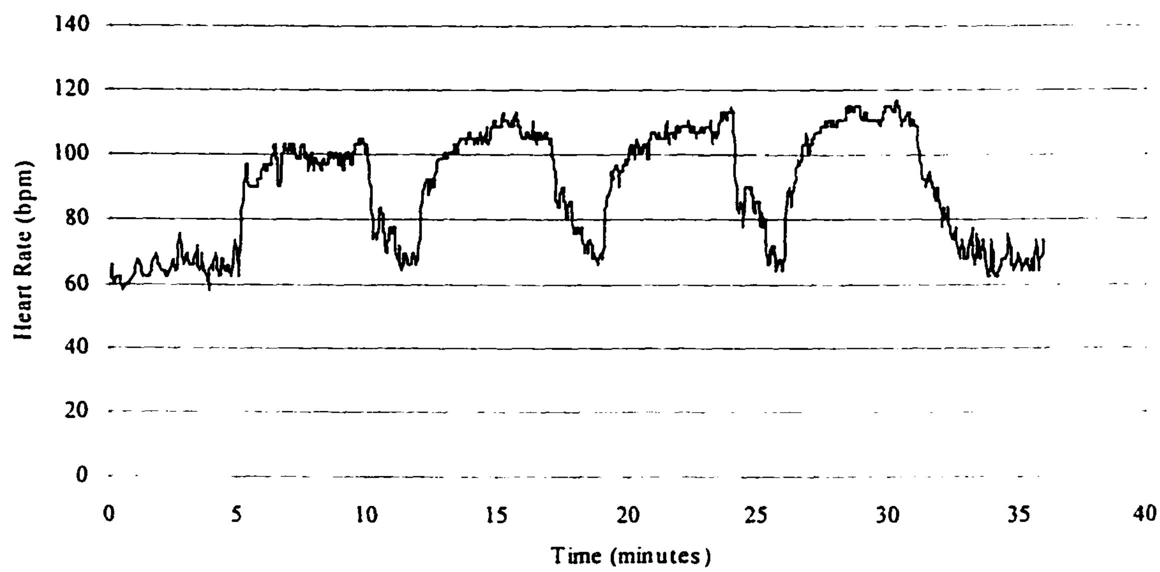

Figure 6.11. Heart Rate Data for Subject 12 at 75% Workload and No-Belt.

Nevertheless, the number of data points needed to be reduced. Data from the last two minutes of each work period were examined, since it was believed that the latter part of the work period would be more representative of the subject's response to the task conditions. There is an inherent relation between the number of data points and the subject's breathing frequency and ultimately his cardio-respiratory fitness, since the data collection rate is equivalent to the respiration rate. Figure 6.12 provides an expanded view of a subset of the data from Figure 6.11 representing the last minute of the fourth work period.

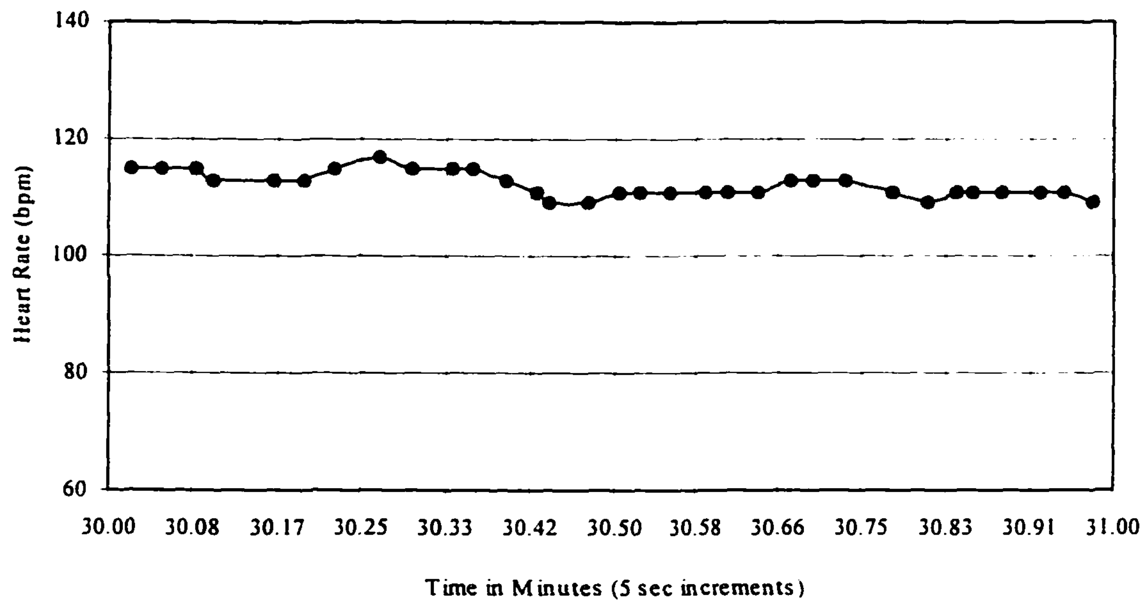

Figure 6.12. Heart Rate Data for Subject 12 in the Last Minute of Work Period 4 at 75% Workload and No-Belt.

The five-second increments on the X-axis in Figure 6.12 correspond to a lift or lower in the task performance cycle. The subject began a lift at time equals 30 minutes and initiated a lower at time equals 30.08 minutes, etc. Examination of Figure 6.12 shows that the heart rate response was essentially stable throughout the last minute. The variations in the oxygen consumption data were not observed here since the heart rate response time was relatively slower once a workload-related rate was achieved. The measurement artifact that confounded the respiratory data did not affect heart rate since respiration rate has a negligible effect on heart rate under the established task conditions. Furthermore, the averaging of heart rate data within each breath also reduced the variation in heart rate measurement. The heart rate was estimated by converting the time between two successive heartbeats to the number of beats per minute. Minor changes in heartbeat intervals would yield a marked change in heart rate, particularly if the data collection rate was high and there was no averaging of signals.

An accurate representation of heart rate response during a work period would be the HR recorded in the latter part of the work period as the subject tries to achieve steady state. However, fitness plays a role in the subject's ability to reach this steady state at higher workloads. Therefore, it was believed that the heart rate recorded in the last minute would be a reasonable representation of the subject's response to the task for that work period. Heart rate values representative of each work period were obtained by averaging the data from the last minute of the corresponding work period. Heart rate data reduced in this manner are presented in Table 6.9.

Figures 6.13 through 6.15 illustrate trends in the heart rate response for each of the three workloads averaged across the four work periods. The relative pattern of WB and NB heart rate response for each subject varied by workload. In addition, a comparison of heart rate across the workloads under the no-belt condition for the same subject did not always show the expected physiological trend. The heart rate for some subjects was higher for a low workload than for a high workload. This variation was due to different resting heart rate levels prior to each session. Hence, it was necessary to normalize the heart rate data.

Table 6.9. Heart Rate Data (beats/min).

Subject 4							Subject 10						
	WP 1	WP 2	WP 3	WP 4	Mean	SD		WP 1	WP 2	WP 3	WP 4	Mean	SD
40 NB	92.5	95.6	93.3	95.3	94.2	1.5	40 NB	100.8	103.3	107.4	110.7	105.6	4.4
40 WB	96.7	93.4	92.3	91.7	93.5	2.2	40 WB	90.2	94.7	99.5	99.9	96.1	4.6
60 NB	100.0	99.8	100.8	101.3	100.5	0.7	60 NB	107.7	112.5	114.8	116.3	112.8	3.8
60 WB	86.8	93.8	97.0	100.3	94.4	5.7	60 WB	105.4	111.7	117.9	119.4	113.6	6.4
75 NB	121.8	129.4	130.8	133.7	128.9	5.1	75 NB	110.1	122.5	132.3	136.7	125.4	11.8
75 WB	109.0	111.3	114.4	117.2	113.0	3.6	75 WB	106.9	112.0	121.8	123.1	116.0	7.8
Subject 5							**Subject 11**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	85.7	85.2	90.0	86.7	86.9	2.2	40 NB	94.4	101.3	99.3	98.6	98.4	2.9
40 WB	95.0	96.3	94.7	95.4	95.3	0.7	40 WB	121.4	131.3	131.0	132.3	129.0	5.1
60 NB	87.7	95.7	98.4	97.4	94.8	4.9	60 NB	124.6	131.3	131.0	133.9	130.2	3.9
60 WB	95.8	103.5	101.3	106.6	101.8	4.6	60 WB	111.2	118.1	121.1	122.8	118.3	5.1
75 NB	118.4	129.1	132.8	134.3	128.6	7.2	75 NB	148.6	158.6	158.3	167.1	158.2	7.6
75 WB	101.5	110.9	114.2	108.5	108.8	5.4	75 WB	129.6	145.3	150.2	153.6	144.6	10.6
Subject 6							**Subject 12**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	102.9	104.8	106.1	103.6	104.3	1.4	40 NB	90.0	92.9	90.7	88.4	90.5	1.8
40 WB	99.2	104.1	110.9	118.8	108.3	8.5	40 WB	89.0	91.3	90.2	91.2	90.4	1.1
60 NB	114.2	119.9	125.2	127.0	121.5	5.8	60 NB	100.2	103.1	99.6	100.1	100.7	1.6
60 WB	103.1	103.0	104.8	108.3	104.8	2.5	60 WB	93.7	93.3	93.6	96.0	94.2	1.2
75 NB	113.3	129.5	129.0	136.3	127.0	9.8	75 NB	101.3	105.8	109.9	112.3	107.3	4.8
75 WB	112.2	114.7	120.3	125.4	118.2	5.9	75 WB	98.8	102.4	105.7	107.6	103.6	3.9
Subject 7							**Subject 13**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	91.2	98.4	99.3	101.6	97.6	4.5	40 NB	108.0	109.4	108.1	107.8	108.3	0.7
40 WB	91.8	93.0	95.9	98.6	94.8	3.0	40 WB	113.1	114.9	117.9	118.3	116.0	2.5
60 NB	89.2	93.9	98.5	102.9	96.1	5.9	60 NB	134.1	132.3	141.7	138.8	136.7	4.3
60 WB	95.0	98.4	99.5	100.2	98.3	2.3	60 WB	108.6	107.1	111.3	113.7	110.2	2.9
75 NB	104.5	104.8	106.4	107.1	105.7	1.3	75 NB	147.5	171.2	173.1	172.1	166.0	12.4
75 WB	101.4	103.5	106.5	108.1	104.9	3.0	75 WB	159.7	169.0	170.9	172.5	168.0	5.7
Subject 8							**Subject 14**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	109.1	109.5	117.1	114.0	112.4	3.8	40 NB	99.1	98.4	97.8	103.4	99.7	2.5
40 WB	118.0	116.0	116.3	112.5	115.7	2.3	40 WB	97.3	100.0	102.6	101.8	100.4	2.4
60 NB	131.4	138.5	139.3	144.4	138.4	5.3	60 NB	127.3	134.2	136.4	137.6	133.9	4.6
60 WB	128.0	129.2	126.7	129.1	128.3	1.2	60 WB	117.2	124.4	121.0	120.5	120.8	3.0
75 NB	136.8	144.3	148.1	152.6	145.5	6.7	75 NB	119.5	121.5	125.8	128.1	123.7	3.9
75 WB	148.0	156.4	160.0	164.5	157.2	7.0	75 WB	145.6	160.2	162.7	159.3	156.9	7.7
Subject 9							**Subject 15**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	93.0	91.2	96.1	96.0	94.1	2.4	40 NB	114.8	117.1	117.4	117.4	116.7	1.3
40 WB	93.7	98.9	101.0	105.0	99.7	4.7	40 WB	95.2	91.2	93.9	93.6	93.5	1.7
60 NB	103.7	105.3	109.2	112.6	107.7	4.0	60 NB	128.6	135.7	135.7	137.8	134.4	4.0
60 WB	98.3	102.0	106.6	109.4	104.1	4.9	60 WB	120.0	127.5	125.7	127.3	125.1	3.5
75 NB	107.9	114.1	116.4	121.5	115.0	5.6	75 NB	135.8	138.4	140.2	143.5	139.5	3.2
75 WB	107.8	116.6	124.3	127.2	119.0	8.7	75 WB	131.1	142.8	151.3	158.0	145.8	11.6
Mean (all subjects)							**Grand Mean**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	98.5	100.6	101.9	101.9	100.7	9.0	Ave NB	110.9	116.1	118.2	119.9	116.3	19.9
40 WB	100.1	102.1	103.9	104.9	102.7	12.0	SD NB	17.1	19.9	20.3	21.5		
60 NB	112.4	116.8	119.2	120.8	117.3	16.9	Ave WB	108.8	113.4	115.9	117.7	113.9	20.1
60 WB	105.3	109.3	110.6	112.8	109.5	11.9	SD WB	17.5	20.3	20.9	21.2		
75 NB	122.1	130.8	133.6	137.1	130.9	19.1							
75 WB	121.0	128.8	133.5	135.4	129.7	23.3							

Legend: WP: work period, NB: no-belt, WB: with-belt, Ave: mean, SD: standard deviation

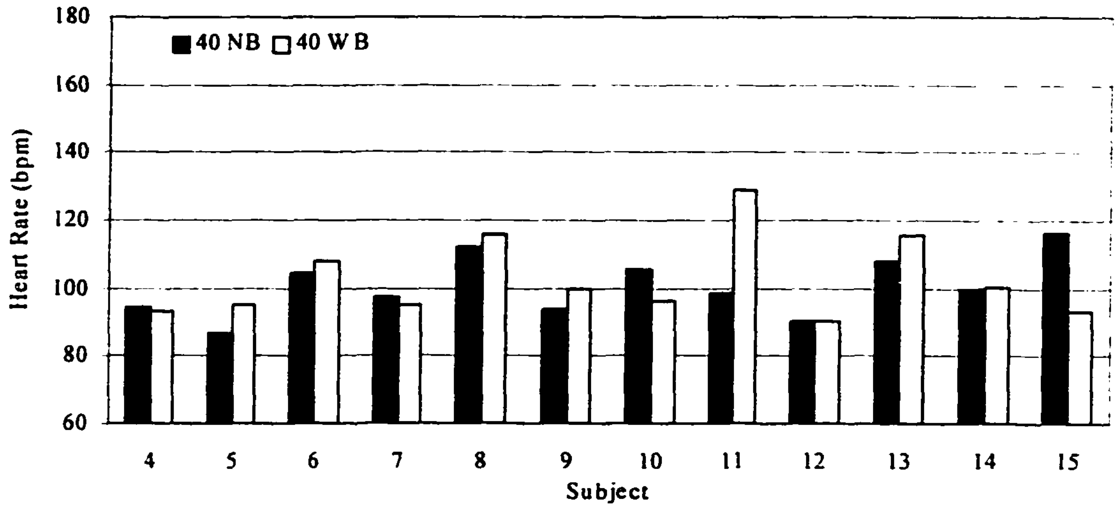

Figure 6.13. Heart Rate Response for 40% Workload.

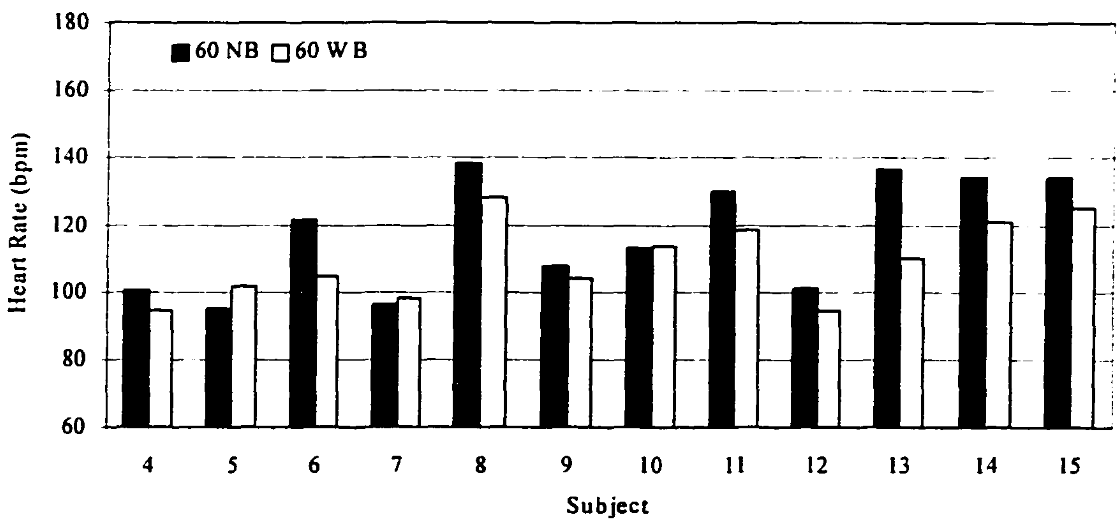

Figure 6.14. Heart Rate Response for 60% Workload.

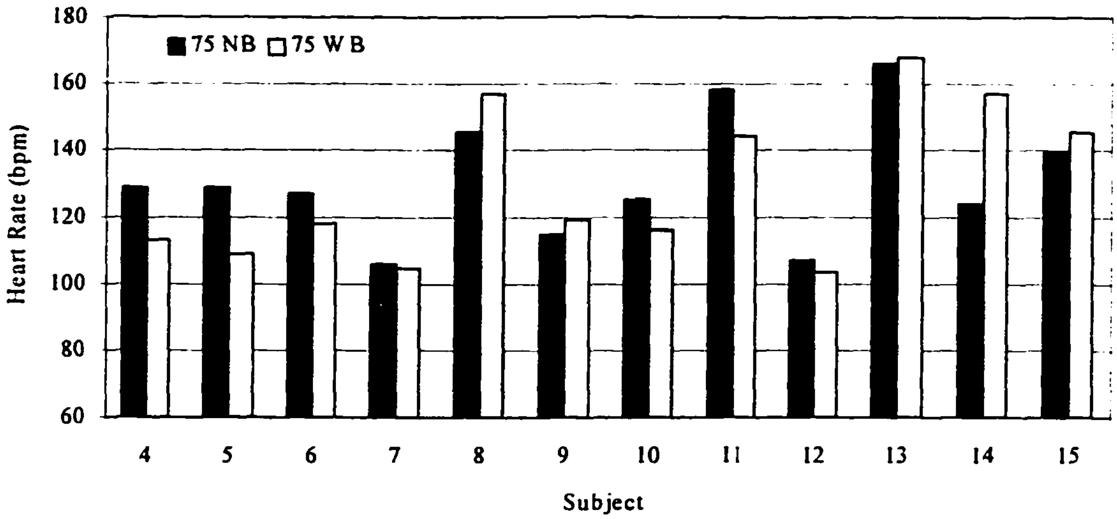

Figure 6.15. Heart Rate Response for 75% Workload.

Resting data were collected at the beginning of each session. Heart rate data were transformed to work pulse data by subtracting the resting heart rate for the session from the heart rate during the task. To facilitate comparison across subjects, work pulse was further normalized as a percentage of the subject's peak test heart rate. Peak test heart rate was more reliable than the resting HR since the subject would essentially achieve the same peak heart rate irrespective of his resting heart rate. Therefore, work pulse data were converted to a percentage of the peak test heart rate. Work pulse data normalized in this manner are presented in Table 6.10.

Table 6.10. Work Pulse Data as a Percentage of Individual Peak Heart Rate.

Subject 4	**WP 1**	**WP 2**	**WP 3**	**WP 4**	**Mean**	**SD**
40 NB	16.9	18.7	17.3	18.5	17.8	0.9
40 WB	11.2	9.3	8.7	8.3	9.4	1.3
60 NB	16.1	16.0	16.5	16.8	16.4	0.4
60 WB	13.6	17.6	19.4	21.3	18.0	3.3
75 NB	25.5	29.8	30.6	32.3	29.5	2.9
75 WB	21.2	22.5	24.3	25.9	23.5	2.0

Subject 5	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	9.0	8.6	12.0	9.7	9.8	1.5
40 WB	9.2	10.1	9.0	9.5	9.5	0.5
60 NB	15.7	21.2	23.0	22.3	20.6	3.3
60 WB	15.9	21.2	19.7	23.3	20.0	3.1
75 NB	25.2	32.6	35.1	36.1	32.3	4.9
75 WB	25.2	31.6	33.8	30.0	30.1	3.7

Subject 6	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	9.7	10.9	11.8	10.2	10.7	0.9
40 WB	12.8	16.1	20.7	26.0	18.9	5.7
60 NB	19.8	23.6	27.1	28.3	24.7	3.9
60 WB	9.8	9.8	11.0	13.3	11.0	1.6
75 NB	22.3	33.2	32.8	37.8	31.5	6.6
75 WB	18.4	20.1	23.9	27.3	22.4	4.0

Subject 7	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	9.1	14.1	14.7	16.2	13.6	3.1
40 WB	8.7	9.5	11.5	13.3	10.8	2.1
60 NB	10.3	13.4	16.6	19.6	15.0	4.0
60 WB	11.8	14.1	14.8	15.3	14.0	1.6
75 NB	17.4	17.6	18.7	19.1	18.2	0.9
75 WB	18.6	20.0	22.1	23.2	21.0	2.1

Subject 8	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	4.9	5.1	8.9	7.4	6.6	1.9
40 WB	13.4	12.4	12.5	10.6	12.2	1.2
60 NB	18.5	22.0	22.5	25.0	22.0	2.7
60 WB	14.4	15.0	13.7	14.9	14.5	0.6
75 NB	22.8	26.5	28.4	30.7	27.1	3.3
75 WB	26.8	31.0	32.8	35.0	31.4	3.5

Subject 9	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	11.3	10.2	13.1	13.1	11.9	1.4
40 WB	8.4	11.5	12.8	15.2	12.0	2.9
60 NB	15.4	16.4	18.7	20.8	17.8	2.4
60 WB	14.5	16.8	19.5	21.2	18.0	3.0
75 NB	17.0	20.8	22.1	25.2	21.3	3.4
75 WB	17.9	23.2	27.9	29.7	24.7	5.3

Mean (all subjects)	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	10.7	12.0	12.8	12.8	12.1	5.2
40 WB	12.2	13.5	14.6	15.3	13.9	6.2
60 NB	19.9	22.7	24.1	25.1	22.9	7.0
60 WB	14.8	17.4	18.1	19.5	17.4	6.9
75 NB	25.4	30.5	32.2	34.4	30.6	8.6
75 WB	24.9	29.6	32.5	33.6	30.1	9.9

Subject 10	**WP 1**	**WP 2**	**WP 3**	**WP 4**	**Mean**	**SD**
40 NB	10.0	11.5	13.7	15.6	12.7	2.5
40 WB	10.9	13.4	16.1	16.3	14.2	2.6
60 NB	14.1	16.8	18.1	19.0	17.0	2.1
60 WB	12.6	16.2	19.6	20.4	17.2	3.6
75 NB	22.1	29.0	34.5	37.0	30.6	6.6
75 WB	13.7	16.6	22.0	22.8	18.8	4.4

Subject 11	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	18.6	23.4	22.0	21.5	21.3	2.0
40 WB	22.3	29.2	29.0	29.9	27.6	3.5
60 NB	36.5	41.1	40.9	42.9	40.3	2.7
60 WB	30.2	35.0	37.1	38.3	35.1	3.6
75 NB	41.2	48.2	47.9	54.0	47.8	5.3
75 WB	39.9	50.8	54.2	56.6	50.4	7.3

Subject 12	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	12.5	14.5	13.0	11.5	12.9	1.2
40 WB	16.2	17.7	17.0	17.7	17.1	0.7
60 NB	25.0	27.0	24.5	24.9	25.3	1.1
60 WB	15.1	14.8	15.0	16.6	15.4	0.8
75 NB	24.5	27.6	30.3	31.9	28.6	3.3
75 WB	24.0	26.5	28.7	30.0	27.3	2.6

Subject 13	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	17.0	17.7	17.1	16.9	17.2	0.4
40 WB	15.4	16.2	17.8	18.0	16.8	1.3
60 NB	22.8	21.9	26.6	25.2	24.1	2.2
60 WB	17.3	16.6	18.7	19.9	18.1	1.5
75 NB	32.7	44.7	45.7	45.2	42.1	6.2
75 WB	35.8	40.4	41.4	42.2	39.9	2.9

Subject 14	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	7.5	7.1	6.7	10.2	7.9	1.5
40 WB	12.7	14.4	15.9	15.5	14.6	1.4
60 NB	23.0	27.2	28.6	29.3	27.0	2.8
60 WB	18.6	23.0	20.9	20.6	20.8	1.8
75 NB	26.3	27.5	30.1	31.5	28.8	2.4
75 WB	34.2	43.1	44.6	42.5	41.1	4.7

Subject 15	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	1.4	2.7	2.9	2.9	2.5	0.7
40 WB	4.7	2.4	4.0	3.8	3.7	1.0
60 NB	21.4	25.4	25.4	26.6	24.7	2.3
60 WB	4.3	8.6	7.6	8.5	7.2	2.0
75 NB	27.7	29.1	30.2	32.0	29.7	1.8
75 WB	22.8	29.4	34.2	38.0	31.1	6.6

Grand Mean	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
Ave NB	18.64	21.75	23.00	24.09	21.87	10.37
SD NB	8.59	10.53	10.45	11.34		
Ave WB	17.29	20.17	21.72	22.80	20.49	10.46
SD WB	8.32	10.51	11.08	11.26		

Legend: WP: work period, NB: no-belt, WB: with-belt, Ave: mean, SD: standard deviation

Figures 6.16 through 6.18 present the normalized work pulse data at different workloads averaged across all work periods.

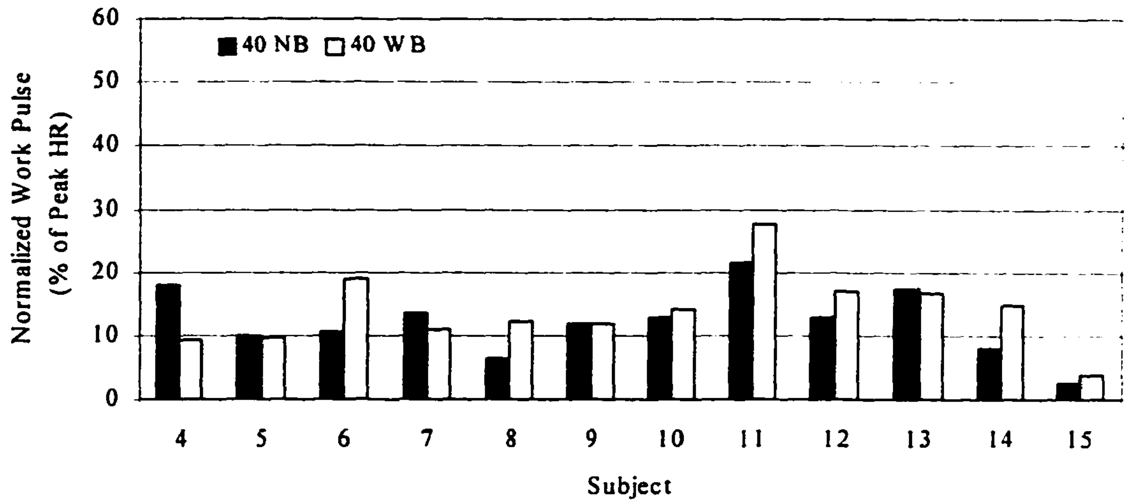

Figure 6.16. Normalized Work Pulse Response to 40% Workload.

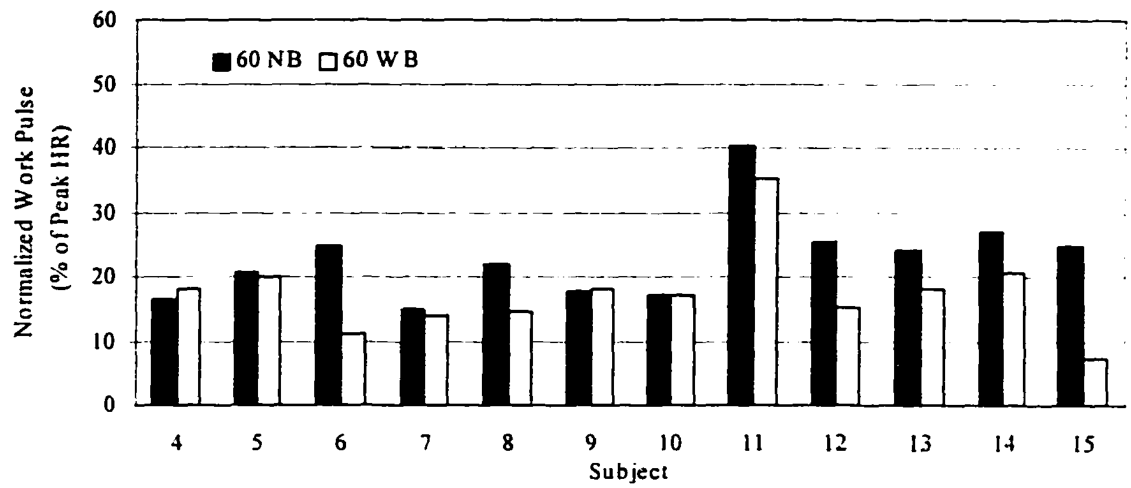

Figure 6.17. Normalized Work Pulse Response to 60% Workload.

Normalized work pulse data show that the WB and NB trend changes with workload and across subjects. This leads to the hypothesis that certain unaccounted factors may be confounding the heart rate response. These factors could include subject-based, instrument-based, or measurement-based sources. Statistical conclusions about heart rate were provided by ANOVA. Table 6.11 provides a summary of the ANOVA results.

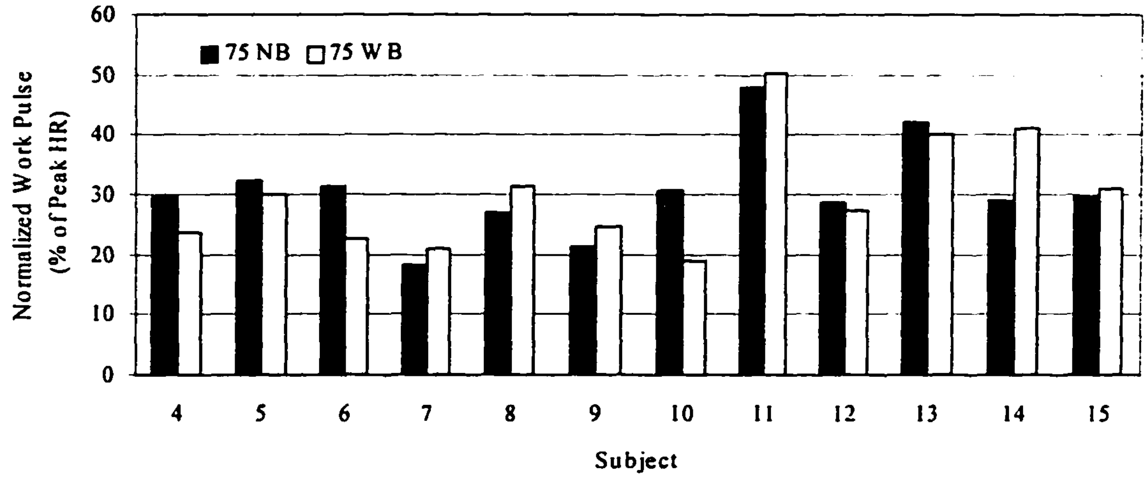

Figure 6.18. Normalized Work Pulse Response to 75% Workload.

Table 6.11. ANOVA Summary for Normalized Work Pulse Data.

Source	DF	Mean Square	F Value	Pr > F
Belt (B)	1	136.40	2.73	0.1266
Workload (L)	2	7342.42	68.90	0.0001
Work Period (P)	3	405.44	63.55	0.0001
Subject (S)	11	813.81	-	-
B × L	2	333.58	4.41	0.0245
B × P	3	0.36	0.12	0.9465
B × S	11	49.93	-	-
L × P	6	44.71	18.51	0.0001
L × S	22	106.56	-	-
P × S	33	6.38	-	-
B × L × P	6	1.94	0.63	0.7052
B × L × S	22	75.61	-	-
B × P × S	33	2.96	-	-
L × P × S	66	2.41	-	-
B × L × P × S	66	3.08		

Legend: DF: degrees of freedom

At a 0.05 level of significance, the two belt conditions did not differ significantly. Workload and work period were significant factors. Response variable differences due to load and work period were due to normal physiological processes. The two-way interactions Workload × Belt and Workload × Work Period were also significant. These interactions modify the interpretation of the HR differences due to the main factors. The variation in the HR response due to different loads and belt conditions can be visualized in Figures 6.16 through 6.18. These figures represent data averaged across work periods.

A better representation of this interaction requires averaging across subjects and work periods (Figure 6.19). Figure 6.19 shows that the belt response varied with the workload levels. Work pulse was lower for the WB condition compared to the NB condition at the 60% workload level, while the effect was reversed (to a lesser extent) for the 40% workload level. At the 75% workload level, the responses for WB and NB were similar. These varying effects explain the statistically significant interaction between belt and workload.

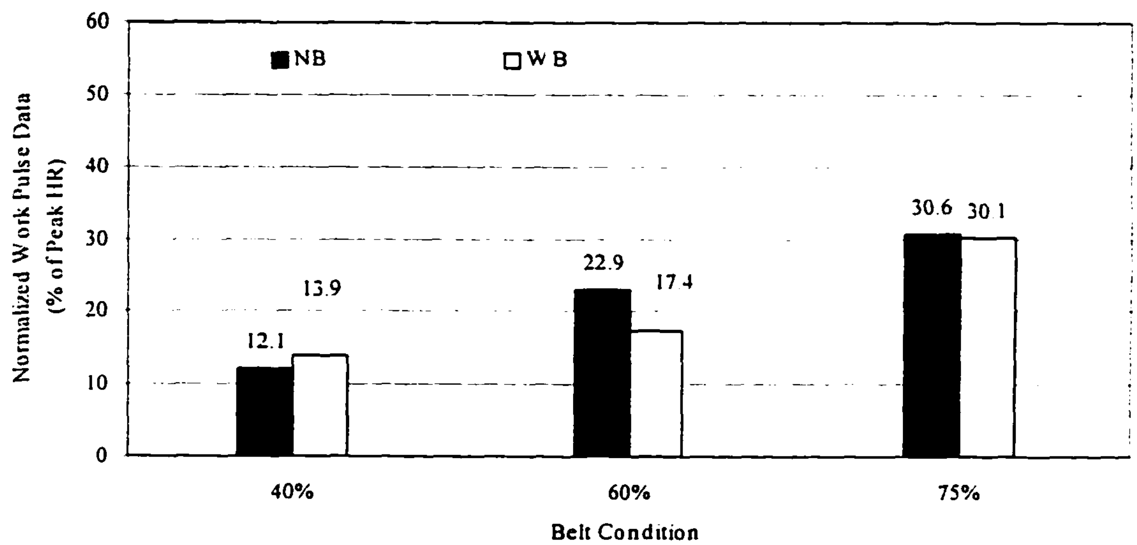

Figure 6.19. Belt by Workload Interaction in Normalized Work Pulse Data.

Figure 6.20 shows the interaction between workload and work period averaged across all subjects. Visual inspection reveals that the interaction essentially stems from the 75% workload as explained below.

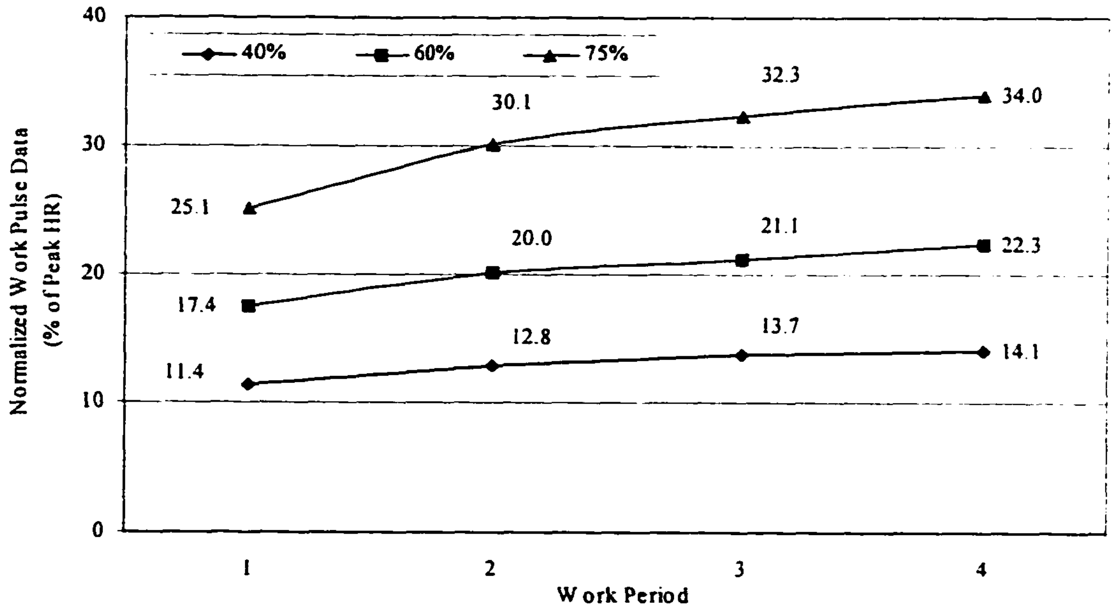

Figure 6.20. Workload by Work Period Interaction in Work Pulse Data.

Examination of Figure 6.20 reveals that the interaction stems from the change in work pulse response from Work Period 1 to Work Period 2 compared to the other chronological pairwise comparisons. The difference in work pulse between different workload levels is clearly seen. The incremental change between work periods is similar for workloads of 40% and 60% compared to the 75% workload. Work pulse differences between work periods were higher at the 75% workload.

A significant Belt × Workload interaction led to a separate analysis of variance on the work pulse data at each workload level. These tests revealed that at the 40% and 75% workload levels, the belt effect was not significant [$F(1,11) = 1.80$, $p = 0.2067$ and $F(1,11) = 0.07$, $p = 0.7973$, respectively]. Work period was significant at both of these workloads [$F(3,33) = 9.40$, $p = 0.0001$ and $F(3,33) = 69.94$, $p = 0.0001$ respectively]. At the 60% workload level, the belt effect was significant [$F(1,11) = 9.96$, $p = 0.0091$]. The WB condition resulted in a lower work pulse response than the NB condition. The Belt ×

Work Period interaction was not significant for all workload levels. These tests help infer that the belt effect was not significant in the full work pulse data set due to the similarity of the NB and WB responses at the 40% and 75% workloads. This also reflects the basis for the significant Belt × Workload interaction.

Observations from Figure 6.20 on the Workload × Work Period interaction could be verified statistically in a similar manner. However, such analyses would involve averaging across the belt conditions. Since belt condition was the main factor of interest, such analyses were omitted. Furthermore, the source of interaction was clearly visible from the interaction plots. The three-way interaction between workload, belt and work period was investigated, although the F-test was not available. Furthermore, a particular response pattern was detected for the oxygen consumption data by plotting the Belt × Workload × Subject interaction. Figure 6.21 presents HR data obtained by averaging across all work periods and then subtracting the WB response from the NB response.

Data plotted in Figure 6.21 show that the majority of NB-WB differences representative of the 60% workload were positive while the opposite was true for the 40% workload data. Furthermore, there seemed to be an equal number of positive and negative differences at the 75% workload. This implied that the belt condition effect differed based on workload. This observation was also reflected in the significant Belt × Workload interaction. The ANOVA conducted on the 40% workload data failed to demonstrate a significant belt effect. The data in Figure 6.21 show that Subject 4 had the highest positive (NB-WB) work pulse difference at the 40% workload. Discarding this subject and performing an ANOVA on the data for the remaining 11 subjects for the 40% workload revealed a significant belt effect [$F(1,10) = 6.49$, $p = 0.0290$]. The WB condition resulted in a higher work pulse response compared to the NB condition at the 40% workload.

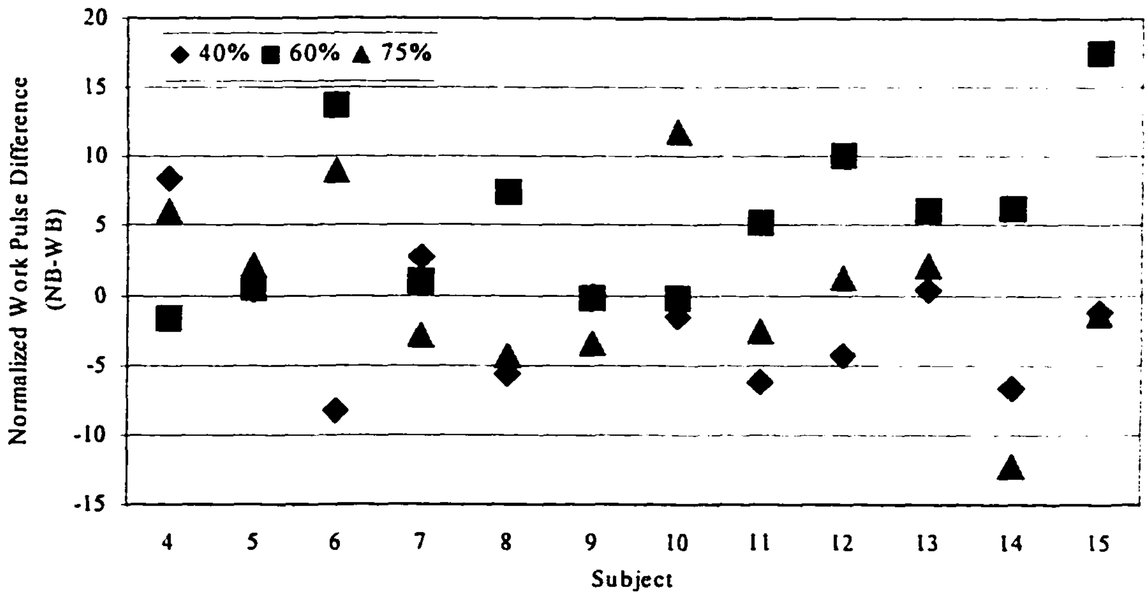

Figure 6.21. Belt by Workload by Subject Interaction for Normalized Work Pulse Data.

The detrimental effect of the belt observed at the 40% workload was reversed for the 60% workload where the heart rate response was lower for the WB condition. At the 75% workload, it may be hypothesized that subject characteristics were responsible for some subjects showing a higher response with the belt while other subjects showed a lower response with the belt. To examine this hypothesis, analysis of covariance (ANCOVA) was performed on the work pulse data for the 75% workload. Covariates considered in this analysis were absolute weight lifted in the peak test, static strength and the dynamic one-repeat maximum. None of the analyses resulted in a significant belt effect. Therefore, there may exist other subject characteristics that may be driving the individual differences at the 75% workload. Visual examination of Figure 6.21 suggests that at 75% there is an equal probability for the work pulse response to be higher at either of the belt conditions.

To ensure that the covariates did not affect the significance of the results at other workload levels, a covariate analysis was performed on the full data set while including the three covariates. The results remained the same with no effect on the 40% and 60% workloads.

Work pulse data suggested that belt use might result in a lower HR response at or within a specific workload range (around 60%), while it may have an opposite or no effect at other lower or higher workload levels.

6.4 Respiration Rate

The following figures illustrate the development of the data reduction procedure for the respiration rate (RR) data. Figure 6.22 presents the respiration rate data for Subject 12 performing the task without the belt at the 75% workload.

Respiration rate data were estimated by the metabolic cart based on the time intervals between successive breaths. This estimation was similar to heart rate estimation wherein the time interval between heartbeats was converted to beats per minute. The number of data points equaled the number of breaths since the metabolic cart recorded data at each breath. The wide variation in values reflected in Figure 6.22 was related to the task (probable breath holding while lifting or lowering) and limitations of the measurement system as discussed in the previous sections. This may be further examined by plotting data from the last minute of the fourth work period (Figure 6.23).

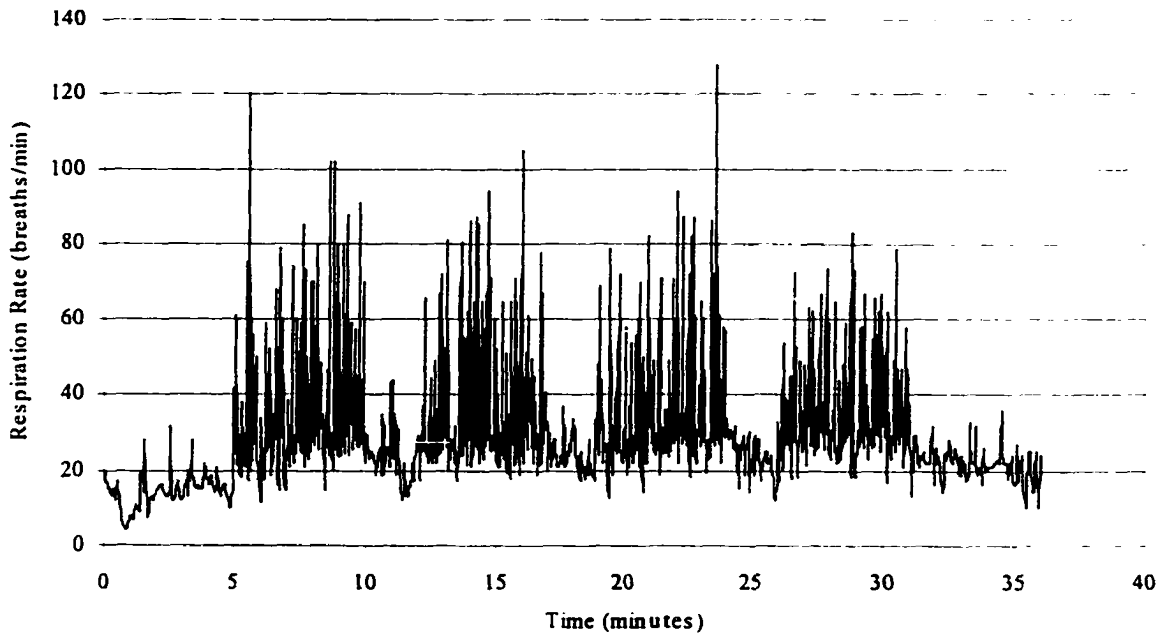

Figure 6.22. Respiration Rate Data for Subject 12 at 75% Workload and No-Belt.

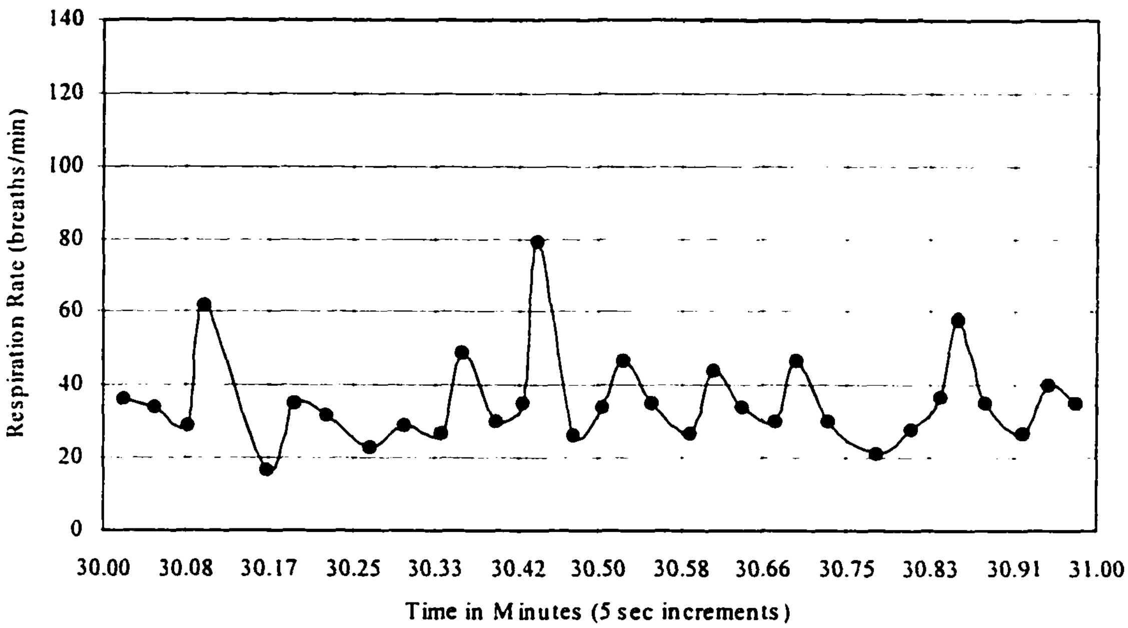

Figure 6.23. Respiration Rate Data for Subject 12 in the Last Minute of Work Period 4 at 75% Workload and No-Belt.

A high respiration rate represents a shorter breath-to-breath interval, perhaps due to a shorter duration of breath holding or rapid breaths prior to breath holding. If the lifting/lowering activity coincides with inspiration, then the subject may tend to hold the breath longer. The breathing pattern was also subject dependent, since not all subjects tended to hold their breath while lifting/lowering. If the breathing pattern was not synchronized with the lifting/lowering pattern, the breath time varied depending on its location in the lifting/lowering cycle. In Figure 6.23, the five-second increments on the X-axis correspond to the task performance cycle. The subject either lifted or lowered the box every five seconds. The subject began the lift at time equals 30 minutes and initiated a lower at time equals 30.08 minutes, etc.

The breathing pattern achieved during the last minute of a work period would be a better representation of the workload since the subject would have sufficient time to achieve a stable breathing pattern. Also, due to the nature of the response variable and the inherent entanglement with the task, it was believed that an average of more data points would be preferable. Respiration rate data were reduced by representing each work period by the average of the data recorded in the last minute for that work period. Table 6.12 presents respiration rate data obtained in this manner.

Figures 6.24 through 6.26 present the respiration rate data for the three different workloads. The data shown in these figures have been averaged across the four work periods.

Table 6.12. Respiration Rate Data (breaths/min).

	WP 1	WP 2	WP 3	WP 4	Mean	SD
Subject 4						
40 NB	21.4	19.7	17.1	25.0	20.8	3.3
40 WB	23.1	23.2	26.4	26.1	24.7	1.8
60 NB	28.8	25.4	28.2	29.3	27.9	1.7
60 WB	24.7	22.2	24.5	25.5	24.2	1.4
75 NB	28.2	28.7	30.6	30.1	29.4	1.1
75 WB	30.9	29.2	30.8	28.5	29.9	1.2
Subject 5						
40 NB	20.9	27.0	25.8	27.2	25.2	3.0
40 WB	24.6	20.9	30.8	23.6	25.0	4.2
60 NB	27.6	28.1	30.5	30.2	29.1	1.5
60 WB	28.0	25.9	29.6	30.6	28.5	2.0
75 NB	34.5	33.7	29.6	33.9	32.9	2.2
75 WB	27.6	30.3	31.6	27.6	29.3	2.0
Subject 6						
40 NB	19.5	19.1	17.1	14.1	17.4	2.5
40 WB	24.0	23.2	25.2	28.9	25.3	2.5
60 NB	23.3	24.3	25.1	25.0	24.4	0.8
60 WB	23.7	24.3	25.7	26.5	25.0	1.3
75 NB	26.7	27.8	29.7	29.4	28.4	1.4
75 WB	27.9	25.2	25.8	25.4	26.1	1.2
Subject 7						
40 NB	20.1	15.2	19.0	19.4	18.4	2.2
40 WB	19.2	19.5	18.6	16.7	18.5	1.2
60 NB	20.1	21.8	20.8	21.2	20.9	0.7
60 WB	23.2	20.8	23.0	25.0	23.0	1.7
75 NB	24.5	24.9	25.8	26.7	25.5	1.0
75 WB	23.8	24.4	25.0	24.3	24.4	0.5
Subject 8						
40 NB	23.2	23.3	23.2	22.8	23.1	0.2
40 WB	24.2	23.5	23.4	24.9	24.0	0.7
60 NB	24.1	25.7	25.2	28.5	25.9	1.9
60 WB	21.8	22.8	23.3	23.2	22.8	0.7
75 NB	26.2	27.3	27.8	28.1	27.4	0.8
75 WB	25.2	24.9	27.5	25.9	25.9	1.2
Subject 9						
40 NB	22.9	20.2	20.4	24.6	22.0	2.1
40 WB	23.0	21.2	23.9	23.1	22.8	1.1
60 NB	22.6	21.6	24.1	24.0	23.1	1.2
60 WB	22.6	29.5	25.5	27.2	26.2	2.9
75 NB	26.8	24.7	29.3	28.7	27.4	2.1
75 WB	22.9	25.4	25.1	27.7	25.3	2.0
Mean (all subjects)						
40 NB	21.9	22.8	23.0	23.9	22.9	4.8
40 WB	24.0	23.0	25.0	24.4	24.1	3.7
60 NB	26.2	26.4	28.0	27.9	27.1	4.7
60 WB	25.4	26.1	26.5	27.3	26.3	4.2
75 NB	29.5	30.4	31.6	30.2	30.4	5.9
75 WB	27.8	29.3	29.1	28.9	28.8	6.0

	WP 1	WP 2	WP 3	WP 4	Mean	SD
Subject 10						
40 NB	18.9	23.9	23.0	25.8	22.9	2.9
40 WB	24.0	26.7	25.9	23.6	25.1	1.5
60 NB	24.8	24.9	23.5	25.7	24.7	0.9
60 WB	25.4	24.9	28.6	27.8	26.7	1.8
75 NB	24.4	24.9	28.7	25.9	26.0	1.9
75 WB	24.9	25.8	23.7	25.1	24.9	0.9
Subject 11						
40 NB	23.7	24.4	24.0	25.1	24.3	0.6
40 WB	24.4	20.9	25.6	23.7	23.7	2.0
60 NB	24.9	23.0	26.5	25.0	24.8	1.4
60 WB	25.5	25.9	26.0	28.2	26.4	1.2
75 NB	25.8	29.8	28.1	25.8	27.4	1.9
75 WB	22.4	25.1	28.2	25.1	25.2	2.4
Subject 12						
40 NB	26.8	31.4	36.2	28.3	30.7	4.2
40 WB	25.4	25.1	25.4	27.8	25.9	1.3
60 NB	34.1	32.9	37.4	34.7	34.8	1.9
60 WB	37.0	36.4	34.4	33.1	35.2	1.8
75 NB	40.9	38.7	40.2	36.0	38.9	2.2
75 WB	38.3	42.2	38.1	38.4	39.2	2.0
Subject 13						
40 NB	28.7	27.4	34.6	33.3	31.0	3.5
40 WB	32.6	29.1	34.2	31.2	31.8	2.2
60 NB	34.2	35.1	39.2	37.0	36.3	2.2
60 WB	29.5	33.9	32.2	34.2	32.5	2.2
75 NB	42.9	48.6	46.2	41.1	44.7	3.3
75 WB	42.1	45.3	37.6	44.3	42.3	3.4
Subject 14						
40 NB	18.8	20.3	18.4	22.0	19.9	1.6
40 WB	19.6	20.5	20.5	18.4	19.7	1.0
60 NB	24.8	25.2	30.3	31.4	27.9	3.4
60 WB	21.4	22.2	21.6	20.5	21.4	0.7
75 NB	27.5	28.2	29.5	30.1	28.8	1.2
75 WB	24.2	28.8	29.9	29.3	28.0	2.6
Subject 15						
40 NB	17.8	21.5	16.9	19.4	18.9	2.0
40 WB	23.8	22.1	19.7	24.4	22.5	2.1
60 NB	25.4	28.2	25.8	22.5	25.5	2.3
60 WB	22.6	24.3	24.0	26.0	24.2	1.4
75 NB	25.2	27.4	33.6	26.6	28.2	3.7
75 WB	23.5	25.5	25.4	24.9	24.8	0.9
Grand Mean						
Ave NB	25.9	26.5	27.5	27.3	26.8	5.9
SD NB	5.7	6.1	6.8	5.3		
Ave WB	25.7	26.1	26.8	26.8	26.4	5.1
SD WB	4.9	5.7	4.6	5.0		

Legend: WP: work period, NB: no-belt, WB: with-belt, Ave: mean, SD: standard deviation

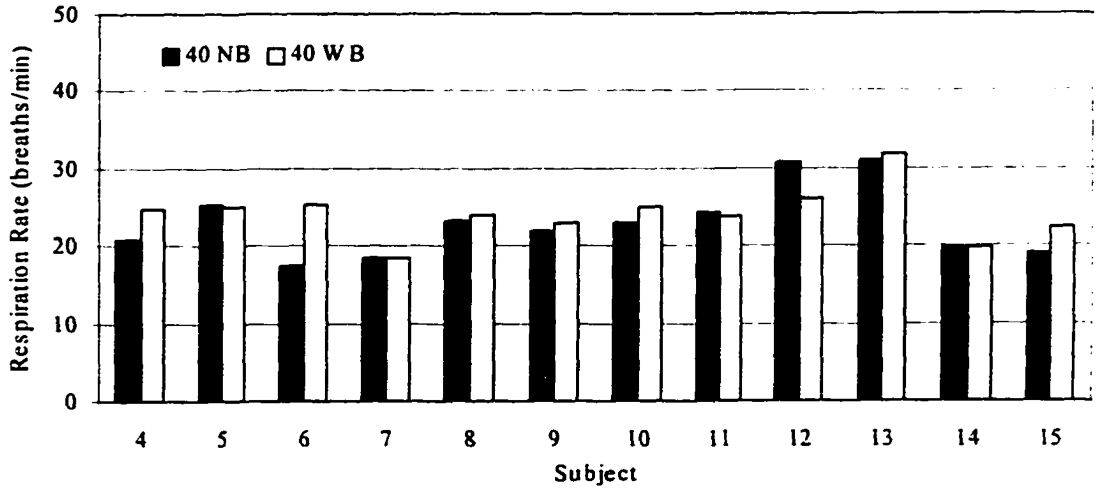

Figure 6.24. Respiration Rate Response to 40% Workload.

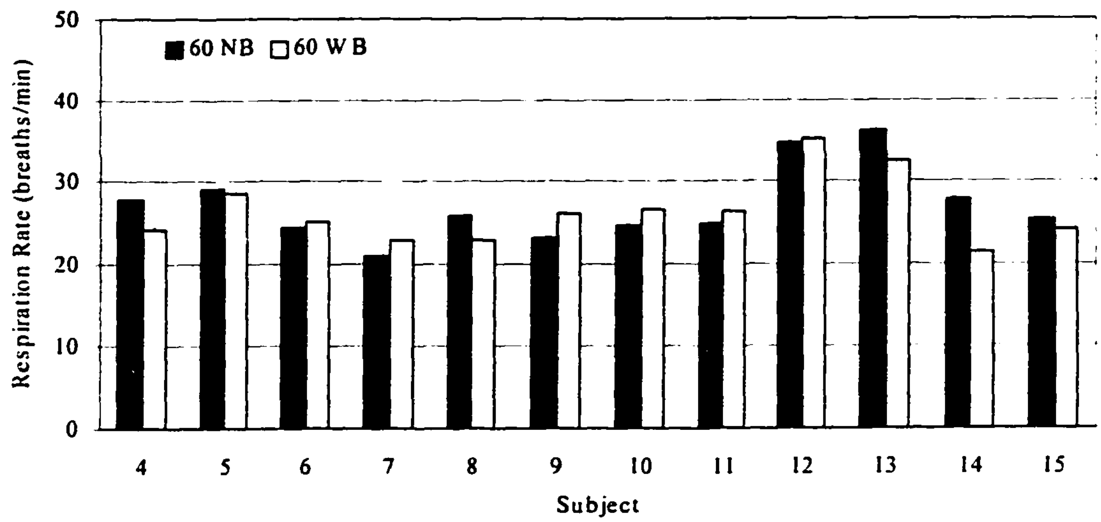

Figure 6.25. Respiration Rate Response to 60% Workload.

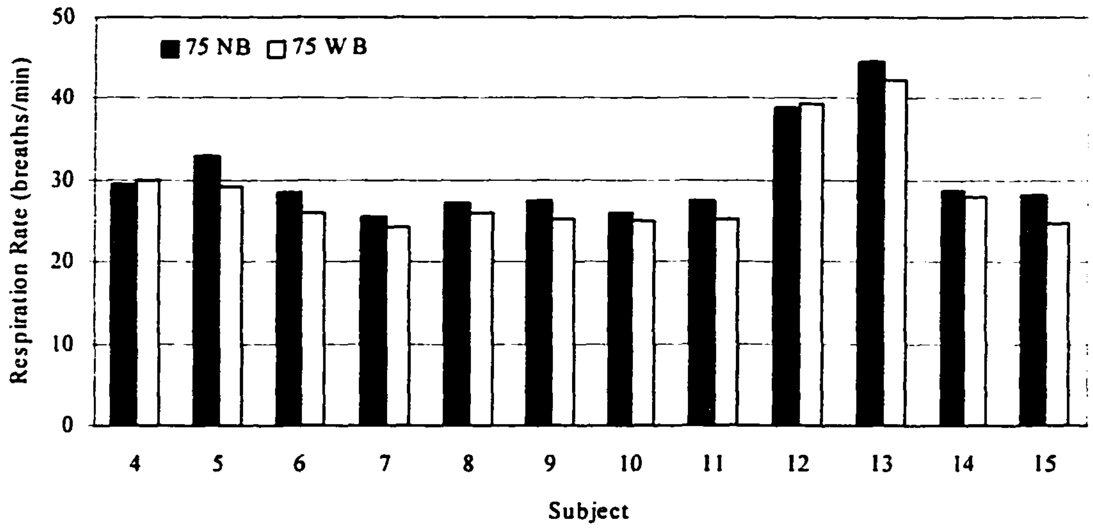

Figure 6.26. Respiration Rate Response to 75% Workload.

Respiration rate data varied as a function of the belt condition and workload, as well as across subjects. There was no discernible trend in the data. Initially, respiration rate data were normalized to the peak test respiration rate. This approach failed since most subjects achieved or exceeded their peak respiration rates during the experimental task. Data normalization with respect to the resting data was attempted. This procedure was also unsuccessful since the resulting data varied widely and did not follow the expected physiological pattern. The normal physiological pattern implies higher rates with higher workloads, but the mechanism by which the subject meets the required respiratory demand is partially subject dependent. A subject might meet the respiratory demand by either increasing respiration rate or by increasing ventilation volume. However, typically at higher workloads such as observed in the current study it was believed that a higher workload would increase the respiration rate, possibly along with increased ventilation volume. Furthermore, the respiration rate for the 40% workload was higher than for the 60% and 75% load levels, which does not have any physiological explanation. Data normalization procedures were therefore discarded.

ANOVA tests were performed on the respiration rate data presented in Table 6.12. A summary of results is presented in Table 6.13.

Table 6.13. ANOVA Summary for Respiration Rate Data.

Source	DF	Mean Square	F Value	Pr > F
Belt (B)	1	12.13	1.17	0.3029
Workload (L)	2	896.12	36.33	0.0001
Work Period (P)	3	31.28	12.49	0.0001
Subject (S)	11	454.34	-	-
B × L	2	50.44	3.46	0.0492
B × P	3	1.03	0.20	0.8937
B × S	11	10.38	-	-
L × P	6	4.23	1.17	0.3307
L × S	22	24.67	-	-
P × S	33	2.50	-	-
B × L × P	6	4.57	1.18	0.3281
B × L × S	22	14.56	-	-
B × P × S	33	5.09	-	-
L × P × S	66	3.59	-	-
B × L × P × S	66	3.88	-	-

Legend: DF: degrees of freedom

The ANOVA revealed that there was no significant belt effect on respiration rate, but there was a significant Belt × Workload interaction. Figure 6.27 shows the interaction. As seen from these data, the interaction was due to the differential response to belt condition based on workload. Workload levels 60% and 75% resulted in a lower response with-belt while the effect was reversed for the 40% workload.

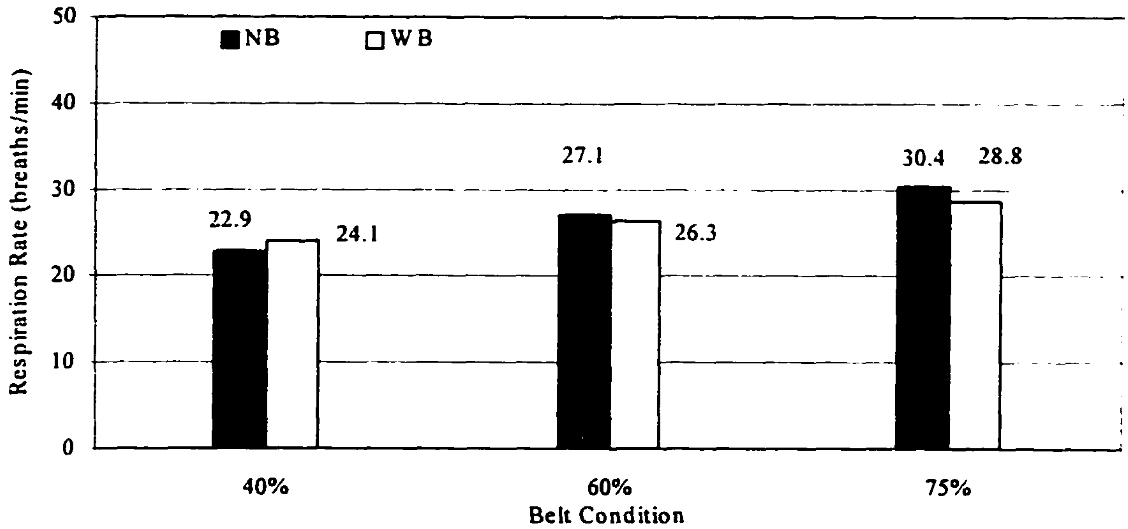

Figure 6.27. Belt by Workload Interaction in Respiration Rate Data.

The three-way interaction of Belt × Workload × Subject was examined as with the previously discussed response measures (Figure 6.28). At the 40% workload, belt use resulted in a higher RR compared to the no-belt condition for seven subjects (Subjects 4, 6, 8, 9, 10, 13, and 15) and a lower RR for the remaining five subjects. A similar trend was observed at the 60% workload. Subjects 6, 7, 9, 10, 11, and 12 had a higher WB response compared to the NB response, while the response was reversed for the remaining subjects. Furthermore, at the 75% workload, the WB RR response was lower than the NB response. These observations support the statistically significant Workload × Belt interaction which implied that the belt effect differed based on workload. ANOVA conducted on the 40% and 60% workload data failed to show a significant belt effect. ANOVA on the 75% workload data showed that the belt effect was significant [$F(1,11) = 19.71$, $p = 0.0010$]. On average, the WB response (28.8 breaths/min) was lower than the NB response (30.4 breaths/min) for the 75% workload.

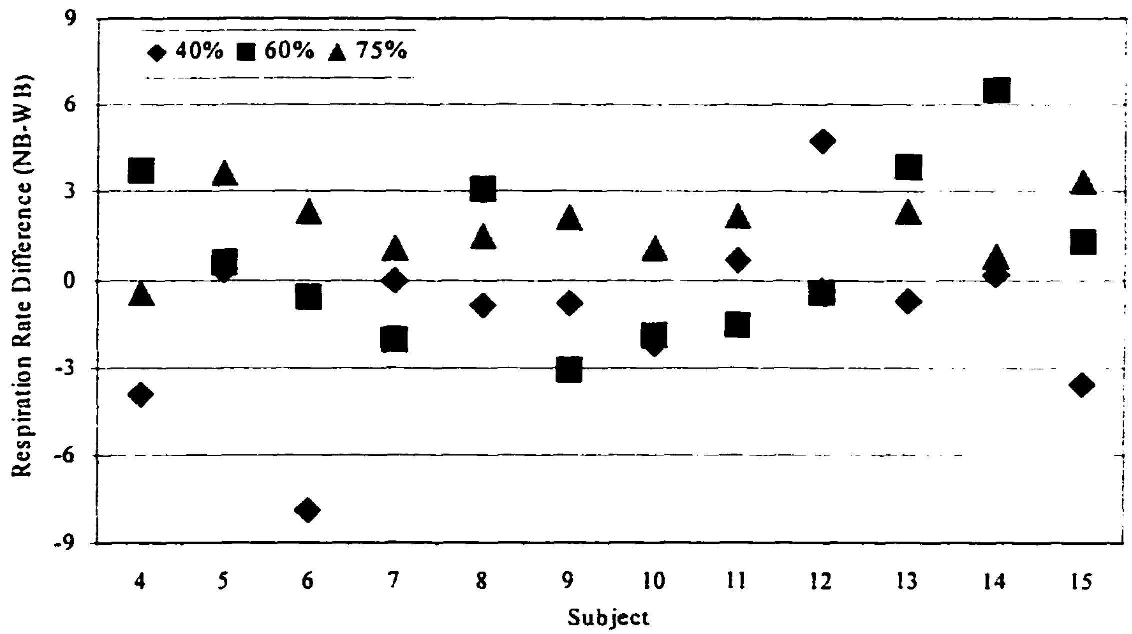

Figure 6.28. Belt by Workload by Subject Interaction for Respiration Rate Data.

It may be hypothesized that subject characteristics were responsible for some subjects showing a higher response while others showed a lower response with the belt condition at the 40% and 60% workloads. These workloads may be transition workloads at which some subjects benefited with a lower respiration rate while others needed to work at higher loads to accrue this benefit.

Analysis of covariance was performed on the full data set using peak test load, static strength, and 1 RM as covariates. The results remained the same with no effect on the F-ratios and p-values of the main factors and their interactions.

6.5 Ventilation Rate

Ventilation rate (VE) represented the volume of air expired during each breath. Since the data collection rate was breath-by-breath, ventilation rate data were obtained for each breath during the test sessions. The following figures illustrate the data reduction procedure developed. The data used in these figures represent the ventilation rate response for Subject 12 performing the experimental task without the belt at 75% workload (Figure 6.29).

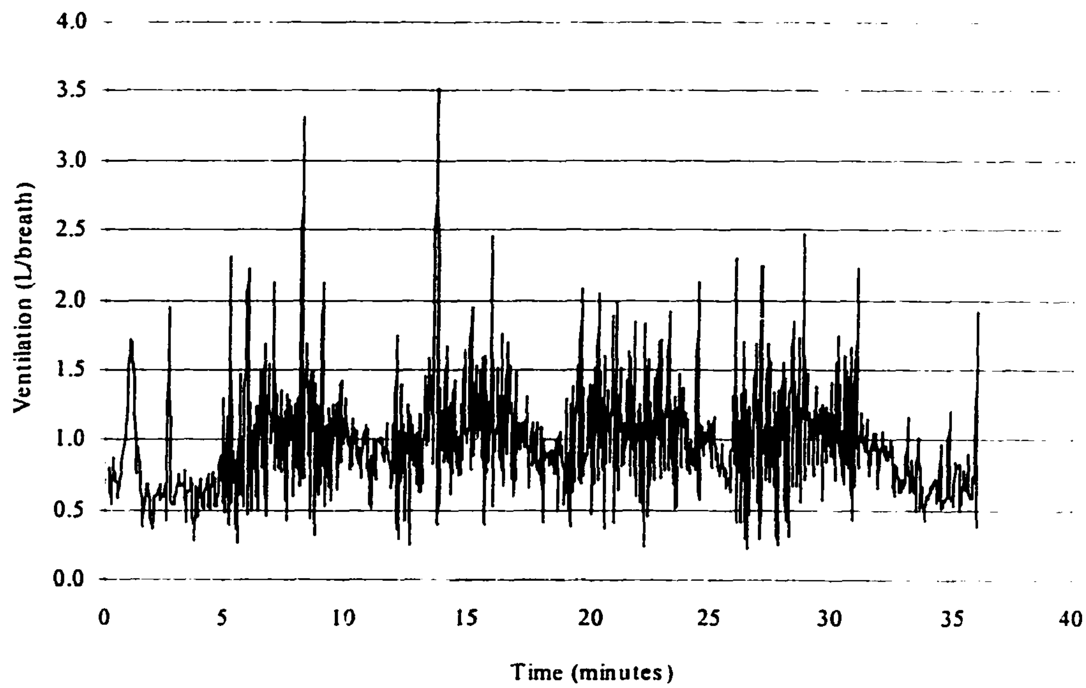

Figure 6.29. Ventilation Data for Subject 12 at 75% Workload and No-Belt.

Figure 6.29 shows a wide variation in response across time. However, the work periods are easily identified. Ventilation varies due to the workload and due to the nature of the task itself. As discussed in the previous section, respiratory demand may be met either by increased respiration rate or by increased ventilation rate. Furthermore, there may be a tendency to take deeper breaths while performing a lift than while performing a lower. The mechanism used by individual subjects to meet the respiratory demand varies. This variation is also seen across workloads and across various types of tasks. The contrast in the respiratory mechanism is observed between tasks that are repetitive in nature such as the current task and tasks that are continuous in nature such as an arm-crank test. The latter task helps maintain a stable (within the confines of moderate workloads) breathing pattern (frequency and ventilation) while the former task modifies the breathing pattern.

Therefore, to obtain an accurate estimate of the ventilation response to the task, it is necessary to calculate a mean of all data recorded in a reasonable time period. Figure 6.30 provides an expanded view of a subset of the data from Figure 6.29 representing the last minute of the fourth work period.

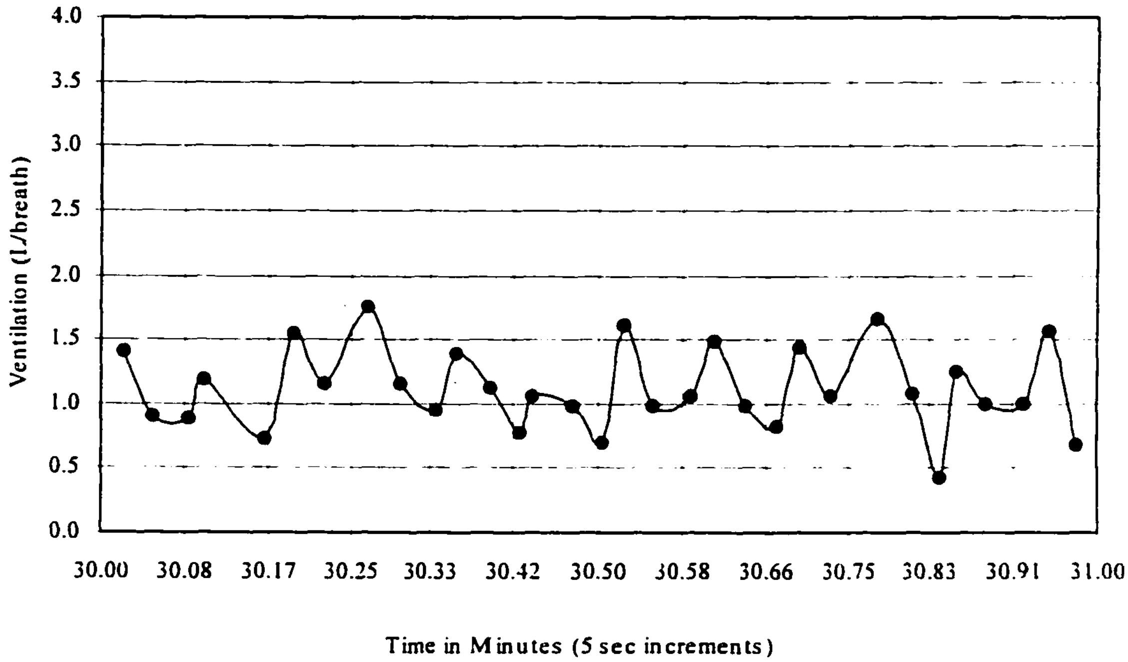

Figure 6.30. Ventilation Data for Subject 12 in the Last Minute of Work Period 4 at 75% Workload and No-Belt.

The five-second increments on the X-axis correspond to a lift or a lower in the task performance cycle. The subject began a lift at time equals 30 minutes and initiated a lower at time equals 30.08 minutes, etc. Examination of Figure 6.30 shows that the ventilation rate varied as did other cardio-respiratory measures with the exception of heart rate. This observation is also reflected in Figure 6.29. Further examination of Figure 6.29 shows that there was a fairly stable ventilation response after the initial stage of each work period. It was felt that even if there were differences in this observation across subjects, the last minute of each work period would be a reasonable representation of the task. Shorter time-periods were not considered for representing the work period due the variability of the ventilation rate data stemming primarily from the measurement artifact. Therefore, the ventilation rate data were reduced by obtaining averages of the last minute of each work period (Table 6.14).

Figures 6.31 through 6.33 illustrate trends in the ventilation data for the three different workloads. The data in these figures have been averaged across the four work periods.

Ventilation rate varied as a function of belt condition and workload, as well as across subjects. To account for the session-to-session variation in the ventilation response, the ventilation rate data were transformed by subtracting the corresponding resting ventilation rate for each session. These data were then expressed as percentages of the peak test ventilation data since this would account for the ventilation rate differences among subjects. The normalized ventilation data obtained in this manner are presented in Table 6.15.

Table 6.14. Ventilation Data (L/breath).

Subject 4							Subject 10						
	WP 1	WP 2	WP 3	WP 4	Mean	SD		WP 1	WP 2	WP 3	WP 4	Mean	SD
40 NB	1.1842	1.2009	1.2242	1.2019	1.2028	0.0164	**40 NB**	1.2683	1.0282	1.1337	1.1896	1.1549	0.1009
40 WB	1.2084	1.1905	1.2033	1.1984	1.2001	0.0076	**40 WB**	0.8413	0.8379	0.8644	1.0164	0.8900	0.0851
60 NB	1.1715	1.2541	1.2196	1.2334	1.2197	0.0351	**60 NB**	1.1983	1.2200	1.2840	1.2644	1.2417	0.0394
60 WB	1.1363	1.3370	1.1276	1.1812	1.1955	0.0972	**60 WB**	1.1716	1.3488	1.3701	1.3357	1.3065	0.0911
75 NB	1.5308	1.5616	1.5765	1.5759	1.5612	0.0214	**75 NB**	1.2963	1.3383	1.3507	1.3510	1.3341	0.0259
75 WB	1.2239	1.3066	1.2764	1.3674	1.2936	0.0599	**75 WB**	1.2318	1.2544	1.3285	1.3642	1.2947	0.0621
Subject 5							**Subject 11**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	0.9507	0.7812	0.8246	0.8059	0.8406	0.0755	**40 NB**	1.0118	1.0935	1.1410	1.1945	1.1102	0.0775
40 WB	0.8742	0.9217	0.8187	0.9413	0.8890	0.0547	**40 WB**	1.0987	1.1538	1.1981	1.0931	1.1359	0.0497
60 NB	0.8502	0.9906	0.9525	0.9736	0.9417	0.0630	**60 NB**	1.3144	1.4373	1.2389	1.3437	1.3336	0.0820
60 WB	1.0591	1.1267	0.9799	0.9378	1.0259	0.0839	**60 WB**	1.2625	1.2661	1.2729	1.2196	1.2553	0.0242
75 NB	1.0532	1.0910	1.1557	1.0404	1.0851	0.0518	**75 NB**	1.5057	1.4594	1.4451	1.4686	1.4697	0.0259
75 WB	1.0760	1.0256	1.0049	1.0224	1.0322	0.0306	**75 WB**	1.6281	1.5275	1.4601	1.6107	1.5566	0.0779
Subject 6							**Subject 12**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	0.6242	0.6479	0.7655	0.8046	0.7105	0.0880	**40 NB**	0.9584	0.9014	0.8523	0.8875	0.8999	0.0441
40 WB	0.7304	0.6727	0.7057	0.7083	0.7043	0.0238	**40 WB**	0.9659	0.9879	0.9244	0.9252	0.9508	0.0314
60 NB	0.7399	0.7506	0.7324	0.7444	0.7418	0.0077	**60 NB**	1.0788	1.0855	0.9915	0.9949	1.0377	0.0514
60 WB	0.6807	0.7188	0.7125	0.6826	0.6987	0.0198	**60 WB**	0.9929	0.9465	0.9630	0.9758	0.9696	0.0196
75 NB	1.0729	1.0181	0.9938	0.8309	0.9789	0.1041	**75 NB**	1.0462	1.1009	1.1124	1.1177	1.0943	0.0328
75 WB	0.6667	0.7749	0.8128	0.7111	0.7414	0.0651	**75 WB**	1.0287	1.0206	1.1066	1.1095	1.0663	0.0483
Subject 7							**Subject 13**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	0.8726	1.2437	0.8908	1.0975	1.0261	0.1773	**40 NB**	1.1147	1.0076	0.8425	0.8078	0.9431	0.1438
40 WB	1.0835	1.0935	1.1402	1.1349	1.1130	0.0287	**40 WB**	0.8964	1.0550	0.9185	0.9513	0.9553	0.0702
60 NB	1.1175	1.0340	1.1185	1.1543	1.1061	0.0510	**60 NB**	1.1469	1.1255	1.0526	0.9868	1.0779	0.0730
60 WB	1.0604	1.1211	1.0432	1.0718	1.0741	0.0335	**60 WB**	1.1091	0.9939	0.9926	1.0455	1.0353	0.0550
75 NB	1.2563	1.3425	1.5191	1.2864	1.3511	0.1176	**75 NB**	1.0741	1.1954	1.1241	1.2496	1.1608	0.0773
75 WB	1.0160	1.0613	1.0380	1.1165	1.0579	0.0432	**75 WB**	1.0735	1.1186	1.2366	1.1288	1.1394	0.0691
Subject 8							**Subject 14**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	1.0018	0.9269	1.1518	1.0277	1.0270	0.0935	**40 NB**	0.7713	0.8013	0.8246	0.7972	0.7986	0.0218
40 WB	1.0535	1.1288	1.1081	1.1021	1.0981	0.0319	**40 WB**	0.7342	0.7308	0.7583	0.8764	0.7749	0.0687
60 NB	1.3968	1.3250	1.3430	1.2287	1.3234	0.0701	**60 NB**	0.9328	0.9290	0.7862	0.7944	0.8606	0.0812
60 WB	1.1296	0.9965	0.9080	0.8929	0.9817	0.1087	**60 WB**	0.9041	0.9241	0.9236	0.9975	0.9373	0.0412
75 NB	1.5404	1.5331	1.3920	1.4296	1.4738	0.0744	**75 NB**	0.9833	0.9623	1.0565	1.0468	1.0122	0.0465
75 WB	1.6683	1.6003	1.5445	1.6973	1.6276	0.0687	**75 WB**	1.0086	0.9461	0.9231	0.9434	0.9553	0.0370
Subject 9							**Subject 15**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	0.9062	1.0740	0.9673	1.0400	0.9969	0.0751	**40 NB**	1.0700	0.9985	1.0899	1.1765	1.0837	0.0732
40 WB	0.8274	0.8314	0.7953	0.8521	0.8265	0.0235	**40 WB**	0.8591	0.8703	0.9575	0.8327	0.8799	0.0541
60 NB	1.0703	1.0415	0.9528	0.9745	1.0098	0.0553	**60 NB**	1.1298	1.0769	1.0994	1.1750	1.1203	0.0425
60 WB	0.9991	0.9190	0.9501	0.8970	0.9413	0.0443	**60 WB**	0.9883	1.0181	0.9990	0.9940	0.9998	0.0129
75 NB	1.1474	1.0975	0.9687	1.1116	1.0813	0.0779	**75 NB**	1.0747	1.1904	1.1948	1.2163	1.1690	0.0639
75 WB	1.1238	1.1331	1.1889	1.1924	1.1596	0.0361	**75 WB**	1.1666	1.3198	1.3485	1.3378	1.2932	0.0852
Mean (all subjects)							**Grand Mean**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	0.9778	0.9754	0.9757	1.0026	0.9829	0.1659	**Av NB**	1.0962	1.1074	1.0936	1.1001	1.0994	0.2088
40 WB	0.9311	0.9562	0.9494	0.9694	0.9515	0.1560	**SD NB**	0.2086	0.2126	0.2140	0.2088		
60 NB	1.0956	1.1058	1.0643	1.0723	1.0845	0.1822	**Av WB**	1.0438	1.0633	1.0529	1.0685	1.0571	0.2149
60 WB	1.0411	1.0597	1.0202	1.0193	1.0351	0.1660	**SD WB**	0.2148	0.2153	0.2107	0.2271		
75 NB	1.2151	1.2409	1.2408	1.2271	1.2310	0.2007							
75 WB	1.1593	1.1741	1.1891	1.2168	1.1848	0.2453							

Legend: WP: work period, NB: no-belt, WB: with-belt, Av: mean, SD: standard deviation

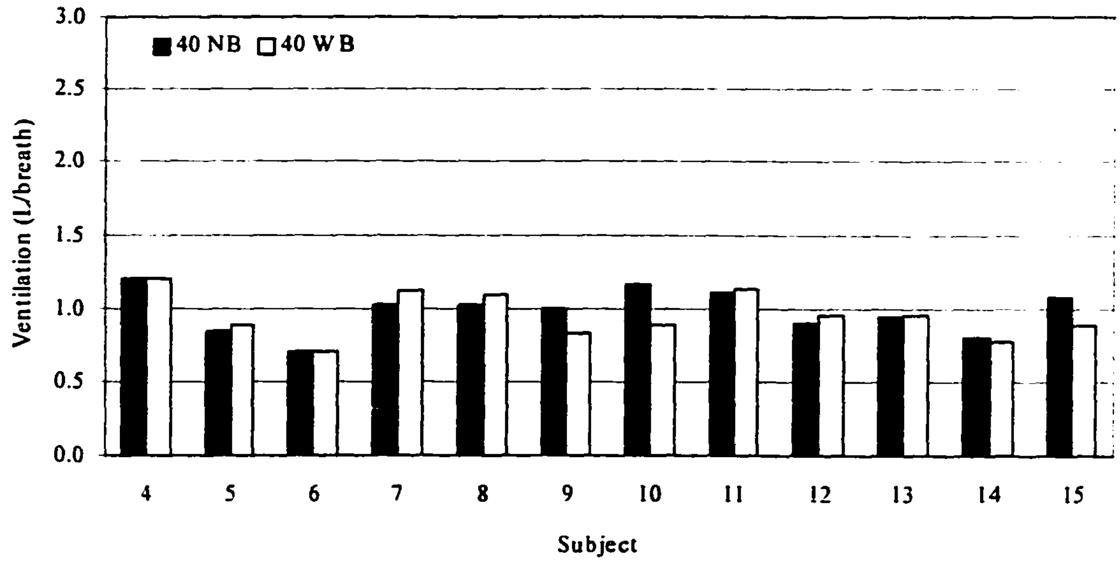

Figure 6.31. Ventilation Rate Response to 40% Workload.

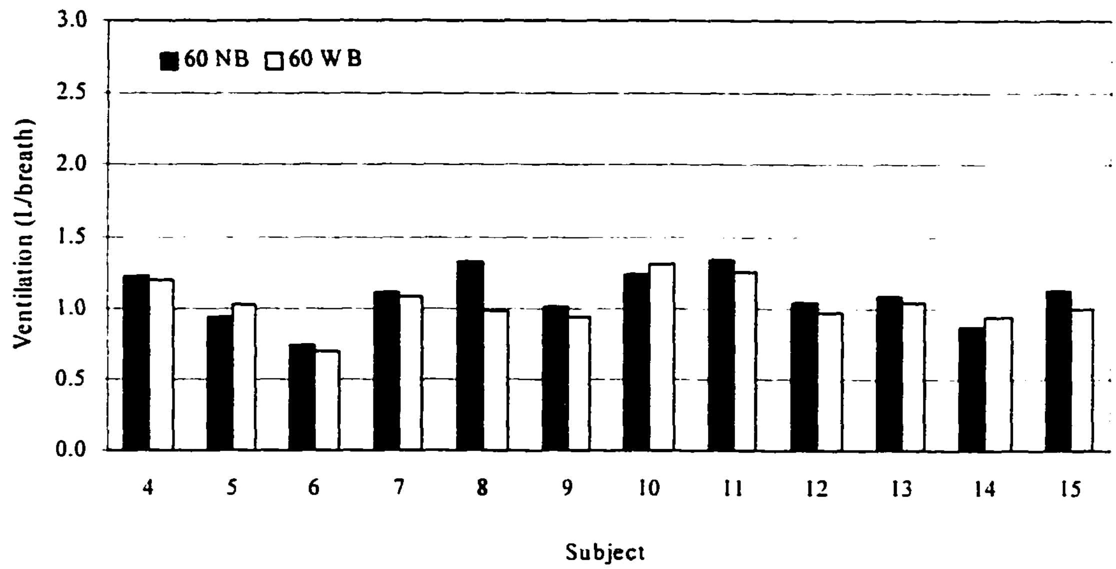

Figure 6.32. Ventilation Rate Response to 60% Workload.

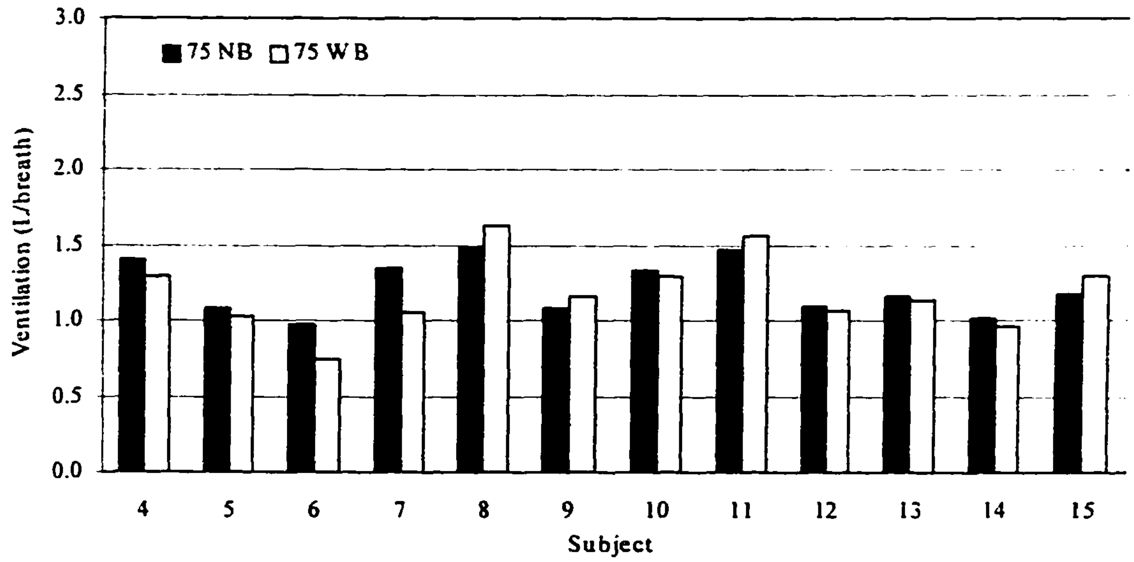

Figure 6.33. Ventilation Rate Response to 75% Workload.

Figures 6.34 through 6.36 show the normalized ventilation data at different workloads and belt conditions averaged across all work periods. The normalized ventilation rate data revealed that the WB and NB effect varied with workload and across subjects. This led to the hypotheses that unaccounted factors including subject-related and instrument-based sources of variation were confounding the ventilation rate. Subject-related factors include underestimation of the true peak capacity in the peak test for some subjects, and the measurement of subject responses to a five-minute work task using a workload based on a long-duration task (the peak tests lasted longer than the five-minute work periods).

Table 6.15. Normalized Ventilation Data as a Percentage of Individual Peak VE.

	WP 1	WP 2	WP 3	WP 4	Mean	SD
Subject 4						
40 NB	13.29	14.28	15.66	14.34	14.39	0.97
40 WB	10.92	9.86	10.62	10.33	10.43	0.45
60 NB	26.17	31.06	29.02	29.84	29.02	2.08
60 WB	10.46	22.33	9.95	13.12	13.96	5.75
75 NB	30.00	31.83	32.71	32.67	31.80	1.27
75 WB	29.27	34.17	32.38	37.77	33.40	3.55
Subject 5	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	23.09	9.88	13.27	11.81	14.51	5.89
40 WB	15.12	18.83	10.80	20.35	16.27	4.26
60 NB	11.53	22.48	19.51	21.16	18.67	4.91
60 WB	31.54	36.81	25.37	22.09	28.95	6.54
75 NB	29.07	32.02	37.07	28.07	31.56	4.04
75 WB	29.13	25.21	23.59	24.96	25.72	2.38
Subject 6	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	5.01	6.53	14.04	16.54	10.53	5.62
40 WB	6.61	2.93	5.04	5.20	4.94	1.52
60 NB	15.43	16.12	14.96	15.72	15.56	0.49
60 WB	8.63	11.06	10.66	8.75	9.77	1.26
75 NB	28.49	24.99	23.44	13.03	22.49	6.65
75 WB	10.76	17.67	20.09	13.59	15.53	4.16
Subject 7	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	25.61	50.59	26.83	40.75	35.94	11.93
40 WB	24.98	25.65	28.80	28.44	26.97	1.93
60 NB	36.09	30.47	36.16	38.56	35.32	3.43
60 WB	38.25	42.34	37.09	39.02	39.17	2.25
75 NB	36.61	42.41	54.30	38.64	42.99	7.91
75 WB	29.26	32.31	30.74	36.02	32.08	2.91
Subject 8	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	16.74	13.05	24.14	18.02	17.99	4.61
40 WB	10.23	13.94	12.92	12.62	12.43	1.57
60 NB	35.01	31.47	32.36	26.72	31.39	3.46
60 WB	23.04	16.48	12.11	11.37	15.75	5.36
75 NB	34.24	33.87	26.92	28.77	30.95	3.67
75 WB	48.40	45.04	42.29	49.82	46.39	3.39
Subject 9	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	24.51	36.59	28.91	34.15	31.04	5.41
40 WB	22.16	22.45	19.85	23.94	22.10	1.69
60 NB	38.95	36.87	30.48	32.05	34.59	3.98
60 WB	31.20	25.43	27.67	23.85	27.04	3.19
75 NB	45.20	41.61	32.34	42.62	40.44	5.61
75 WB	42.80	43.47	47.48	47.74	45.37	2.60
Mean (all subjects)	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	18.59	18.87	18.15	19.84	18.86	9.74
40 WB	14.52	16.11	15.38	17.06	15.77	8.52
60 NB	27.21	27.89	24.89	25.44	26.36	8.36
60 WB	22.95	23.92	21.39	21.54	22.45	9.51
75 NB	31.70	33.32	33.67	32.64	32.83	8.98
75 WB	30.87	31.69	32.71	34.08	32.34	10.37

	WP 1	WP 2	WP 3	WP 4	Mean	SD
Subject 10						
40 NB	18.84	8.17	12.86	15.35	13.81	4.49
40 WB	3.89	3.74	4.92	11.68	6.06	3.78
60 NB	13.62	14.59	17.43	16.56	15.55	1.75
60 WB	14.55	22.42	23.37	21.84	20.54	4.05
75 NB	24.12	25.98	26.53	26.55	25.80	1.15
75 WB	15.11	16.12	19.41	21.00	17.91	2.76
Subject 11	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	1.33	5.45	7.85	10.54	6.29	3.91
40 WB	3.16	5.94	8.17	2.87	5.03	2.51
60 NB	16.51	22.71	12.70	17.99	17.48	4.14
60 WB	13.98	14.16	14.50	11.81	13.61	1.22
75 NB	23.69	21.35	20.63	21.81	21.87	1.31
75 WB	32.33	27.26	23.86	31.45	28.72	3.93
Subject 12	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	18.32	14.40	11.02	13.44	14.30	3.04
40 WB	21.63	23.14	18.77	18.83	20.59	2.16
60 NB	27.46	27.92	21.45	21.69	24.63	3.54
60 WB	20.70	17.51	18.64	19.52	19.09	1.35
75 NB	27.16	30.93	31.72	32.08	30.47	2.26
75 WB	24.01	23.46	29.37	29.58	26.60	3.32
Subject 13	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	33.03	25.59	14.11	11.70	21.11	9.99
40 WB	14.00	25.02	15.54	17.82	18.09	4.88
60 NB	34.16	32.67	27.61	23.04	29.37	5.07
60 WB	32.64	24.64	24.55	28.22	27.51	3.82
75 NB	26.35	34.78	29.82	38.54	32.37	5.37
75 WB	29.06	32.20	40.40	32.90	33.64	4.80
Subject 14	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	21.20	23.83	25.88	23.47	23.60	1.92
40 WB	26.30	26.00	28.42	38.80	29.88	6.04
60 NB	43.59	43.25	30.70	31.42	37.24	7.14
60 WB	32.88	34.63	34.59	41.08	35.79	3.62
75 NB	48.20	46.35	54.63	53.78	50.74	4.09
75 WB	50.26	44.76	42.73	44.52	45.57	3.25
Subject 15	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	22.08	18.11	23.19	28.00	22.85	4.07
40 WB	15.25	15.87	20.72	13.78	16.40	3.01
60 NB	28.02	25.08	26.34	30.54	27.50	2.36
60 WB	17.54	19.20	18.14	17.86	18.18	0.72
75 NB	27.23	33.66	33.90	35.09	32.47	3.55
75 WB	30.07	38.58	40.17	39.58	37.10	4.73
Grand Mean	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
Ave NB	25.83	26.69	25.57	25.97	26.02	10.65
SD NB	10.53	11.49	10.56	10.41		
Ave WB	22.78	23.90	23.16	24.22	23.52	11.64
SD WB	11.89	11.23	11.35	12.49		

Legend: WP: work period, NB: no-belt, WB: with-belt, Ave: mean, SD: standard deviation

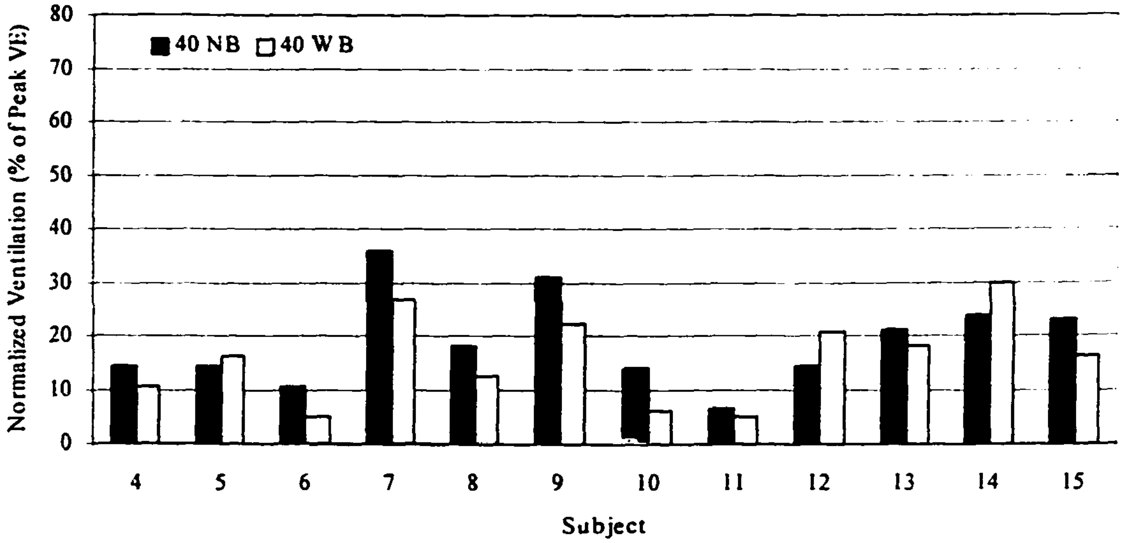

Figure 6.34. Normalized Ventilation Rate Response to 40% Workload.

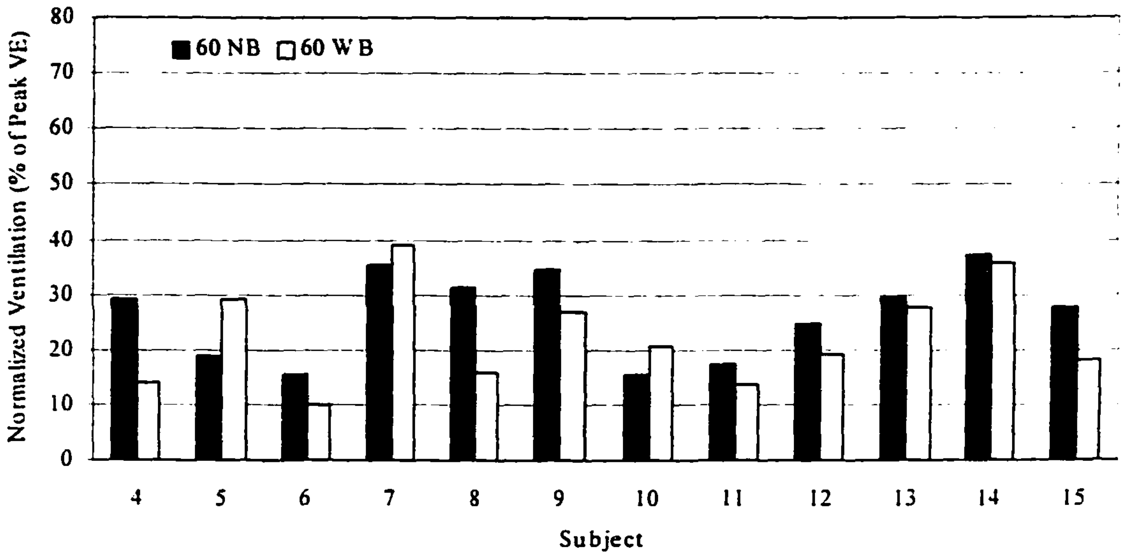

Figure 6.35. Normalized Ventilation Rate Response to 60% Workload.

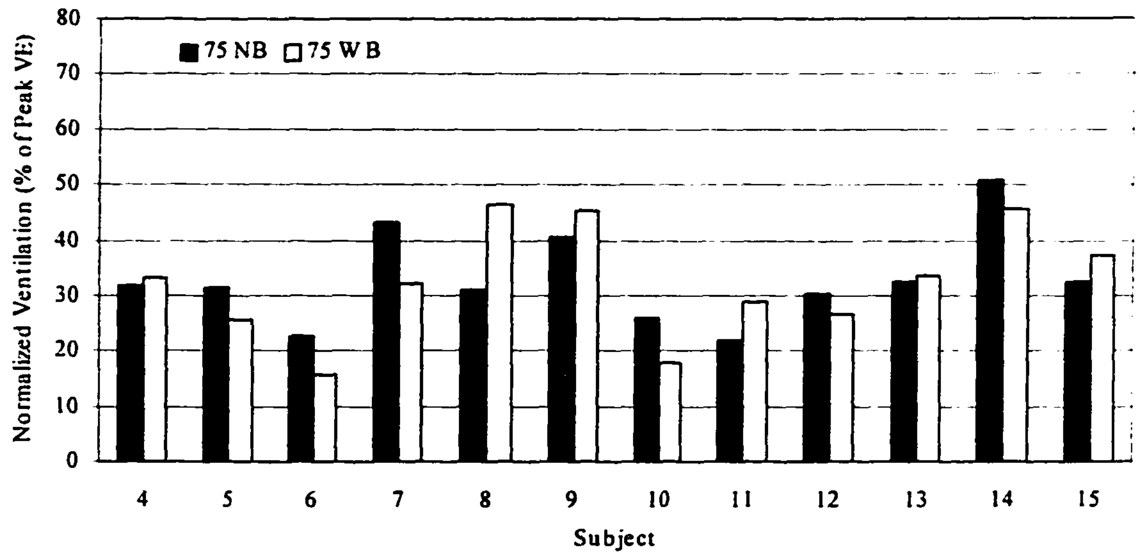

Figure 6.36. Normalized Ventilation Rate Response to 75% Workload.

Statistical results based on analysis of variance performed on the normalized ventilation rate data are summarized in Table 6.16.

Table 6.16. ANOVA Summary for Normalized Ventilation Rate Data.

Source	DF	Mean Square	F Value	Pr > F
Belt (B)	1	449.82	10.75	0.0073
Workload (L)	2	5604.32	82.45	0.0001
Work Period (P)	3	!8.46	1.26	0.3057
Subject (S)	11	1422.93	-	-
B × L	2	76.42	0.61	0.5544
B × P	3	5.76	0.43	0.7329
B × S	11	41.83	-	-
L ×P	6	30.79	1.59	0.1646
L × S	22	67.97	-	-
P × S	33	14.71	-	-
B × L × P	6	4.02	0.19	0.9780
B × L × S	22	126.10	-	-
B × P × S	33	13.41	-	-
L × P × S	66	19.39	-	-
B × L × P × S	66	20.93	-	

Legend: DF: degrees of freedom

At the 0.05 level of significance, the two belt conditions differed significantly. On average, the with-belt condition resulted in a lower ventilation response than the no-belt condition. The effect of workload was also statistically significant. Interactions involving the main factors were not significant. However, based on the trends for other response measures, the Belt × Workload × Subject interaction was plotted (Figure 6.37).

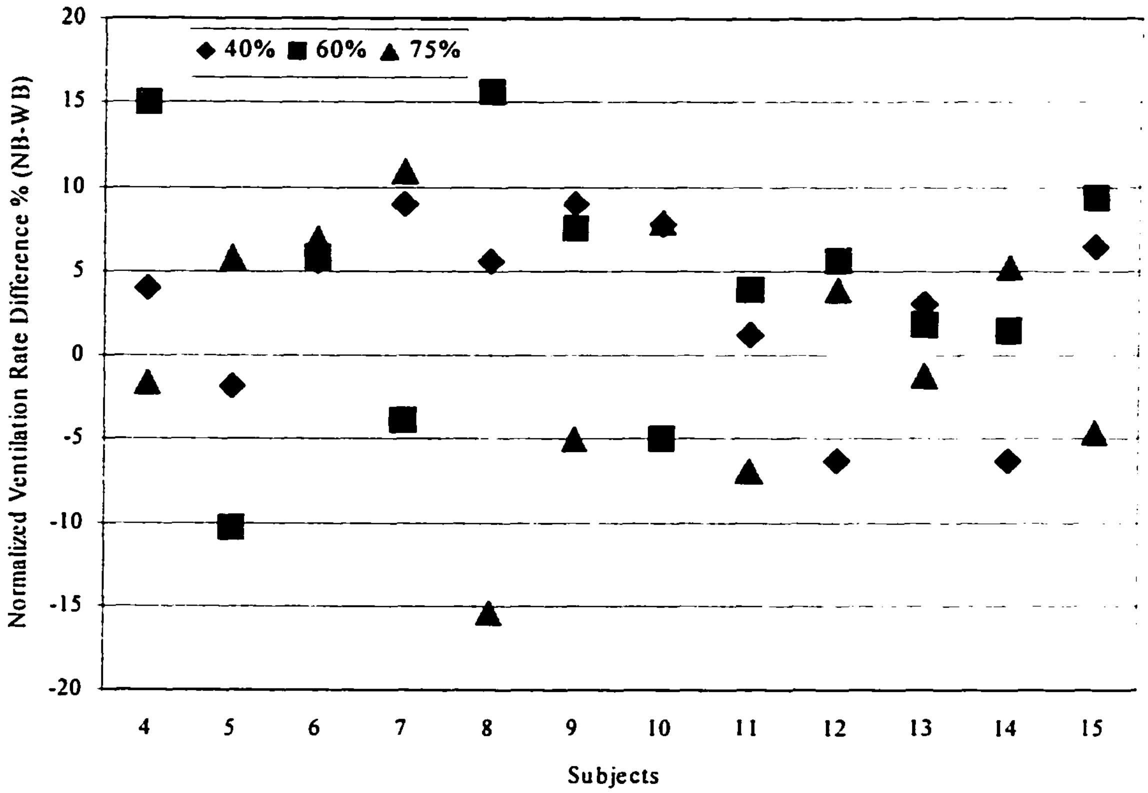

Figure 6.37. Belt by Workload by Subject Interaction for Normalized Ventilation Rate Data.

Most of the points representative of the 40% and 60% workloads showed a decreased ventilation while wearing the belt. The effect of the belt appeared balanced for the 75% workload. Thus, the belt effect differed based on workload. ANOVA conducted on the 40% workload data showed that, statistically, the belt and no-belt conditions were not different [$F(1,11) = 3.98, p = 0.0714$]. Visual examination of Figure 6.37 revealed that Subjects 5, 12, and 14 were the only subjects with a higher ventilation rate under the belt condition versus the no-belt condition. Discarding these subjects and performing ANOVA on the 40% workload data from the remaining nine subjects showed a significant belt difference [$F(1,8) = 42.11, p = 0.0002$].

ANOVA on the 60% workload data showed that the belt effect was not significant [$F(1,11) = 3.05, p = 0.1086$]. Discarding outlier data (Subject 5) resulted in a significant belt effect [$F(1,10) = 6.73$, $p = 0.0267$], with the belt response lower than the no-belt response. ANOVA tests on the 75% workload data failed to show a significant [$F(1,11) = 0.05, p = 0.8265$] belt effect.

It may be hypothesized as with the respiration rate data that subject characteristics may have interacted with the workload and belt conditions to cause variable responses. Analysis of covariance was performed on the full data set while using peak test load, static strength, and 1 RM as covariates. The results of this test did not affect the F-ratios and p-values associated with the main factors and their interactions.

6.6. Blood Pressure

Systolic blood pressure was recorded at the end of each work period. Since there was only a single observation, there was no need for data reduction. The blood pressure data are presented in Table 6.17. Figures 6.38 through 6.40 illustrate trends in systolic blood pressure for the three workloads. The data in these figures have been averaged across the four work periods.

Systolic blood pressure varied as a function of belt condition and workload. However, the daily variation in blood pressure may have been confounded with this observation. To account for the daily or session-to-session variation in blood pressure,

Table 6.17. Systolic Blood Pressure Data (mm Hg).

Subject 4	WP 1	WP 2	WP 3	WP 4	Mean	SD
40 NB	162	164	142	151	154.8	10.2
40 WB	157	152	153	160	155.5	3.7
60 NB	158	157	145	145	151.3	7.2
60 WB	162	126	150	169	151.8	18.9
75 NB	164	159	163	150	159.0	6.4
75 WB	166	162	159	168	163.8	4.0
Subject 5	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	142	145	153	147	146.8	4.6
40 WB	130	146	138	136	137.5	6.6
60 NB	148	138	159	158	150.8	9.8
60 WB	152	148	159	171	157.5	10.1
75 NB	146	159	159	152	154.0	6.3
75 WB	145	148	150	148	147.8	2.1
Subject 6	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	122	151	147	136	139.0	13.0
40 WB	133	132	148	166	144.8	15.9
60 NB	147	132	132	150	140.3	9.6
60 WB	136	139	139	144	139.5	3.3
75 NB	136	160	139	159	148.5	12.8
75 WB	139	150	142	144	143.8	4.6
Subject 7	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	157	147	164	175	160.8	11.8
40 WB	163	140	148	164	153.8	11.7
60 NB	153	156	164	142	153.8	9.1
60 WB	153	174	172	150	162.3	12.5
75 NB	181	171	160	157	167.3	11.0
75 WB	152	159	169	162	160.5	7.0
Subject 8	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	154	145	152	174	156.3	12.4
40 WB	165	156	176	172	167.3	8.8
60 NB	178	159	186	166	172.3	12.1
60 WB	159	152	160	148	154.8	5.7
75 NB	169	180	166	154	167.3	10.7
75 WB	189	164	182	177	178.0	10.6
Subject 9	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	150	159	163	159	157.8	5.5
40 WB	140	148	147	145	145.0	3.6
60 NB	140	153	157	141	147.8	8.5
60 WB	158	151	156	157	155.5	3.1
75 NB	158	157	181	157	163.3	11.8
75 WB	144	154	181	174	163.3	17.2
Mean (all subjects)	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	151.8	152.7	160.0	153.6	154.5	13.7
40 WB	150.9	148.5	151.5	156.2	151.8	14.7
60 NB	160.3	158.7	160.5	153.3	158.2	15.7
60 WB	157.6	156.8	158.8	160.3	158.4	14.6
75 NB	158.1	166.7	161.8	162.9	162.4	16.7
75 WB	163.1	163.8	172.4	164.3	166.0	17.2

Subject 10	WP 1	WP 2	WP 3	WP 4	Mean	SD
40 NB	157	152	153	160	155.5	3.7
40 WB	139	129	132	135	133.8	4.3
60 NB	147	178	150	132	151.8	19.2
60 WB	144	158	142	158	150.5	8.7
75 NB	140	141	134	183	149.5	22.5
75 WB	140	142	163	138	145.8	11.6
Subject 11	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	169	160	168	163	165.0	4.2
40 WB	141	135	132	147	138.8	6.7
60 NB	164	175	157	175	167.8	8.8
60 WB	168	174	168	165	168.8	3.8
75 NB	157	159	159	150	156.3	4.3
75 WB	177	188	188	180	183.3	5.6
Subject 12	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	168	178	188	156	172.5	13.7
40 WB	172	168	178	176	173.5	4.4
60 NB	178	170	176	160	171.0	8.1
60 WB	163	162	184	172	170.3	10.2
75 NB	164	166	178	166	168.5	6.4
75 WB	180	178	177	164	174.8	7.3
Subject 13	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	141	148	159	147	148.8	7.5
40 WB	178	162	159	154	163.3	10.4
60 NB	157	146	168	134	151.3	14.6
60 WB	163	163	165	168	164.8	2.4
75 NB	186	205	204	200	198.8	8.8
75 WB	186	186	190	175	184.3	6.4
Subject 14	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	141	156	177	158	158.0	14.8
40 WB	158	168	165	172	165.8	5.9
60 NB	170	183	193	178	181.0	9.6
60 WB	186	174	184	188	183.0	6.2
75 NB	158	180	163	174	168.8	10.0
75 WB		184	196	195	191.7	6.7
Subject 15	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
40 NB	159	127	154	117	139.3	20.4
40 WB	135	146	142	147	142.5	5.4
60 NB	183	157	139	158	159.3	18.1
60 WB	147	160	127	134	142.0	14.6
75 NB	138	163	136	153	147.5	12.8
75 WB	176	151	172	147	161.5	14.6
Grand Mean	**WP 1**	**WP 2**	**WP 3**	**WP 4**		
Ave NB	156.7	159.3	160.8	156.6	158.3	15.6
SD NB	14.7	15.5	16.9	15.7		
Ave WB	157.0	156.4	160.9	160.3	158.7	16.5
SD WB	16.6	15.7	18.3	15.4		

Legend: WP: work period, NB: no-belt, WB: with-belt, Ave: mean, SD- standard deviation

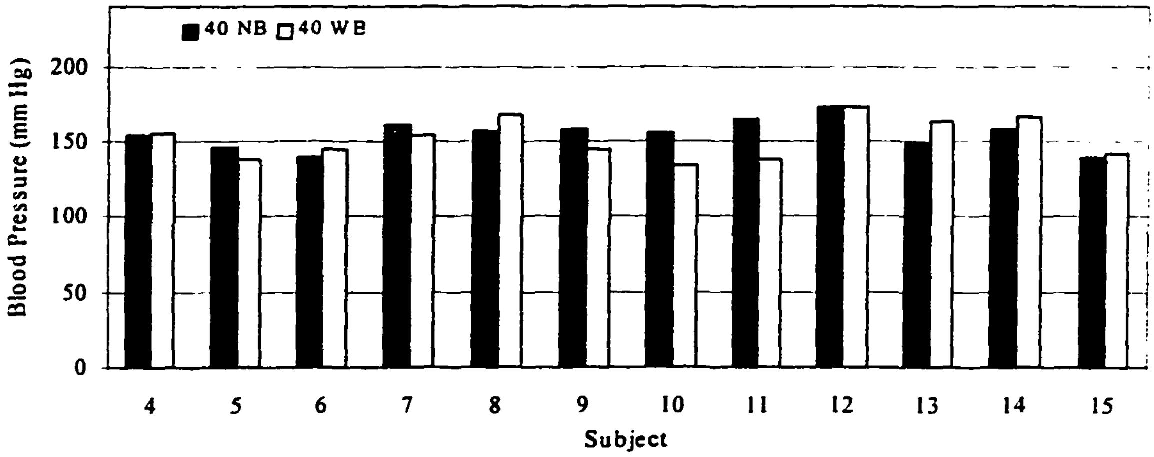

Figure 6.38. Systolic Blood Pressure Response to 40% Workload.

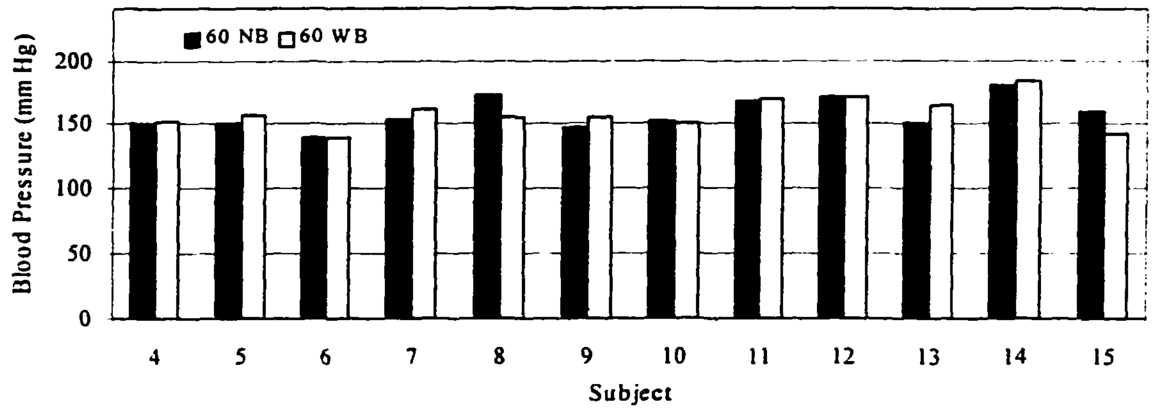

Figure 6.39. Systolic Blood Pressure Response to 60% Workload.

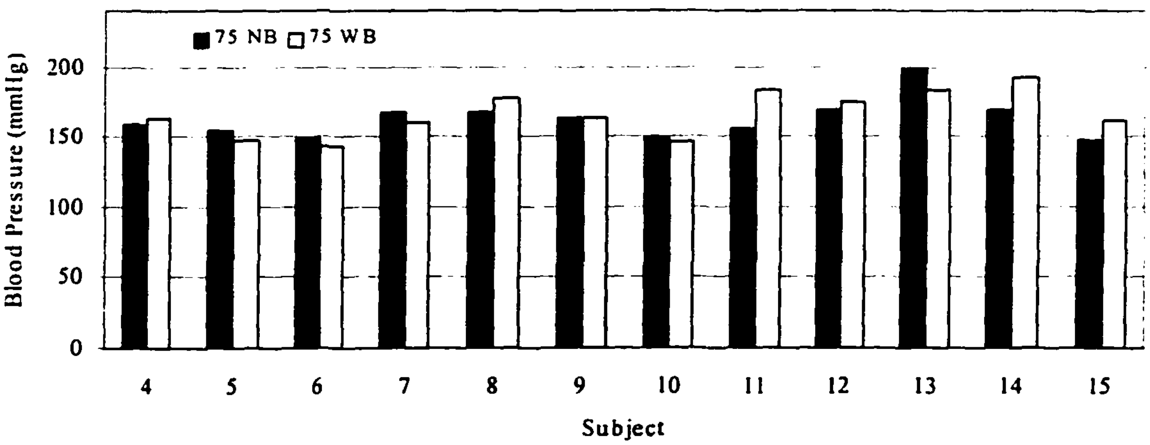

Figure 6.40. Systolic Blood Pressure Response to 75% Workload.

the data were transformed by subtracting the corresponding resting blood pressure for that session. This procedure resulted in negative blood pressure values for certain work periods, and this attempt at normalization was discarded. It was theorized that even if a subject's pre-test blood pressure was high, the blood pressure response at the end of Work Period 4 would reflect an accurate task-related response. This procedure would reasonably minimize anxiety or "white-coat" effects on blood pressure responses. Thus, the blood pressure data from Work Period 4 were not transformed to account for pre-test resting blood pressure differences. Blood pressure values recorded following the fourth work period are presented in Table 6.18.

Table 6.18. Fourth Work Period Blood Pressure Data.

Sub	40 NB	40 WB	60 NB	60 WB	75 NB	75 WB
4	151	160	145	169	150	168
5	147	136	158	171	152	148
6	136	166	150	144	159	144
7	175	164	142	150	157	162
8	174	172	166	148	154	177
9	159	145	141	157	157	174
10	160	135	132	158	183	138
11	163	147	175	165	150	180
12	156	176	160	172	166	164
13	147	154	134	168	200	175
14	158	172	178	188	174	195
15	117	147	158	134	153	147
Mean	153.6	156.2	153.3	160.3	162.9	164.3
SD	16.0	14.2	15.1	14.8	15.5	17.2

The data in Table 6.18 show no particular pattern across load levels or belt conditions. ANOVA performed on these data failed to demonstrate a significant belt effect [$F(1,11) = 0.15, p = 0.7019$]. The workload effect was significant [$F(2,22) = 9.11$, $p = 0.0013$], while the Workload × Belt interaction was not significant [$F(2,22) = 0.83, p = 0.4484$]. These observations can be visualized in Figure 6.41 which shows the Belt × Workload × Subject interaction. Data for Figure 6.41 were obtained by subtracting the

WB blood pressure from the NB blood pressure. Figure 6.41 shows that there were an equal number of positive and negative observations across all workloads, confirming the absence of a belt effect.

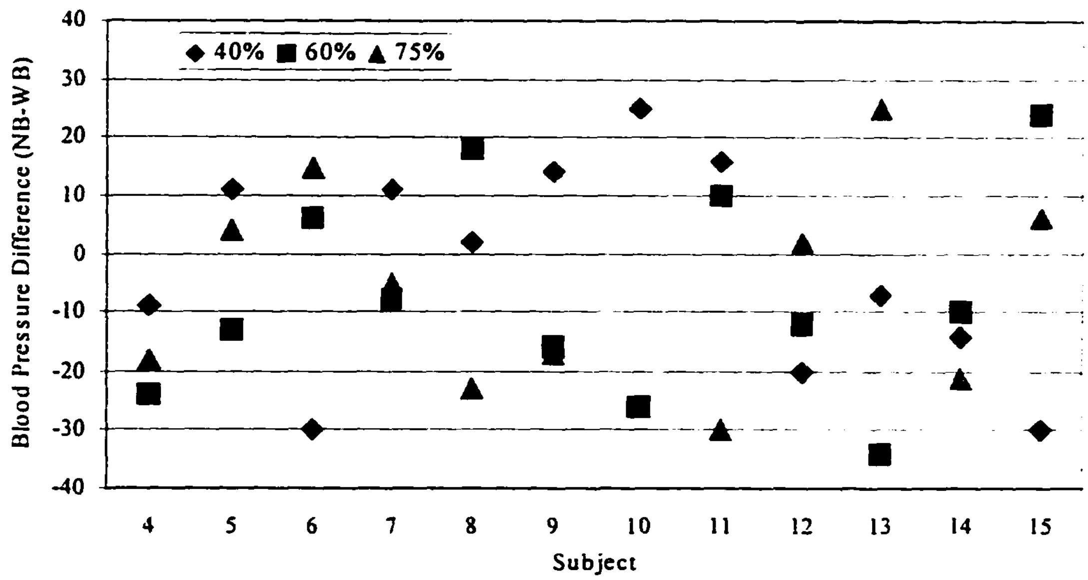

Figure 6.41. Belt by Workload by Subject Interaction for Systolic Blood Pressure in Work Period 4.

These observations lead to the hypothesis that unknown factors were affecting the blood pressure observations. Blood pressure recovery is known to be rapid and hence the time within which the observation is recorded is crucial. Blood pressure acquisition took approximately 45 seconds. The time taken for blood pressure acquisition was a function of the time required to pump the air bladder, which was a function of the biceps size and the blood pressure response itself. A statistical analysis was conducted on the blood pressure data using biceps size and time for data acquisition as covariates. Blood pressure data from Table 6.17 and blood pressure acquisition time for each individual blood pressure observation (Table 6.5) were analyzed. ANCOVA results showed that the belt effect was not significant. A similar analysis was performed on the data from Table

6.18. The results were identical. The belt effect was not significant. ANCOVA tests on the blood pressure data from Tables 6.17 and 6.18 were also performed using biceps size as a covariate. The belt effect was not significant. In addition, the workload effect was not significant in all cases.

6.7. Subjective Data

Subjective data included the ratings of perceived exertion (RPE) at the end of each work period and the questionnaire responses. RPE data are presented in Table 6.19 and the complete set of questionnaire responses is presented in Appendix J.

Figures 6.42 through 6.44 illustrate trends in the RPE data for the three workloads. The data shown in these figures have been averaged across the four work periods. Figure 6.45 presents the data obtained by averaging the RPE scores across all work periods and then subtracting the WB RPE score from the NB RPE score. Examination of the figures reveals no apparent difference in scores between the two belt conditions.

ANOVA confirmed that there was no significant belt effect [$F(1,11) = 0.01$, $p = 0.9210$]. Workload and work period effects were significant [$F(2,22) = 51.20$, $p = 0.0001$ and $F(3,33) = 38.75$, $p = 0.0001$, respectively]. Furthermore, the Workload × Work Period interaction was also significant [$F(6,66 = 10.01$, $p = 0.0001$]. The significance of the workload and work period effects was expected since it is easier for the subject to perceive a change in workload and fatigue. However, unless the belt produces a substantial subjective effect, it is difficult for the subject to detect and remember the relative effort of the NB and WB conditions at the same workload.

Table 6.19. RPE Data.

Subject 4							Subject 10						
	WP 1	WP 2	WP 3	WP 4	Mean	SD		WP 1	WP 2	WP 3	WP 4	Mean	SD
40 NB	2	3	3	4	3.0	0.8	40 NB	3	4	5	5	4.3	1.0
40 WB	3	4	4	4	3.8	0.5	40 WB	2	2	3	3	2.5	0.6
60 NB	3	4	6	6	4.8	1.5	60 NB	2	3	4	4	3.3	1.0
60 WB	3	4	6	6	4.8	1.5	60 WB	5	6	8	9	7.0	1.8
75 NB	3	6	8	9	6.5	2.6	75 NB	4	5	7	8	6.0	1.8
75 WB	4	6	7	9	6.5	2.1	75 WB	3	4	5	7	4.8	1.7
Subject 5							**Subject 11**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	2	2	2	2	2.0	0.0	40 NB	2	3	3	4	3.0	0.8
40 WB	0.5	0.5	0.5	0.5	0.5	0.0	40 WB	2	3	3	3	2.8	0.5
60 NB	4	4	4	4	4.0	0.0	60 NB	2	3	4	4	3.3	1.0
60 WB	2	2	2	2	2.0	0.0	60 WB	3	4	4	5	4.0	0.8
75 NB	3	3	3	3	3.0	0.0	75 NB	3	5	6	7	5.3	1.7
75 WB	5	5	5	5	5.0	0.0	75 WB	3	3	4	5	3.8	1.0
Subject 6							**Subject 12**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	2	3	3	3	2.8	0.5	40 NB	0	1	3	2	1.5	1.3
40 WB	4	4	4	5	4.3	0.5	40 WB	2	3	5	6	4.0	1.8
60 NB	6	7	7	8	7.0	0.8	60 NB	1	3	4	4	3.0	1.4
60 WB	5	5	5	5	5.0	0.0	60 WB	0.5	1	3	3	1.9	1.3
75 NB	7	8	9	9	8.3	1.0	75 NB	4	6	7	7	6.0	1.4
75 WB	7	8	9	9	8.3	1.0	75 WB	1	3	5	6	3.8	2.2
Subject 7							**Subject 13**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	2	3	3	3	2.8	0.5	40 NB	2	3	3	3	2.8	0.5
40 WB	2	2	3	3	2.5	0.6	40 WB	2	3	3	4	3.0	0.8
60 NB	3	3	4	4	3.5	0.6	60 NB	4	4	5	4	4.3	0.5
60 WB	4	5	5	6	5.0	0.8	60 WB	4	4	4	4	4.0	0.0
75 NB	4	4	5	6	4.8	1.0	75 NB	3	5	6	8	5.5	2.1
75 WB	5	6	6	6	5.8	0.5	75 WB	5	6	7	7	6.3	1.0
Subject 8							**Subject 14**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	1	2	3	3	2.3	1.0	40 NB	2	2	2	2	2.0	0.0
40 WB	1	2	3	3	2.3	1.0	40 WB	2	2	2	2	2.0	0.0
60 NB	2	4	7	6	4.8	2.2	60 NB	6	8	8	8	7.5	1.0
60 WB	1	3	4	4	3.0	1.4	60 WB	3	3	3	3	3.0	0.0
75 NB	3	4	4	5	4.0	0.8	75 NB	9	9	9	9	9.0	0.0
75 WB	3	6	8	10	6.8	3.0	75 WB	7	9	10	10	9.0	1.4
Subject 9							**Subject 15**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	3	3	4	5	3.8	1.0	40 NB	2	2	2	2	2.0	0.0
40 WB	1	1	2	3	1.8	1.0	40 WB	1	1	2	2	1.5	0.6
60 NB	2	2	3	4	2.8	1.0	60 NB	2	3	3	4	3.0	0.8
60 WB	5	6	7	7	6.3	1.0	60 WB	4	5	5	5	4.8	0.5
75 NB	5	7	8	8	7.0	1.4	75 NB	5	7	8	8	7.0	1.4
75 WB	6	6	7	7	6.5	0.6	75 WB	4	6	8	10	7.0	2.6
Mean (all subjects)							**Grand Mean**						
	WP 1	WP 2	WP 3	WP 4				WP 1	WP 2	WP 3	WP 4		
40 NB	1.9	2.6	3.0	3.2	2.7	1.0	Ave NB	3.2	4.1	4.9	5.1	4.3	2.2
40 WB	1.9	2.3	2.9	3.2	2.6	1.3	SDNB	1.8	1.9	2.1	2.2		
60 NB	3.1	4.0	4.9	5.0	4.3	1.8	Ave WB	3.2	3.9	4.8	5.2	4.3	2.3
60 WB	3.3	4.0	4.7	4.9	4.2	1.8	SDWB	1.8	2.0	2.2	2.5		
75 NB	4.4	5.8	6.7	7.3	6.0	2.1							
75 WB	4.4	5.7	6.8	7.6	6.1	2.1							

Legend: WP: work period, NB: no-belt, WB: with-belt, Ave: mean, SD: standard deviation

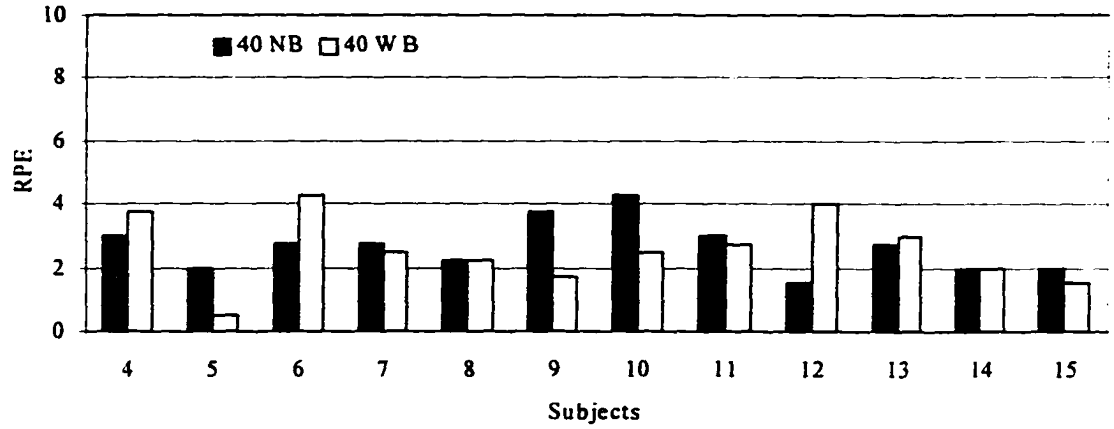

Figure 6.42. RPE Response to 40% Workload.

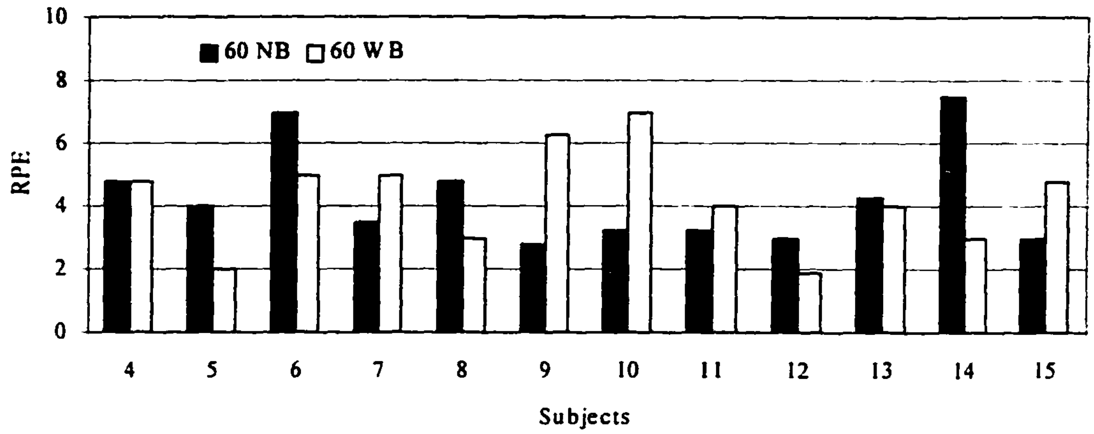

Figure 6.43. RPE Response to 60% Workload.

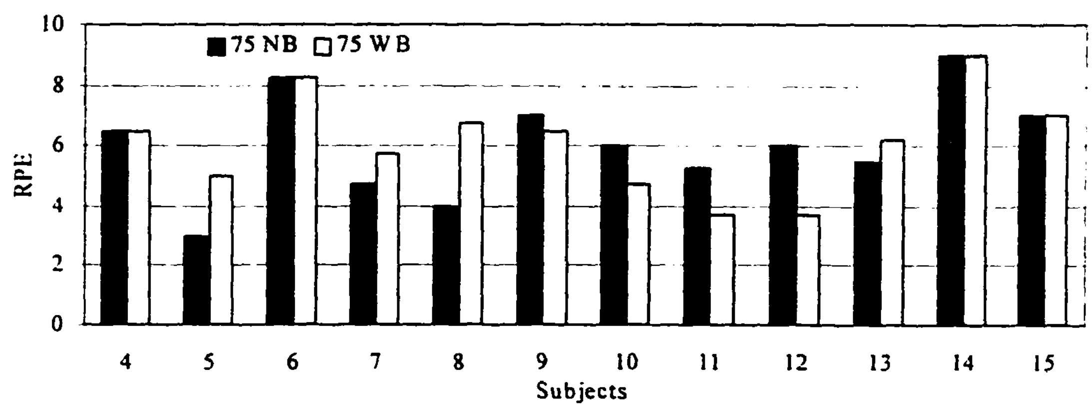

Figure 6.44. RPE Response to 75% Workload.

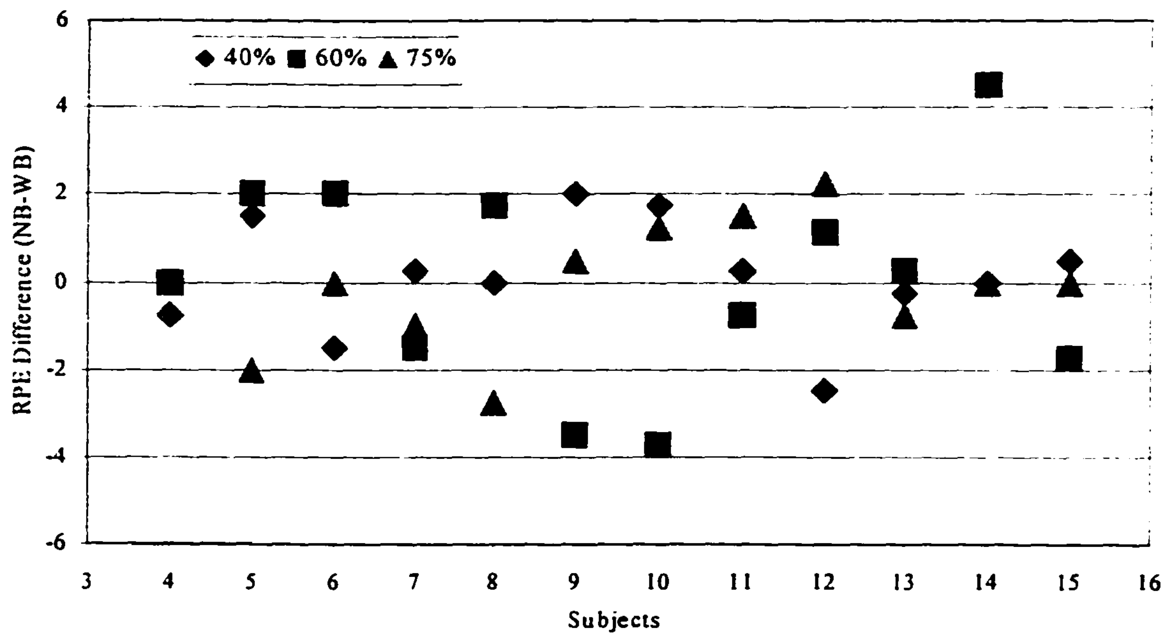

Figure 6.45. Belt by Workload by Subject Interaction for RPE Data.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The results of this study have partially addressed the questions related to the cardio-respiratory effects of abdominal belt use during a short-duration symmetric lifting task. Specifically, the study illustrated the existence of a workload range within which positive belt effects could be detected. An effective workload range is more appropriate than a threshold value when discussing belt use effects, primarily to accommodate the variation across subjects.

Table 7.1 presents a summary of the significant statistical results obtained in the current study. Table 7.2 presents the trends that were obtained from visual examination of the response data.

Table 7.1. Summary of Statistical Results.

Factor	Oxygen Consumption		Heart Rate		Respiration Rate		Ventilation Rate	
	F-ratio	*p*-value	F-ratio	*p*-value	F-ratio	*p*-value	F-ratio	*p*-value
Belt (B)	5.76	0.0353	-	-	-	-	10.75	0.007
Workload (L)	125.07	0.0001	68.90	0.000	36.33	0.000	82.45	0.000
Work Period (P)	2.55	0.0723	63.55	0.000	12.49	0.000	-	-
B × L	-	-	4.41	0.024	-	-	-	-
B × P	-	-	-	-	3.46	0.049	-	-
L × P	4.20	0.0012	18.51	0.000	-	-	-	-
B × L × P	-	-	-	-	-	-	-	-

Significant Belt Effect	Oxygen Consumption	Heart Rate	Respiration Rate	Ventilation Rate
Overall	Yes	No	No	Yes
40%	No	No	No	No
60%	No	Yes	No	Yes*
75%	No	No	Yes	No

* refers to the result obtained by eliminating Subject 5's data

Table 7.2. Subjective Trends Observed.

Subjects with Positive Belt Effect	Oxygen Consumption	Heart Rate	Respiration Rate	Ventilation Rate
40%	8, 9, 10, 13, 14, 15	4, ***5***, 7, ***13***	5, 11, 12, ***14***	4, 6, 7, 8, 9, 10, 11, 13, 15
60%	4, 6, 7, 8, 9, 11, 12, 14, 15	***5***, 6, 7, 8, 11, 12, 13, 14, 15	4, 5, 8, 13, 14, 15	4, 6, 8, 9, 11, 12, 13, 14, 15
75%	5, 6, 9, 10, 11, 12, 13	4, 5, 6, 10, 12, 13	5, 6, 7, 8, 9, 10, 11, 13, 14, 15	5, 6, 7, 10, 12, 14
Subjects with Negative Belt Effect	**Oxygen Consumption**	**Heart Rate**	**Respiration Rate**	**Ventilation Rate**
40%	4, 5, 6, 7, ***11***, 12, ***13***	6, 8, ***9***, 10, 11, 12, 14, 15	4, 6, ***7***, 8, 9, 10, 13, 15	5, 12, 14
60%	5, 10	***9***, ***10***	6, 7, 9, 10, 11, ***12***	5, 7, 10
75%	***4***, 7, 8, 14, 15	7, 8, 9, 11, 14, 15	4, ***12***	4, 8, 9, 11, 13, 15

Legend: Subject number in **bold-*italics*** denotes borderline data

7.1 Oxygen Consumption

Oxygen consumption analyses revealed that the overall belt effect was significant and the WB response was lower than the NB response. Although the Belt × Workload interaction was not significant, further examination of VO_2 response at each workload level showed that the belt effect was not similar across all workloads. At the 40% workload, four subjects had a lower NB response than WB response. At 60%, only two subjects had a lower NB response. Furthermore, at the 75% workload, there were four subjects with a lower NB response. ANOVA for the individual workload levels failed to confirm any belt effects. Considering that both positive (NB response > WB response) and negative belt effects were observed at all three workloads, this result was expected. It must be noted that there were only two subjects (Figure 6.10) with a negative belt response at the 60% workload level and that the majority of subjects had positive responses at all three workload levels. Conclusions based on this observation may be that the overall belt effect was positive and the maximum benefit was attained around the

60% workload level. For the current set of subjects and task, the average 60% VO_2 workload was 19 kg (SD = 2.3).

The overall VO_2 response did not differ significantly across work periods. However, the Workload × Work Period interaction was significant. Further analysis determined that the 75% workload yielded a significant work period effect. These results implied that subject recovery was essentially complete in the two-minute break between work periods at the 40% and 60% workloads. At the 75% workload, each successive work period reflected the cumulative fatigue of the preceding work period since physiological recovery was not complete within the two-minute rest period.

The overall load effect was significant with respect to VO_2 response. This implied that the VO_2 response differed among the three workloads. Due to violation of the sphericity assumption inherent with mixed models, standard multiple comparison procedures could not be used to detect difference between workloads. Since work period was not a significant factor, marginal means (averaged over work periods) were used in multiple comparisons among the workload levels. There were two means (NB and WB) for each load level for each subject. Comparisons were made among the six groups of means (2 belts x 3 workloads). Ryan's multiple comparison procedure was used to detect difference among the six groups. The results showed three distinct groupings which were associated with the three workload levels. The NB and WB conditions of each workload were grouped together.

A significant positive belt effect on VO_2 response implies that belt use results in lower oxygen consumption. Physically this result is not valid since the energy required to perform a given task remains the same. However, an increased task efficiency or muscle support may result in lower energy consumption. Hence, belt use may result in lowering the energy consumption via an unknown mechanism.

Probable mechanisms for this effect are increased mechanical efficiencies and/or physiological efficiencies. Mechanical efficiencies may involve better lifting postures and lifting style. These may be achieved via more energy efficient body movements. Lifting style or postural changes may involve increased use of the arms and shoulders while decreasing the use of wasteful larger muscle mass movements of the trunk. Fixation of the abdominal cavity by use of the belt may also enhance the action of the muscles attached to the chest. In effect, constriction of the abdominal cavity by the belt may result in better utilization of the shoulder and chest muscles.

Upper body tasks are also limited in their efficiency due to the energy cost of static loading. Additional energy is consumed in the recruitment of extra musculature used solely to stabilize the torso during activities involving the arms and the upper body. A constricted abdominal region may reduce the static loading to a certain extent and thereby reduce energy consumption. The belt may also facilitate this postural or lifting style change by restricting trunk flexion.

The cost of breathing at higher workloads accounts for about 19% of the total energy consumed. The major muscles involved in exhalation during work activity are the abdominal muscles and the internal intercostal muscles. The presence of a belt may support these muscles in exhalation and thereby reduce the energy cost of breathing. A probable support mechanism could be external pressure on the diaphragm via increased compression of the abdominal cavity.

However, it is not feasible that mechanical assistance alone accounts for lower oxygen consumption with the belt. Physiological efficiencies may be improved via increased blood flow to the exercising muscles, which increases oxygen extraction from the blood. The belt may facilitate increased blood flow by increasing the venous return from the lower body. A probable mechanism for this may involve the rhythmic muscle pump action that is possible when there is external pressure to the abdominal region via a tightly cinched belt. In the absence of a belt, there is no major constriction of the veins by the abdominal muscles since there is no external pressure on the peripheral muscles. In the presence of a belt, the external pressure on the abdominal musculature may induce a muscle pump action on the venous blood flow.

Any factor that increases venous return causes greater ventricular filling during the diastolic phase of the cardiac cycle. This is also referred to as an increase in pre-load, which in turn increases end-diastolic volume stretching the myocardial fibers and causing a powerful ejection stroke. This results in an increase in stroke volume.

During exercise, the increased demand for oxygen by the active musculature is met in two ways, increased oxygen extraction and increased blood flow. The level of oxygen extraction increases immediately with commencement of work activity. Oxygen extraction refers to the oxygen concentration difference between blood in the arteries and blood in the veins or the arterio-venous difference ($a\text{-}vO_2$). Oxygen rich blood in the arteries has an oxygen concentration of 20 ml/100 ml of blood. At rest, the oxygen concentration of venous blood is about 15 ml/100 ml of blood. This implies that about 5 ml of oxygen is extracted. With increased demand for oxygen, oxygen extraction increases as high as 17 ml resulting in a venous blood oxygen concentration of 3 ml/100 ml.

Increased oxygen extraction cannot satisfy the total requirement for additional oxygen. Increased blood flow, which is almost concomitant with the increased oxygen extraction, supplies the additional demand not met by increased oxygen extraction. In the absence of a belt, the increases in blood flow are limited by the volume of venous return from the inactive musculature, and the a-vO_2 concentration decreases as oxygen demand is met by higher extractions. Oxygen deficient blood in the left ventricle stimulates the need for oxygen replenishment via gaseous exchange at the lungs. Therefore, the amount of oxygen consumption as measured by the concentration of oxygen in the exhaled air increases. In the presence of a belt, the need for higher oxygen extraction is reduced since the demand for oxygen is satisfied by an increased blood volume via an increased stroke volume. Therefore the a-vO_2 difference is maintained at higher levels. This in turn reduces the need for oxygen exchange at lungs.

7.2 Heart Rate

The increases in cardiac output or blood volume and flow during work depend on the intensity of the work. Cardiac output is defined as the product of stroke volume and heart rate. Work intensities up to 40% of VO_{2max} are accompanied by cardiac output increases via increases in stroke volume. As the work intensity increases beyond this level, higher cardiac outputs are achieved by an increase in heart rate. Therefore, in the absence of a belt at the 60% workload level, cardiac output increases via higher heart rates. In the presence of a belt, there is an increase in the 40% threshold limit for stroke volume increases due to additional venous return from the lower body. This would imply that the WB HR response for 60% workload would be lower than for the NB condition. A probable explanation for the lack of a positive belt effect at the 75% workload would be that the stroke volume increases resulting from the increased venous return diminish at this workload and higher cardiac outputs can only be achieved by higher HR.

Overall, the belt did not result in a significant change in heart rate response. However, workload and work period effects were significant, even though VO_2 did not change across work periods. A probable cause relates to the recovery rates of the response variables. The oxygen consumption response to cessation of the task was observed to be faster compared with the heart rate response. Oxygen uptake is governed by faster-acting direct neural and chemical stimuli. Therefore, oxygen uptake recovery was nearly complete in the two-minute rest period while heart rate recovery remained incomplete. Each work period HR reflected a carry-over effect from the previous work period.

Significant workload and work period effects on HR response can be explained as part of the normal physiological response to workload level and fatigue. Significant Belt × Workload and Workload × Work Period interactions led to a separate analysis at each workload. These analyses demonstrated that the belt effect was significant at the 60% workload. At the 40% workload, the belt effect was not significant since half of the subjects (Figure 6.21) showed a higher WB response compared to the NB response while the trend was reversed for the other subjects.

At the 75% workload, the observed HR trend was similar to that observed at the 40% workload level. However, the magnitude of the normalized work pulse difference when the WB response was greater than the NB response was within the range of 1.4% to

4.3% compared to a range of 2.1% to 11.9% for the reverse trend. A normalized work pulse magnitude of 1% represents a HR increase above rest of approximately 1.6 beats per minute. Physiologically, the significance of a 4.3% difference implies a HR difference of 7 bpm. In addition, the number of subjects with a negative belt effect was smaller than the number of subjects with a positive belt effect. The fact that the belt effect on HR was significant and positive at the 60% workload, combined with a similar observation for the oxygen consumption response, supports the hypothesis that the belt provides a positive physiological effect around the 60% workload.

Possible mechanisms explaining the belt effect on HR response are invariably related to those for oxygen uptake. Essentially all cardio-respiratory effects of the belt will be interrelated. The ability to measure various cardio-respiratory responses enables formulation of a probable mechanism describing the belt effect. Blood circulation and heart rate responses to work are achieved via neural and chemical mechanisms. Neural control involves withdrawal of the parasympathetic activity in the active muscles. The inactive muscles remain under the influence of this vaso-constriction neural influence. In addition, as the work activity progresses, the sympathetic neural process increases heart rate stimulation and causes further dilation of the active muscle vasculature.

Increased venous return increases the ventricle filling time and thereby blunts the HR increase via neural pathways. Reflex feedback from the peripheral mechanical and chemical receptors that monitor the active muscle's energy requirements also help control cardiovascular circulation. Chemical receptors act via changes in concentrations of CO_2, ADP, and H^+. These chemicals, in combination with temperature changes, cause auto-regulatory vasodilation of the active muscles.

Blood flow control is also achieved via changes in venous blood flow. A phenomenon called venoconstriction helps maintain adequate blood flow to the active musculature by reducing flow to the inactive musculature while maintaining the overall blood pressure. The increased venous return that is hypothesized to occur in the presence of a belt may be achieved via increased venoconstriction in the torso. Venoconstriction helps move large volumes of blood from the peripheral veins to the central circulation for a redistribution of blood flow to the active musculature.

Tightly cinched belts may provide a physical mechanism for additional venoconstriction, specifically of the peripheral trunk musculature. The additional venoconstriction provided by the belt may augment blood redistribution from the inactive peripheral musculature to the central circulation and on to the active musculature. Additional blood flow from the central circulation via redistribution helps maintain a lower heart rate. In the presence of a belt, the cardiac output requirement is probably satisfied by a higher stroke volume due to increased central circulation blood volume. In the absence of a belt, the cardiac output demands are usually met by an increased heart rate above the 40% VO_{2max} workload. The use of a belt may enable higher stroke volume response beyond that normally observed. Observation of HR belt effects at the 60% workload level supports the stroke volume increase hypothesis.

The above conjecture also implies that the venoconstriction caused by the belt does not completely replace the other autonomous mechanisms of the body. The HR belt effect was not significant at the 40% workload. A probable explanation for this observation may be that the belt does not affect the first mechanism used by the body to respond to increased blood flow demands. At higher workloads, the body may respond favorably to the belt-induced venoconstriction compared to the normal blood flow redistribution response to work activity in the absence of a belt.

The lack of a similar HR belt effect at the 75% workload may be attributable to the subject differences in the body's utilization of the belt-induced venoconstriction or leveling of the stroke volume increase. In addition, it may also be due to the limitation of the belt-induced venoconstriction to completely satisfy the additional demands on blood circulation made by higher workloads. Therefore, at higher workloads the body may revert to the usual mechanisms to supply the blood flow demands, including a higher heart rate to increase cardiac output.

7.3 Respiration Rate

The statistical results with respect to respiration rate were similar to those for heart rate. The belt effect was not significant, while workload and work period effects were significant. However, the Belt × Workload interaction was significant. Therefore, individual tests were conducted at each workload. The results of these tests showed a significant belt effect only at the 75% workload, where the WB respiration rate was lower than the NB response. For VO_2 and HR, significant belt effects were primarily observed at the 60% workload. This observation supports the proposition that belt use has a positive effect in the 60% workload range rather than above a specific threshold load.

The establishment of workloads based on peak VO_2 was not completely successful as witnessed by the actual VO_2 response recorded. On average, subjects only reached 71.2% (SD = 7.8%) of the peak VO_2 at the load designed to elicit 75% of peak VO_2.

Therefore, assuming that the 75% workload was in fact 71%, the workload range of 60% to 75% of peak VO_2 may be ideal to observe positive belt effects.

A range is also appropriate since individual subject responses involving positive WB effects varied over a wide range. Furthermore, it may be hypothesized that the normalization procedure used and the instrument-based measurement artifacts may have limited the size of the RR belt effect at certain workload levels. Higher workload levels such as 75% probably produce a larger belt effect for RR response compared to the other workloads and other cardio-respiratory responses.

The positive WB RR response is easily related to the mechanisms proposed for the VO_2 and HR effects. A lower VO_2 and HR achieved via venoconstriction or increased venous return from the lower body reduces the respiration needs. Since the demand on for the external supplies of oxygen is reduced or postponed, the increase in respiration rate normally associated with increased workloads is absent. Therefore, in the presence of a belt, respiration rate drops to account for a higher efficiency in the distribution of oxygen-saturated blood from the inactive peripheral musculature via higher stroke volumes.

7.4 Ventilation Rate

It may be hypothesized that a lower WB RR response may be achieved via higher ventilation. This seems probable particularly considering the effort required to breathe against a tightly cinched belt. The subject may adapt to the presence of the belt by either taking a number of short breaths or a few deep breaths per minute. The former would result in a higher RR and the latter in higher ventilation volumes in the presence of a belt.

Ventilation rate data showed a significant belt effect with the overall WB response lower than the NB response. None of the interactions was significant. The workload effect on ventilation rate was expected and classified as a normal physiological response. Examination of belt effects at each workload revealed that a majority of subjects exhibited lower WB VE response (Figure 6.37). However, at all workload levels there were some subjects with a negative belt effect. The physiological validity of these higher WB RR responses relative to NB RR responses can be ignored when their magnitudes are compared with those of the positive belt effects.

The presence of a belt resulted in a lower respiration rate and a lower ventilation rate. This observation ruled out the possibility that the RR belt effect was being caused by the subject attempting to compensate for the cinched belt. A physiological explanation has more credence for this observation than a mere change in respiration rate due to deeper breathing. The decrease in both respiration rate and ventilation response may result from increased mechanical efficiency or higher efficiency in the distribution of blood flow from the lower body peripheral musculature aided by the belt.

7.5 Blood Pressure

Blood pressure data failed to reveal any significant belt effects. A probable explanation could be the time taken to measure the blood pressure. Possible effects could have withdrawn in the 45-second data acquisition time. Blood pressure data may also have been affected by the manner in which it was measured. Cessation of exercise would cause an immediate dilation of the active muscle vasculature as the external pressure caused by the rhythmic muscle action is removed and there is less resistance to the blood flow. Using part of the active muscle vasculature to acquire blood pressure data may affect the blood pressure reading.

It was observed that for certain work periods, the blood pressure observations were lower than the pre-session resting blood pressure. A probable explanation for this hypotensive response is that after task termination there is a period of blood pooling and the central blood volume decreases, thus lowering the systemic arterial blood pressure (McArdle et al., 1996). Another probable cause for high pre-session blood pressures could be the effect of "white-coat" hypertension.

Measurements of static strength and dynamic 1 RM were made for comparisons with other studies. The correlations among the three measures are shown in Table 7.3.

Table 7.3. Correlations Among Various Peak Measures (kg).

	Peak VO_2 load	Static Strength	Dynamic 1 RM	Mean	SD
Peak VO_2 Load	1.0000	0.2975	0.7431	31.64	3.82
Static Strength	0.2975	1.0000	0.5403	45.91	12.53
Dynamic 1 RM	0.7431	0.5403	1.0000	56.58	8.49

Examination of Table 7.3 reveals that a low correlation exists between the peak load and the static strength. This was a typical response since the two measures correspond to fundamentally different physiological capacities. However, it must be noted that there were some outliers (SD = 12.53 kg) in the static strength measurement that might have resulted in the extremely poor correlation. Furthermore, data from only ten subjects were used in the estimation of correlations. The low correlation between the static strength and the dynamic 1 RM also reflects the fundamental difference in the tasks. On the other hand, a higher correlation between 1 RM and peak VO_2 load reflects the similarity in the nature of the tasks.

The lack of any specific pattern in either 1 RM response or static strength response may be responsible for the lack of corresponding covariate effects on the response measures.

7.6 Comparisons with other Studies

Soh et al. (1997) conducted a study designed to detect the effects of belt use on respiration rate. The belts used in the study were a non-flexible nylon belt, a non-flexible belt with an inflatable air sac in the lumbar region, and a flexible belt made of elastic material. The belt tensions used by the subjects were not clearly reported. The task involved lifting a 5.4 kg bucket and placing it on a table with a 45 degree twist of the trunk. The bucket was lifted from a height of 36.8 cm and placed at a height of 83 cm. The task frequency was 10 lifts per minute. Respiration rate was measured using a pneumograph strain gauge attached external to the chest. The respiration rate was statistically higher while lifting with the non-flexible nylon belt. The authors reported that this belt may have been more successful in preventing abdominal distension and thereby increased the pressure against the diaphragm. Additional pressure against the diaphragm would result in a decrease in the tidal volume, resulting in compensation via an increased respiration rate.

The findings of the current study are not in agreement with the results of the research by Soh et al. In the current study, respiration rate was significantly lower with belt use. However, in the current study the weight lifted by the subjects was much higher, the task did not involve any asymmetry, and the task frequency was lower. These differences may explain the opposing conclusions from the two studies. In addition, the belt worn by the subjects in Soh et al. was a non-flexible belt as opposed to the flexible belt used in the current study. The flexibility of the belt may be able to relieve pressure on the diaphragm and facilitate near-normal response to activity in terms of respiration rate.

Marley and Duggasani (1996) investigated the effects of abdominal belt use during a symmetric sagittal plane lifting task. The task involved lifting loads of 7 and 14 kg from floor height to a platform at a height of 76 cm. Task frequencies were 3, 6, and 9 lifts per minute. The belt used was not described adequately but can be thought of as a flexible industrial belt from the information reported. The authors reported no significant belt effect on HR, VO_2, VCO_2, tidal volume, RR, and rate of energy expenditure. The authors, however, did report a significant blood pressure effect. Both systolic and diastolic blood pressure were reported to be higher with the use of the belt.

The task used by Marley and Duggasani was a repetitive 15-minute task. The longer task duration may have facilitated recording the blood pressure response, thereby reflecting any belt effects. The possibility of interaction between the blood pressure data collection methodology and the observed blood pressure exists in this study, and as weel as the current study. Blood pressure measurements were acquired from the brachial artery immediately after cessation of the task. Blood vessel dilation is a common phenomenon observed after the sudden withdrawal of rhythmic muscle action. The result of this dilation is an overall reduction in systemic blood pressure. The use of the belt may affect this natural drop in systemic blood pressure at task termination. This effect can then manifest as a higher blood pressure in the presence of a belt. Therefore, belt use effects on blood pressure may not necessarily cause higher blood pressures during the task. The limitations of current non-invasive blood pressure measuring devices prevent accurate determination of belt effects.

Marley and Duggasani also failed to consider the effect of the variable blood pressure acquisition time on blood pressure observations. This is very critical, considering the response time of blood pressure recovery following cessation of the task. Hollingsworth, Bendick, Franklin, Gordon, and Timmis (1990) reported that the brachial artery systolic blood pressure obtained immediately after arm-crank ergometry was significantly lower than the blood pressure estimated during exercise. Blood pressure during exercise was estimated by measuring ankle blood pressure during exercise. Working blood pressure was obtained by adding the difference between resting and exercise ankle pressure to the resting brachial blood pressure.

It may be argued that the design of an experiment which compares the effects of a belt with the effects of the same task in the absence of a belt would nullify the issues of data acquisition and blood pressure recovery time. However, when one is dealing with an unknown such as the belt, it would be prudent to consider and control all possible sources of error. This control is even more important since no valid mechanism for belt effects has been demonstrated.

Marley and Duggasani used absolute units of oxygen consumption in their analyses. The same argument as for blood pressure can be put forth by the authors in defense of using absolute units (ml/min) in comparison of oxygen uptake values. However, it would be more appropriate to use relative oxygen uptake units (ml/kg/min) while comparing effects across the subjects as that would partially account for differences across subjects.

NIOSH cautions against the use of back belts, suggesting that higher blood pressures may result from their use. Marley and Duggasani quote NIOSH in support of their recommendations drawn from their observation of belt effects. An important factor when examining blood pressure effects in any lifting task is the influence of the Valsalva maneuver. Subjects may intentionally or unintentionally perform a lift by breathing out against a closed glottis. Such an action would dramatically increase the blood pressure response (Narloch, and Brandstater, 1995). The use of a belt may support this style of lifting.

NIOSH reviewed the scientific literature and concluded that the use of belts by workers with a compromised cardiovascular system should be avoided. This conclusion was reached primarily on the basis of a single study (Hunter et al., 1989) which reported higher blood pressure during isometric and aerobic exercises and higher heart rate during aerobic exercises while using a non-flexible leather belt. The current study does not support this conclusion with respect to the use of belts in manual material handling. The belt used and the task performed in industrial manual material handling are quite different from the conditions of the study cited by NIOSH.

Earlier studies examining physiological responses to belt use failed to detect any significant belt effects. All of these studies employed workloads that were lower than those used in the current study. Soh et al (1997) used a load of 5.4 kg for a duration of 6 minutes. Marley and Duggasani (1996) used loads of 7 and 14 kg for durations of 15 minutes. Madala et al. (1997) used an average load of 10.5 kg for five four-minute work periods. In the current study, belt effects on physiological measures were observed at an average task load of 19.0 kg (SD = 2.3) performed for four five-minute work periods. From these observations, it seems that the belt effect is present and beneficial at higher workloads. Although the absolute workload varied from subject to subject, on average the belt produced a positive effect at a workload that was equivalent to 60% of the subject's peak aerobic capacity.

A NIOSH recommended weight of lift (RWL) was calculated for the current task using the guidelines developed by NIOSH. An RWL of 12.61 kg was obtained (for Subject 12), which was lower than the 19.0 kg average load (Subject 12 60% load = 22.9 kg) at the 60% level (Table 7.4). The limitations of applying the NIOSH RWL to the current task are that RWL considers either lifting or lowering (not both) and the two-minutes rest periods after each work period cannot be explicitly considered in the calculations. The results of the current study may be interpreted in the following manner in relation to the NIOSH RWL. Users performing short-duration (five minutes) lifting tasks involving workloads that exceed the NIOSH recommended guidelines may benefit from belt use.

Subjective assessments of belt use recorded via questionnaires and psychophysical experiments have typically supported the use of belts. Analysis of the current questionnaire data (Appendix J) also supports the use of belts. The 60 WB task condition was perceived to require lower effort than the 60 NB condition. Overall fatigue was similarly perceived with a WB score of 2.6 compared to 2.7 for NB. These scores were on a 1-5 scale with 1 representing "not at all" and 5 representing "very much". The average response for "did the belt aid in lifting?" was 2.8 on the same 1-5 scale. This response implied that most subjects felt the belts did provide some assistance. Post-study questionnaires determined that most subjects believed the belt aided the lifting task (score of 3.2). Seven of the twelve subjects felt that they would use the belt in a similar lifting task.

Table 7.4. RWL Calculations.

RWL = LC × HM × VM × DM × AM × FM × CM
LC = load constant = 23 kg HM = horizontal multiplier = 25/H [where H = horizontal distance =30 cm] = 0.83 VM = vertical multiplier = 1-(0.003|V-75|) [where V = vertical location = 73 cm] = 0.99 DM = distance multiplier = 0.82 + (4.5/D) [where D = vertical travel distance = 57 cm] = 0.89 AM = asymmetric multiplier = 1-(0.0032A) [where A = angle of asymmetry = 0] = 1.00 FM = frequency multiplier = [from NIOSH (1994b), with a frequency of 6 lifts/min] = 0.75 CM = coupling multiplier = [from NIOSH (1994b)] = 1.0
RWL = 12.61 kg.

In summary, the current study has been able to demonstrate that positive belt effects are observed for short-duration lifts involving high workloads. Belt effects are definitely load-based. The NIOSH conclusions about belt use by workers with compromised cardiovascular systems do not appear valid with respect to flexible belts. However, it must be noted that like any experimental study, this study can only attempt to model belt use in an actual situation. Real world situations often have a multitude of uncontrollable and inevitably confounding factors. Can this study attempt to predict belt effects in such situations? The answer would be a definite "NO". For a definite answer to real world situations, a systematic approach in the laboratory is required. Such an approach needs to study and control as many variables in real world situations as possible, while considering the inter-relationships among these variables. No single study can successfully achieve this goal. Therefore, the following recommendations are presented to expand the approach initiated by the current study.

1. Explore the belt effects at the 60% workload using different values for other task parameters such as lift heights, lift frequency and asymmetry.
2. Determine a similar effective workload range for tasks involving lift asymmetry.
3. Explore how the belt effects and corresponding workload would be affected in tasks that include carrying the load a certain distance.
4. Identify blood pressure measurement devices that would facilitate non-invasive blood pressure observations during the task. The most promising approach currently seems to be adapting the available instruments for ankle blood pressure.
5. Explore the effect of longer rest periods between the work periods to investigate the possibility of belt effects at higher workloads but with a lower work period duration.
6. Measure cardiac output or stroke volume to verify the belt effect mechanism proposed in this study.
7. Improve the VO_2 peak test protocol so that the relative workloads developed from the peak test data produce VO_2 responses closer to target.
8. Develop an easily measured response that is highly correlated with the muscle-set specific VO_2 response that can then be used in prescribing workloads in industry.

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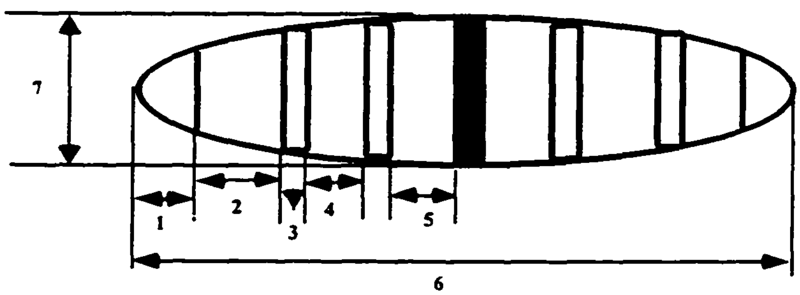
APPENDIX A

Abdominal Belt

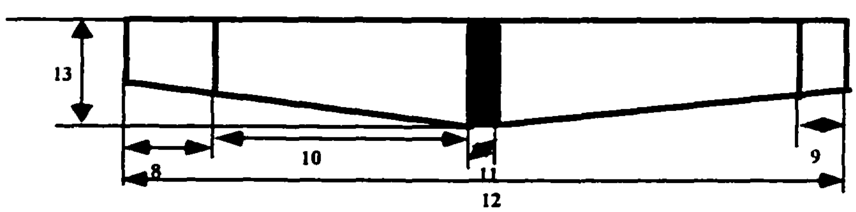
Manufacturer : OK-1 Manufacturing Company, Inc.

Model : OK-505.

Abdominal belt outer strap



Abdominal belt inner - tensioning strap



Belt dimensions (in inches)

Dim #	SMALL (24-33 in)	MEDIUM (29-38 in)	LARGE (35-44 in)
1	7.5	9.5	9.5
2	5.25	5.5	7.5
3	1.0	1.0	1.0
4	1.5	1.75	1.75
5	0.75	0.75	0.75
6	33.5	36.9	40.0
7	8.4	8.5	8.5
8	6.0	6.0	6.0
9	2.0	2.0	2.0
10	9.5	10.75	12.0
11	1.4	1.0	1.0
12	30.75	34.25	36.5
13	6.25	6.25	6.25

Legend: Parenthesis show suggested waist sizes. All dimensions in cm.

APPENDIX B

INFORMED CONSENT FORM

Signing this form constitutes individual consent for participation in a research project conducted under the auspices of the School of Industrial Engineering, University of Oklahoma, Norman.

INTRODUCTION

Title: PHYSIOLOGICAL EFFECTS OF ABDOMINAL BELT USE DURING A SYMMETRIC LIFTING TASK
Investigator: Deepak S. Madala, Graduate student, School Of Industrial Engineering, University of Oklahoma.
Research Committee: Dr. Robert E. Schlegel, Dr. Randa L. Shehab, Dr. B. Mustafa Pulat, School of Industrial Engineering, Dr. Michael G. Bemben, Department of Health and Sports Sciences, and Dr. Larry E. Toothaker, Department of Psychology.

DESCRIPTION OF THE STUDY

Purpose of the Study: The use of abdominal belts is widespread today. However, the amount of scientific data that supports the use of belts is limited and also contradictory. Further, NIOSH (National Institute of Occupational Safety and Health) feels that the use of belts by individuals with abnormal cardiovascular systems may place them at a greater risk. The basis of this conclusion is a study conducted by sports researchers involving a rigid, weightlifting belt. An earlier study conducted by some members of this research team suggested the possibility of a critical weight, above which the use of belts may result in lower physiological strain or at the least cause no additional physiological strain. This study will address this issue and also verify the conclusions reached by NIOSH about the physiological effects of belt use while using a flexible industrial abdominal belt in a typical industrial lifting situation.

Earlier studies have shown that the use of rigid abdominal belts may cause cardiovascular strain under certain physical task conditions. This research will attempt to determine if the flexible belt has similar effects. This study will examine the effects of using an industrial abdominal belt during a lifting task on the physiological measures of oxygen consumption, heart rate, and blood pressure. The study will also investigate any differences in physiological recovery that might arise out of the use of abdominal belts.

You will be performing a lifting task which will involve lifting a box from your knuckle height to your shoulder height and then lowering it back to your knuckle height. You will perform the lift-lower cycle at a rate of 6 repetitions per minute. In the first session, your maximum oxygen uptake (VO_{2max}) will be determined. Maximum oxygen uptake is reached when any additional load added to the task does not cause an additional increase in oxygen uptake by the body. Task loads for subsequent sessions will be fixed at different percentages of your maximal oxygen uptake. Basing the task load on VO_{2max} compensates for cardiovascular system differences between subjects. In Sessions II, III and IV, there will be two sub-sessions and each sub-session will involve four 5-minute work periods separated by 2-minute rest periods. Sub-sessions will be separated by 25-minute rest periods.

Computer-based instruments will be used to determine oxygen consumption, heart rate, and blood pressure, thus reducing human error in their determination. Throughout the study your oxygen consumption, heart rate, and blood pressure will be monitored. The task will be terminated at any sign of risk. The criteria used for task termination will be based on your specific physiological responses and well-established exercise testing protocols.

POTENTIAL RISKS AND BENEFITS OF PARTICIPATION

Risks

The risk to healthy individuals will be minimal as the task load is based on your physical condition. There is always a possibility of an injury. No compensation for injuries or medical treatment will be available. You should have medical insurance if you volunteer to participate in this study. If you are aware of any condition that you feel would be aggravated by this exercise, please refrain from participating in this study. If you are in doubt, please ask the investigator.

Benefits

The results from this study will help to further understand the effects of abdominal belt usage. The results may also help resolve the issue of cardiovascular risks of abdominal belt use. Participation in this study will also result in an assessment of your own physical condition, which may serve as an impetus for your own physical fitness program.

SUBJECT'S ASSURANCES

The data collected shall remain confidential and no identifying characteristics shall be used other than the age, sex, height, and weight. You shall suffer no repercussions or penalty for refusal to participate. You may withdraw and/or discontinue participation in the study at any time without penalty or loss of benefits to which you may otherwise be entitled. There will be no compensation for any injuries. You will be required to inform the investigator of any medication that you are currently using. If you have any questions about the research itself or about your rights as a research subject please contact: Deepak S. Madala, or Dr. Robert E. Schlegel, or Dr Randa L. Shehab at (405) 325-3721.

I ____ understand the purpose of the research and the implications of being a research subject. I volunteer to participate in the research with an understanding that I am free to refuse to participate and to withdraw from the study at any time without prejudice to me.

______________________________ ____________________

(Subjects' Signature) (Date)

HEALTH STATUS QUESTIONNAIRE

Physical Activity Questionnaire

(Adapted from PAR-Q)

Please read the questions carefully and answer each one honestly:

1.	Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?	Yes	No
2.	Do you feel any pain in your chest when you do physical activity?	Yes	No
3.	In the past month, have you had any chest pain when you were not doing physical activity?	Yes	No
4.	Do you have a heart condition or any other cardiovascular disorder?	Yes	No
5.	Do you lose balance because of dizziness or do you ever lose consciousness?	Yes	No
6.	Do you have a bone or joint problem that could be made worse by a change in your physical activity?	Yes	No
7.	Is your doctor currently prescribing drugs for a blood pressure or heart condition?	Yes	No
8.	Do you know of <u>any other reason</u> why you should not do physical activity?	Yes	No
9.	Have you ever had a back injury (low back pain, spinal injuries, slipped disc, etc.)?	Yes	No
10.	Have you undergone surgery in the past year?	Yes	No
11.	Have you had any noticeable back pain in the past year?	Yes	No
12.	Have you had any joint dislocations (wrist injuries, elbow injuries, etc.), broken bones (wrist, arm, legs, ribs, etc.), or any other physical injuries in the past year?	Yes	No
13.	Were you under medication for any ailment in the past year?	Yes	No
14.	Are you under 18 years of age?	Yes	No

15. Please list all medications that you are currently taking or have taken in the past year

____
____
____
____

16. Please provide additional information if you answered "yes" to any of the questions 1 through 13.

____
____
____
____
____
____

17. Rate your physical condition

1------------------2--------------------3-------------------4----------------------5
Poor Average Excellent

18. How many cigarettes do you smoke per day? ________

19. Do you exercise regularly? Yes No

20. How many days per week do you spend at least 20 minutes in moderate to strenuous exercise?

0-------------1-------------2------------3--------------4--------------5--------------6---------
----7

Please inform the experimenter if you do not understand any of these questions or have any questions about the study.

I have answered all the questions honestly and to the best of my knowledge. I understand the test procedures that I will perform and the associated risks and discomforts. Knowing these risks and discomforts, and having had an opportunity to ask questions that have been answered to my satisfaction, I consent to participate in the study. I understand my participation in the study is subject to the experimenter's review of this questionnaire and any other material submitted by me. The experimenter has the prerogative to terminate my participation at any stage.

Name *(please print)*:________________________________
Social Security Number:________________________________
Telephone Number________________________________

Abdominal Belt Study Questionnaire

1. Have you ever used an abdominal belt? (If no, go to Question 2) Yes No
   a) If yes, how long ago did you use it? ______________
   b) For what period of time did you use it ? ____________
   c) For what reasons/tasks did you use it? Please describe below:

____

____

____

____

   d) Do you *think* it helped in lifting/handling heavier loads? Yes No
   e) Do you *think* it helped you to reduce strain on your body? Yes No

Go to Question 5

2. How do rate your awareness of abdominal belts and their applications? (draw a vertical line on the scale below)

1---------------------2----------------------3---------------------4----------------------5

Unaware Somewhat Aware Fully Aware

3. Do you *think* an abdominal belt would aid in lifting more weight? Yes No
4. Do you *think* an abdominal belt would aid in lifting more weight with less strain on your body? Yes No
5. If you have any further conceptions about belt use, please mention them below.

____

____

____

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APPENDIX C

PRE-STUDY INFORMATION

INTRODUCTION

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Computer-based instruments will be used to determine oxygen consumption, heart rate, and blood pressure, thus reducing human error in their determination. Throughout the study your oxygen consumption, heart rate, and blood pressure will be monitored. The task will be terminated at any sign of risk. The criteria used for task termination will be based on your specific physiological responses and well-established exercise testing protocols.

SUBJECT REQUIREMENTS

Subjects with any of the following conditions will not be allowed to participate in the study. Please ensure that you understand all these requirements.

- Subjects who require a Doctor's recommendation for performing physical activity
- Subjects with a heart condition, or any other cardiovascular disorder
- Subjects who have had any surgery performed in the past one year
- Subjects with back injuries such as low back pain, spinal injuries, weak back, etc.
- Subjects who have injured their bones or joints such as wrist injuries, rib cage injuries, elbow joint injuries, knee injuries, etc.
- Subjects under medication prescribed by a Doctor
- Subjects under temporary medication for any ailment
- Subjects with musculoskeletal injuries such as sprained ankles, pulled muscles, torn ligaments, etc.
- Subjects who are less than 18 years of age

You will be required to answer specific questions addressing each of the above restrictions and sign a consent form before you can participate in the study. If in doubt please consult your Doctor. If you need further clarification about the study, please contact one of the research team members. Please make sure that all your questions are answered to your satisfaction before you participate in the study.

Please ensure that you fulfill the following requirements before any test session.

- Drink plenty of fluids during the 24-hour period preceding the test.
- Avoid food, tobacco, alcohol, and caffeine for 3 hours prior to testing.
- Avoid exercise or strenuous activity the day of the test.
- Get an adequate amount of sleep (6 to 8 hours) the night before the test.

TESTING SCHEDULE

For any clarifications about the study, contact Deepak Madala: XXXX@ou.edu (preferred) or XXX-XXXX

APPENDIX D

SUBJECT INSTRUCTIONS SESSION-1

Part-I: Peak Test

The objective of this test will be to determine the peak capacity of your body to supply oxygen to the working muscles. Cardio-respiratory data collection will require you to wear a mouthpiece and you will be able to breath only through your mouth. You will also be fitted with 6 skin surface electrodes to measure your heart rate continuously throughout the test. Resting cardio-respiratory data will be recorded for 5 minutes while you are standing on the work platform.

The task that you will perform is a knuckle-to-shoulder lifting task which involves lifting a box from your knuckle height to your shoulder height and then lowering it back to your knuckle height. You will place the box completely on the shoulder height shelf before bringing it back to the knuckle height shelf. You may remove your hands from the box handles only after you bring the box back to the knuckle height. You will perform the task at a frequency of 6 repetitions per minute. You will either lift or lower the box every 5 seconds. The experimenter will increase the weight of the box at regular intervals. You will perform the task until you can no longer lift the box. ***It is very important that you absolutely reach your peak capacity and can no longer perform the given task.***

A timer will beep every five seconds to help you pace your task. Ensure that you do not flex your elbows at the initiation of the lift. You should keep your feet in the region marked on the platform during the entire test. You will be asked to give subjective ratings of your effort every 2-minutes using the following 10-point rating scale.

Rating	Description of Effort
0	Nothing at all
0.5	Very, very weak
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong
6	
7	Very Strong
8	
9	
10	Very, very strong
*	Maximal

Instructions for rating your subjective effort using the 10 point scale :

This is a scale for rating perceived exertion. Perceived exertion is the overall effort or distress of your body during the task. The number 0 represents no perceived exertion and the number 10 represents the greatest amount of exertion that you have experienced. At various times during the test, you will be asked to point to the number which indicates your rating of perceived exertion at the time. The number you have selected will be repeated aloud by the experimenter to avoid miscommunication.

Since this is a test of peak capacity, it is critical that you perform the test until you have reached a point where you cannot perform the task any longer. Your physiological responses will be continuously monitored to ensure that you remain within acceptable safety levels during the test.

Part-II: Belt Tension Adjustment

This test will be performed after a 25-minute break. You will not be required to wear the mouthpiece for this test. However, your heart rate will be monitored continuously with the help of the surface electrodes. The objective of this test is to determine your maximum acceptable belt tension for a short duration, moderate frequency lifting task. The experimenter will initially position the belt around your waist in the required manner and help you tighten the belt to the maximum tension level. You will perform a similar lifting task as in the peak test for a period of 8 minutes. However, the weight you lift will be based on the maximum weight you lifted in the peak test and will not be increased during the test.

During this task you will adjust the tension in the belt until it is as tight as possible while still being comfortable. Adjustments should be made between the lifts at any time during the 8-minute period. Adjust the tension using both the left and right tension straps. Whenever you adjust the straps, ensure that adjustments are completed before continuing to lift. You are requested to make as many adjustments as necessary, both increasing and decreasing, to obtain your maximum acceptable belt tension for the task.

APPENDIX E

RPE SCALE

Rating	Description of effort
0	Nothing at all
0.5	Very, very weak
1	Very Weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong
6	
7	Very strong
8	
9	
10	Very, very strong
*	Maximal

APPENDIX F

SUBJECT INSTRUCTIONS SESSIONS 2-4

The objective of the tests that you will perform today (Session II), tomorrow (Session III) and the day after (Session IV) will be to record your cardio-respiratory responses (heart rate, blood pressure, oxygen consumption, etc.) to three different weights while lifting with the belt and without the belt. There will be a total of six sub-sessions, two on each day.

You will be instrumented as in Session I with a mouthpiece to measure respiratory data and surface electrodes to measure your heart rate. In addition, your blood pressure will be recorded at the end of every work period. For this measurement, you will wear a blood pressure cuff on your right arm throughout the session. Resting cardio-respiratory data will be collected for five minutes at the beginning of the session. Recovery data will be collected for 5 minutes at the end of the last work period.

The task you will perform will be similar to the task you performed in Session I. However, the weight lifted will not be increased during the test. It will be based on a fixed percentage of the peak load you lifted in session I peak test. You will perform the task continuously for 5-minutes followed by a 2-minute break. You will perform four cycles of 5-minute work periods and 2-minute rest breaks.

Subjective ratings of perceived exertion using the same 10-point scale as in Session I will be taken at the end of the each 5-min work period.

Instructions for rating your subjective effort using the 10 point scale:
This is a scale for rating perceived exertion. Perceived exertion is the overall effort or distress of your body during the task. The number 0 represents no perceived exertion and the number 10 represents the greatest amount of exertion that you have experienced. At various times during the test, you will be asked to point to the number which indicates your rating of perceived exertion at the time. The number you have selected will be repeated aloud by the experimenter to avoid miscommunication.

APPENDIX G

Post Lifting Task Questionnaire

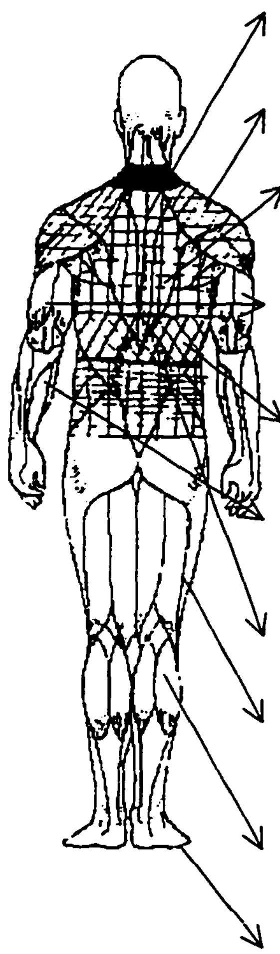
(after each sub-session)

Answer the following to the best of your ability based on your impressions from the lifting task you just completed. Draw a vertical line on the scale to indicate your responses.

1. How do you rate the lifting task you performed?

1------------------2------------------3------------------4------------------5
Very Easy   Manageable   Very Difficult

2. Use the following picture to report **discomfort** in different parts of your body.



a) Neck
1-------------2-------------3-------------4---------------5
No Discomfort   Tolerable   Intolerable

b) Shoulders
1-------------2-------------3-------------4---------------5
No Discomfort   Tolerable   Intolerable

c) Upper Back
1-------------2-------------3-------------4---------------5
No Discomfort   Tolerable   Intolerable

d) Upper Arm
1-------------2-------------3-------------4---------------5
No Discomfort   Tolerable   Intolerable

e) Mid-Back
1-------------2-------------3-------------4---------------5
No Discomfort   Tolerable   Intolerable

f) Forearm
1-------------2-------------3-------------4---------------5
No Discomfort   Tolerable   Intolerable

g) Lower Back
1-------------2-------------3-------------4---------------5
No Discomfort   Tolerable   Intolerable

h) Upper Leg
1-------------2-------------3-------------4---------------5
No Discomfort   Tolerable   Intolerable

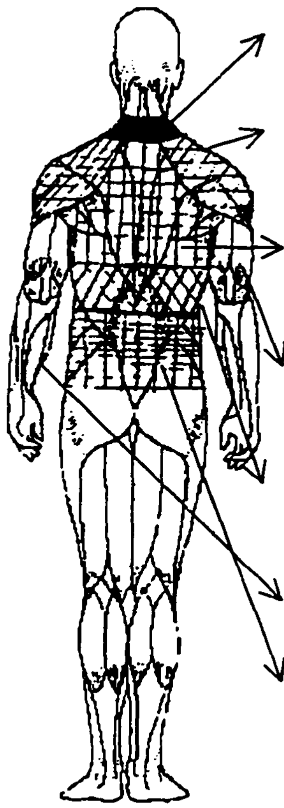
i) Lower Leg
1-------------2-------------3-------------4---------------5
No Discomfort   Tolerable   Intolerable

j) Feet
1-------------2-------------3-------------4---------------5
No Discomfort   Tolerable   Intolerable

3. How do you rate your overall fatigue (tiredness)?

1---------------------2---------------------3---------------------4---------------------5
Not at All Somewhat Very Much

4. Use the following picture to report **fatigue** in different parts of your body



a) **Neck**
1------------2-------------3-------------4----------------5
Not at All Somewhat Very Much

b) **Shoulders**
1-------------2-------------3-------------4----------------5
Not at All Somewhat Very Much

c) **Upper Back**
1-------------2-------------3-------------4----------------5
Not at All Somewhat Very Much

d) **Upper Arm**
1-------------2-------------3-------------4----------------5
Not at All Somewhat Very Much

e) **Mid-Back**
1-------------2-------------3-------------4----------------5
Not at All Somewhat Very Much

f) **Forearm**
1-------------2-------------3-------------4----------------5
Not at All Somewhat Very Much

g) **Lower Back**
1------------2-------------3-------------4----------------5
Not at All Somewhat Very Much

Post Lifting Task Questionnaire (with belt only)

(after each lifting sub-session performed with belt)

5. Did the belt aid in lifting?

1-------------------2--------------------3--------------------4---------------------5
Not at All Somewhat Very Much

6. Did the belt restrict your movement during lifting?

1-------------------2--------------------3--------------------4---------------------5
Not at All Somewhat Very Much

7. Did the belt affect your breathing?

1-------------------2--------------------3--------------------4---------------------5
Not at All Somewhat Very Much

8. Was the belt uncomfortable to wear?

1-------------------2--------------------3--------------------4---------------------5
Not at All Somewhat Very Much

APPENDIX H

Post Study Questionnaire

Answer the following questions with respect to your impressions from the ***entire study****. Draw a vertical line on the scale to indicate your responses.*

1. Do you think a belt aids in lifting tasks?

1--------------------2--------------------3--------------------4--------------------5

Not at All | Somewhat | Very Much

2. Do you think a belt restricts movement during lifting tasks?

1--------------------2--------------------3--------------------4--------------------5

Not at All | Somewhat | Very Much

3. Did you think a belt affects normal breathing pattern?

1--------------------2--------------------3--------------------4--------------------5

Not at All | Somewhat | Very Much

4. Is a belt uncomfortable to wear?

1--------------------2--------------------3--------------------4--------------------5

Not at All | Somewhat | Very Much

5. If you were to perform this lifting task in your job, would you use an abdominal belt? Yes No

   Was this decision based on your current experience or on earlier impressions? Current Earlier Both

Please explain your decision to use or not use an abdominal belt.

____

____

____

____

____

APPENDIX I

RAW DATA FOR SUBJECT 12 AT 75% WORKLOAD AND NO-BELT

Time	VO2	HR	RR	VE	Time	VO2	HR	RR	VE	Time	VO2	HR	RR	VE
0.178	5.5	60	15	0.7936	13.783	8.3	105	55	0.4104	24.283	10.3	82	26	0.8931
0.247	3.3	62	15	0.5313	13.809	10.3	103	39	0.6136	24.315	11.4	84	32	0.8128
0.326	5.7	62	13	0.8769	13.836	7.5	105	38	0.5508	24.351	11.7	84	27	0.9288
0.393	4.6	62	15	0.6968	13.854	42.5	105	55	1.3608	24.392	8.1	86	25	0.7913
0.474	3.6	58	12	0.7047	13.877	17.5	107	43	0.8947	24.428	11.1	84	27	0.8676
0.532	3.6	60	17	0.5858	13.922	14.1	107	22	1.206	24.495	14.5	78	15	2.1172
0.619	3.6	60	11	0.7134	13.938	27.6	107	62	0.9376	24.537	7.3	86	24	0.756
0.891	2.5	62	4	1.0336	13.971	15.1	105	30	1.1022	24.574	6.9	90	27	0.5624
1.019	6.6	68	8	1.7152	14.007	11.8	105	28	0.9072	24.617	13	90	23	1.0922
1.166	4	64	7	1.2789	14.019	35.8	105	86	0.84	24.652	13.9	90	29	1.022
1.254	4	62	11	0.7744	14.056	14.8	105	27	1.1618	24.704	9.8	90	19	1.092
1.37	3.7	62	9	0.9512	14.103	19.7	105	21	1.6732	24.749	10.2	88	22	0.891
1.43	4.5	62	16	0.684	14.142	11.4	103	26	0.9789	24.785	14.2	90	28	1.0476
1.479	5.4	62	20	0.7301	14.173	12.4	105	32	0.837	24.823	11.8	86	26	1.0526
1.55	2.1	66	14	0.5396	14.188	36	105	65	1.0275	24.857	11.1	84	30	0.9724
1.586	3.3	66	28	0.3852	14.219	16.2	105	33	1.1222	24.926	6	82	14	1.0212
1.713	2.4	70	8	0.6731	14.256	16.4	105	27	1.258	24.97	11	84	23	1.1396
1.805	3.5	66	11	0.6808	14.267	22.3	103	87	0.6039	25.019	8.7	86	20	0.9506
1.881	3.5	66	13	0.5624	14.302	12.7	103	29	1.015	25.06	13	86	24	1.0988
1.967	2.3	64	12	0.3698	14.34	9.3	105	26	0.8322	25.095	10.3	80	29	0.7945
2.037	3.2	64	14	0.525	14.352	43.3	105	85	0.7776	25.147	9.3	78	19	1.0036
2.104	4	62	15	0.5762	14.389	14.7	107	27	1.1618	25.185	12.9	82	26	1.159
2.169	4.1	64	16	0.598	14.434	17.4	105	22	1.431	25.221	11.8	80	28	1.0692
2.231	4.5	62	16	0.62	14.473	13.5	103	26	1.092	25.257	10.3	78	28	0.9216
2.291	5.1	64	16	0.69	14.503	12.3	105	33	0.87	25.296	8.9	80	25	0.8541
2.361	4	66	14	0.574	14.518	39	105	65	1.062	25.344	7.6	76	21	0.9024
2.436	3.8	68	13	0.615	14.559	11.6	107	24	0.984	25.401	6.3	66	17	0.8037
2.511	3.5	64	13	0.6	14.589	10.8	109	34	0.744	25.446	7	68	22	0.774
2.571	6.2	66	17	0.774	14.604	33.4	107	67	0.939	25.486	6.8	70	25	0.744
2.602	4.4	68	32	0.4495	14.635	14.2	105	32	0.9796	25.528	7.9	72	24	0.8442
2.684	10	76	12	1.9434	14.672	12.9	103	27	1.0286	25.568	9.7	70	25	0.976
2.77	3.3	72	12	0.6106	14.683	37.9	103	94	0.7568	25.612	6.8	72	22	0.7348
2.845	2.6	66	13	0.54	14.719	16.6	105	28	1.242	25.656	7.6	72	23	0.8052
2.903	3.7	68	17	0.5336	14.755	15.3	105	28	1.116	25.702	6.9	68	22	0.782
2.981	4.2	70	13	0.6474	14.769	28.9	107	71	0.8638	25.747	5.6	64	22	0.648
3.061	4.9	66	12	0.744	14.808	14.8	109	26	1.1973	25.788	7.1	66	24	0.7216
3.136	4.8	66	13	0.7575	14.848	23.3	111	25	1.648	25.85	4.3	68	16	0.6262
3.195	4.8	66	17	0.6667	14.883	14.3	111	29	1.0745	25.931	4.7	64	12	0.8505
3.27	4.2	66	13	0.69	14.921	14.9	111	26	1.1248	25.977	10.9	66	22	0.9936
3.321	5.9	70	20	0.6783	14.937	29.1	109	60	0.9968	26.008	20	68	33	1.3113
3.381	6.5	72	17	0.774	14.965	16.9	109	37	1.0752	26.048	7.7	74	25	0.852
3.417	4	68	28	0.4068	14.998	14.2	109	30	0.9702	26.104	16.6	88	18	2.3016
3.464	5.4	64	21	0.611	15.017	27.9	109	52	1.1305	26.13	3.6	88	38	0.4264
3.519	4.8	68	18	0.627	15.053	17.3	109	28	1.332	26.173	2.8	90	23	0.5031
3.586	4.2	70	15	0.6566	15.1	19.8	109	21	1.9411	26.192	28.1	90	54	1.2882
3.653	4.9	64	15	0.7236	15.125	13.6	109	40	0.78	26.24	5.6	86	21	0.768
3.716	5.1	64	16	0.6867	15.173	17.3	111	21	1.4688	26.271	12.7	84	33	1.1315
3.782	1.2	62	15	0.2706	15.207	19.3	113	30	1.2886	26.308	8	86	27	0.7733
3.847	5	58	15	0.6695	15.244	16	111	27	1.1729	26.334	4.3	90	39	0.429
3.892	6.2	62	22	0.6435	15.259	26.9	111	65	0.882	26.361	22.8	90	38	1.3203
3.948	3.7	66	18	0.4592	15.294	15.9	111	28	1.2145	26.398	7	93	27	0.7141
3.997	3.1	64	21	0.4508	15.337	19.3	111	23	1.5265	26.432	21.2	95	29	1.7068
4.058	5.9	64	16	0.732	15.368	17.3	111	33	1.1718	26.47	5.1	97	26	0.608
4.119	3.8	70	17	0.5185	15.416	12.6	111	21	1.1376	26.493	1.8	97	44	0.3036
4.179	3.8	68	17	0.51	15.435	22.8	109	51	1.0241	26.515	29.1	99	45	1.3486
4.232	4.4	62	19	0.5406	15.486	13.8	109	20	1.1679	26.569	6	97	18	0.6966
4.303	4.9	64	14	0.7171	15.514	28.7	109	35	1.5008	26.589	1.2	97	49	0.238

Time	VO2	HR	RR	VE	Time	VO2	HR	RR	VE	Time	VO2	HR	RR	VE
4.359	5.9	68	18	0.756	15.57	9.6	111	18	0.8792	26.603	43	97	72	1.19
4.406	5	68	21	0.5781	15.597	27.9	111	36	1.5822	26.638	7.5	99	28	0.7
4.466	3.5	64	17	0.516	15.613	10.7	109	65	0.3984	26.667	4.8	103	34	0.4843
4.541	5.1	64	13	0.7725	15.648	19.1	111	28	1.26	26.686	36.5	103	53	1.2407
4.604	3.1	66	16	0.5166	15.675	29.8	113	37	1.593	26.716	12.4	103	34	0.888
4.667	5.9	66	16	0.7245	15.704	16.4	111	35	1.1397	26.757	10.6	103	24	0.8979
4.728	3.8	62	16	0.5246	15.746	14.1	111	23	1.2558	26.808	9.6	103	19	0.9792
4.833	3.4	66	10	0.6825	15.76	23.7	111	71	0.7672	26.838	13.4	107	34	0.723
4.919	5.7	74	12	0.8944	15.786	15.9	109	38	1.0114	26.858	30.3	107	49	1.118
4.976	3.9	70	18	0.5529	15.829	14.9	109	23	1.2685	26.899	20.9	105	25	1.6851
5.019	15.1	62	23	1.2986	15.845	23.4	109	65	0.8384	26.939	20	101	25	1.56
5.043	6.4	62	42	0.4728	15.881	16.7	109	28	1.26	26.976	9.5	101	27	0.8695
5.083	9.5	66	25	0.968	15.933	23.8	105	19	2.4544	27.004	6.5	103	36	0.574
5.099	13.3	72	61	0.5728	15.963	9.7	105	34	0.762	27.025	31.6	103	48	1.2852
5.145	7.7	80	22	0.8602	16.001	12	105	26	0.95	27.062	13	105	27	1.073
5.182	13.7	86	27	1.1433	16.011	28.1	105	105	0.525	27.108	21.1	105	22	2.2264
5.217	3.3	90	29	0.427	16.041	17.6	105	32	1.05	27.126	6.7	105	56	0.3132
5.262	21.3	93	22	2.3175	16.087	11.3	105	22	0.9154	27.158	10.2	105	32	0.7296
5.316	3.5	97	19	0.5778	16.133	18.4	107	22	1.2926	27.191	34.2	107	63	2.2341
5.343	18.5	97	38	1.107	16.164	17.5	107	32	1.0509	27.219	16	107	35	0.9072
5.384	6.4	93	24	0.697	16.184	38.9	107	51	1.518	27.257	13.6	107	27	1.0336
5.427	10.9	90	23	0.9116	16.21	21	107	39	1.2922	27.275	26.3	107	55	0.909
5.474	7.3	90	21	0.7708	16.248	15	105	26	1.3034	27.312	16.1	107	27	1.1914
5.498	3.7	90	42	0.3672	16.264	26.2	105	61	1.0496	27.339	12.2	107	37	0.7182
5.511	43.3	90	75	0.8372	16.293	13.4	105	35	1.0266	27.356	30.9	107	62	1.0642
5.532	4.8	90	48	0.3717	16.318	12.9	107	39	0.8325	27.386	17.7	109	32	1.125
5.581	7.2	90	20	0.7791	16.345	29.6	111	38	1.7631	27.429	21	109	24	1.6813
5.589	19.9	90	120	0.272	16.367	14	109	44	0.803	27.467	14.2	109	26	1.1894
5.636	15.3	90	21	1.4758	16.405	13	107	26	1.1096	27.495	10.5	109	36	0.6944
5.671	7	90	29	0.623	16.429	23.1	107	41	1.2984	27.522	30	109	37	1.5579
5.689	28.4	90	56	1.0062	16.45	12.6	103	49	0.6762	27.549	16	111	37	1.0395
5.732	7.1	90	23	0.7267	16.495	14.4	105	22	1.233	27.585	13.4	109	27	1.0872
5.76	19.4	93	36	1.022	16.517	29	107	45	1.2914	27.6	23.7	109	67	0.8115
5.797	10.4	93	27	0.7992	16.553	13.9	107	28	1.0728	27.632	14.9	109	31	1.0944
5.822	8.7	93	39	0.5275	16.591	23	105	26	1.7024	27.658	10.8	111	38	0.6734
5.842	23.5	93	50	0.838	16.618	14.8	105	38	0.9072	27.685	23.2	111	37	1.3419
5.877	14.2	93	29	0.9625	16.672	16.8	107	19	1.5228	27.712	14.2	111	38	0.8829
5.929	19	93	19	1.8356	16.706	17.3	105	30	1.1934	27.75	15.1	111	26	1.197
6.009	14.9	97	12	2.184	16.75	14.4	105	22	1.2672	27.768	24.5	109	56	0.918
6.039	5.7	97	34	0.48	16.763	23.3	105	78	0.728	27.804	14.6	109	28	1.098
6.093	14.9	95	18	1.2474	16.807	11.6	105	23	0.9944	27.827	8.8	109	43	0.5474
6.147	11.7	95	18	1.0854	16.829	9	105	45	0.5918	27.841	1.6	111	73	0.2786
6.175	6.6	97	36	0.4956	16.844	43.5	107	67	1.083	27.855	57.2	111	69	1.3412
6.192	39.9	97	59	1.0608	16.867	22.5	107	43	1.0764	27.885	13.9	111	34	0.927
6.224	12.9	97	31	0.8256	16.904	16	105	27	1.2395	27.92	11.9	109	29	0.882
6.258	19	97	29	1.0982	16.93	24.9	105	38	1.4716	27.937	35.9	109	59	1.2087
6.297	15.5	97	25	0.9906	16.954	15.5	103	41	0.888	27.972	14.3	109	28	1.0745
6.335	9	99	27	0.703	16.981	11	103	36	0.7128	28.014	20.8	111	23	1.554
6.354	13.3	101	52	0.6061	17.013	15.8	105	31	1.0784	28.046	14.8	111	31	1.0432
6.391	18.6	103	27	1.2099	17.044	16.6	101	33	1.1222	28.083	13	111	28	0.999
6.445	15.6	103	19	1.242	17.095	10.2	99	20	1.1118	28.11	27.8	111	36	1.4445
6.484	5.1	99	25	0.4875	17.13	12.5	97	28	0.9345	28.151	11.2	111	25	0.8692
6.513	33.9	99	35	1.4674	17.164	15.1	95	30	1.0404	28.173	5.7	111	44	0.4224
6.548	19	97	28	1.2075	17.211	11.4	86	21	1.1139	28.189	45.4	111	65	1.1392
6.583	13.4	90	28	1.043	17.248	11.4	86	27	0.9435	28.217	16.9	111	36	1.008
6.598	22.4	90	68	0.7935	17.291	11.5	84	23	1.0664	28.262	17.7	111	22	1.278
6.629	16.1	90	33	1.1315	17.328	13.2	84	28	1.1285	28.304	4	111	24	0.2982
6.678	17	93	20	1.6905	17.363	12.1	86	28	0.994	28.336	22	113	31	1.1264
6.744	7.1	99	15	0.9702	17.405	13.7	90	24	1.3104	28.359	34.5	113	44	1.4306
6.757	16.1	101	79	0.4511	17.446	6.7	90	24	0.6683	28.391	20.6	115	31	1.376
6.791	18.1	101	29	1.0506	17.493	9.2	90	21	0.8883	28.435	21.2	113	23	1.8524
6.821	6.2	103	34	0.513	17.541	9.6	86	21	0.96	28.47	14.1	113	29	1.1235
6.838	45.3	103	60	1.241	17.583	10.2	86	24	0.9156	28.498	9.1	113	36	0.6636
6.874	18.9	103	28	1.3176	17.627	11.8	82	23	1.1132	28.519	32.9	115	48	1.3965

Time	VO2	HR	RR	VE	Time	VO2	HR	RR	VE	Time	VO2	HR	RR	VE
6.922	17.3	101	21	1.5264	17.673	7.8	80	22	0.8188	28.548	17.4	115	34	1.131
6.987	10.2	103	15	0.9815	17.7	13.9	82	37	0.8613	28.584	14.3	115	28	1.1196
7.013	27.9	103	38	1.2454	17.735	11.2	86	28	0.8995	28.601	30.5	113	59	1.1458
7.047	16.8	103	30	1.0982	17.783	11.1	86	21	1.1136	28.635	16.1	113	29	1.2818
7.094	24.3	103	21	2.1197	17.829	8.2	86	22	0.7912	28.663	9.6	113	36	0.6748
7.125	11.2	101	32	0.8308	17.869	11	82	25	0.84	28.69	32.3	115	37	1.7361
7.163	11	103	26	0.893	17.909	8.8	76	24	0.76	28.723	14.3	115	31	1.1154
7.177	27.3	103	74	0.7896	17.946	12.2	76	27	0.9176	28.756	12.5	115	30	0.9108
7.205	15.6	103	35	0.9772	17.984	12.9	76	27	1.083	28.768	29.6	115	83	0.7668
7.251	14.5	99	22	1.3248	18.024	2.8	78	25	0.412	28.817	12.6	115	20	1.0927
7.285	14.8	99	29	1.037	18.053	14.1	78	34	0.9802	28.842	8.3	115	39	0.5525
7.325	12.6	99	25	1.032	18.089	11	76	28	0.9972	28.856	51	115	73	1.218
7.342	20.7	99	60	0.7973	18.119	10.4	76	34	0.873	28.887	18.6	113	32	1.1532
7.375	19.3	99	30	1.3497	18.152	10	76	30	0.8646	28.941	23.6	111	19	2.4786
7.405	11.7	99	33	0.777	18.191	8.6	78	26	0.858	28.987	7.4	111	22	0.7314
7.425	24.4	99	51	1.05	18.234	8.6	76	23	0.9073	29.026	18.7	111	25	0.9165
7.453	14.6	101	36	1.0332	18.29	6.5	72	18	0.812	29.058	22.5	113	31	1.3504
7.492	14.6	103	26	1.1544	18.333	8.9	70	24	0.9202	29.096	19.1	113	27	1.4744
7.508	25.1	103	59	0.8576	18.391	5.8	72	17	0.8352	29.113	34.6	113	58	1.292
7.542	15.9	103	30	1.2036	18.431	9.5	70	25	0.924	29.148	14.4	111	28	1.0885
7.582	13.4	101	25	1.144	18.482	7.2	72	20	0.8211	29.172	14.3	111	42	0.8232
7.594	19.8	101	85	0.5736	18.53	7.3	74	21	0.7584	29.189	30.7	111	58	1.173
7.639	13.3	99	22	1.0575	18.587	8.8	70	18	0.9975	29.219	14.8	111	34	1.092
7.661	4.9	101	45	0.4202	18.637	4.1	68	20	0.495	29.256	12.6	111	27	1.0101
7.675	53.6	101	73	1.3104	18.673	10.9	70	28	0.9144	29.271	32.1	111	67	1.023
7.704	14.8	99	34	0.957	18.726	9	70	19	1.0547	29.308	14.7	111	27	1.1803
7.747	14.1	97	24	1.2771	18.777	7.9	68	20	0.9588	29.333	12.9	111	40	0.74
7.767	27.8	95	50	1.158	18.822	7.3	66	22	0.855	29.356	23.7	111	43	1.2006
7.795	15	97	36	0.9968	18.875	7	66	19	0.9646	29.381	21.1	111	40	1.1725
7.838	14.5	99	23	1.2341	18.934	5.5	70	17	0.7316	29.424	14.5	111	23	1.2943
7.875	15	101	27	1.11	18.965	6	70	32	0.5363	29.451	22	111	37	1.3662
7.915	13.5	99	25	1.024	18.993	8.7	70	35	0.7112	29.489	12	111	27	0.8322
7.93	18	97	70	0.594	19.014	25.1	68	48	1.2957	29.521	22.9	111	31	1.184
7.965	18.2	95	28	1.246	19.045	9.6	68	33	0.9269	29.559	13.2	111	26	1.0412
7.995	11.7	99	33	0.804	19.085	7.1	72	25	0.876	29.595	18.2	111	28	1.2168
8.01	38.1	99	70	1.086	19.1	20.9	80	69	0.9045	29.614	29.9	111	55	1.1457
8.047	15.6	99	27	1.2987	19.135	7	86	28	0.784	29.651	15.2	109	27	1.2321
8.078	12.9	99	32	0.8959	19.163	2.5	86	36	0.392	29.676	7.6	111	40	0.5725
8.096	26.3	97	58	1.053	19.186	22	88	44	1.2512	29.691	42.3	111	66	1.182
8.128	13.8	97	30	1.0048	19.222	5.9	88	28	0.6768	29.722	17.9	111	33	1.2214
8.162	8.8	97	29	0.6698	19.268	10	88	22	1.3846	29.755	12.8	113	30	0.9339
8.175	28.2	97	80	0.7696	19.304	6.4	90	27	0.63	29.773	29.4	113	56	1.1736
8.213	16.6	97	26	1.3376	19.344	12.5	95	25	1.128	29.807	14.4	113	29	1.0778
8.26	32.9	95	48	3.3135	19.382	7	93	27	0.6954	29.84	10.9	115	30	0.8382
8.283	14.3	97	44	0.7406	19.434	14.1	93	19	1.5288	29.856	31	115	62	1.056
8.314	11	97	32	0.7316	19.508	3.5	97	13	0.7252	29.884	20.5	115	36	1.2432
8.343	25.6	99	35	1.3282	19.521	35.7	97	79	0.8229	29.922	13.6	115	26	1.1172
8.375	15.8	99	31	1.0976	19.561	13.6	97	25	1.112	29.937	37.1	115	67	1.1865
8.427	18	97	19	1.69	19.613	17.1	93	19	2.08	29.964	17.4	115	37	1.0854
8.493	8.8	99	15	0.8976	19.646	7.9	90	30	0.6996	29.995	13.2	115	32	0.9238
8.515	30.6	99	46	1.2254	19.678	21	93	32	1.3728	30.022	27.3	115	36	1.4121
8.545	19.9	101	34	1.245	19.709	9.3	95	32	0.7533	30.052	12.6	115	34	0.903
8.584	15.8	101	25	1.2675	19.748	10.1	95	26	0.9009	30.087	12	115	29	0.889
8.594	16.7	101	102	0.443	19.768	20.3	95	49	0.908	30.103	37.4	113	62	1.1808
8.633	15.5	99	26	1.3065	19.801	11.6	95	31	0.8811	30.163	7.5	113	17	0.72
8.672	21	101	25	1.5015	19.841	10	97	25	0.892	30.192	32.3	113	35	1.5544
8.706	13.5	101	30	1.0676	19.855	32.2	97	72	0.9268	30.223	18.9	115	32	1.147
8.752	14.8	99	21	1.3846	19.891	13.2	99	28	1.0908	30.267	23.8	117	23	1.7512
8.762	9.6	99	102	0.322	19.933	16.9	99	24	1.3902	30.301	16	115	29	1.156
8.793	17.3	99	32	1.0974	19.972	10.8	97	25	0.9477	30.338	12.3	115	27	0.9472
8.83	13.2	101	27	0.9398	20.018	15.6	99	22	1.3846	30.359	36.3	115	49	1.3986
8.845	17.1	101	67	0.633	20.051	13.9	101	30	1.0263	30.392	15.8	113	30	1.122
8.874	21.4	101	34	1.2441	20.082	4.5	103	32	0.4805	30.421	10.8	111	35	0.7714
8.914	15	99	25	1.22	20.099	45.2	103	58	1.5079	30.434	41.3	109	79	1.0582

Time	VO2	HR	RR	VE	Time	VO2	HR	RR	VE	Time	VO2	HR	RR	VE
8.926	22	97	80	0.618	20.129	8.2	101	34	0.684	30.473	13.2	109	26	0.9789
8.962	15	97	28	1.1052	20.183	14.5	103	19	1.3662	30.503	9.2	111	34	0.696
9.002	12.4	101	24	1.024	20.218	16.4	101	28	1.127	30.524	37.9	111	47	1.6065
9.018	19.5	101	64	0.6944	20.265	22.8	101	21	2.0445	30.553	15.6	111	35	0.986
9.055	19.2	99	27	1.4134	20.293	10.3	99	37	0.7336	30.59	14	111	27	1.0619
9.097	22	97	24	2.1126	20.333	10.4	105	25	0.884	30.613	31.3	111	44	1.4881
9.126	10.4	95	34	0.8149	20.352	32	105	54	1.1628	30.643	14.3	111	34	0.984
9.162	10.7	99	27	0.8424	20.382	14.6	105	33	0.939	30.676	11	113	30	0.8151
9.175	16.1	99	80	0.5213	20.427	18.8	103	22	1.485	30.697	35.3	113	47	1.4385
9.207	16.9	101	31	1.0816	20.461	10.3	101	29	0.7786	30.73	14.5	113	30	1.0626
9.248	14.6	101	25	1.107	20.501	17.2	101	25	1.3	30.777	20.3	111	21	1.6544
9.264	28.9	99	61	0.92	20.519	30.9	101	56	1.0656	30.812	13.6	109	28	1.071
9.296	15.6	99	31	1.0496	20.558	10.5	103	26	0.8892	30.84	3.8	111	37	0.4228
9.33	13.8	101	29	0.9554	20.584	2.8	103	38	0.3718	30.857	41.8	111	58	1.2563
9.342	26.6	101	88	0.6696	20.601	56	101	60	1.5997	30.885	16.7	111	35	0.9884
9.377	16.7	99	28	1.218	20.627	14.3	101	38	0.845	30.923	12.9	111	27	0.9956
9.418	9.7	97	24	0.8938	20.673	10.7	103	22	1.0626	30.948	30.7	111	40	1.5675
9.435	25.6	97	59	0.8857	20.688	37.3	103	70	1.0545	30.976	11.1	109	35	0.6804
9.465	18.7	99	33	1.143	20.727	14.3	103	25	1.17	31.051	14.6	109	13	2.22
9.492	7.1	101	38	0.5697	20.767	19.2	99	25	1.34	31.091	12	107	25	0.952
9.51	36.8	101	56	1.2546	20.832	8.4	99	15	0.8515	31.142	10.8	99	20	1.0251
9.542	17.7	103	31	1.2128	20.852	27.2	103	50	1.038	31.176	12.2	99	29	0.8024
9.58	15.1	103	26	1.1818	20.886	20.7	105	29	1.3158	31.217	15.1	97	25	1.189
9.598	25.6	103	57	1.0314	20.931	23.8	107	22	1.8855	31.251	13.6	93	29	0.9826
9.62	19.8	103	44	1.0428	20.961	14.8	107	33	1.017	31.292	12.2	93	25	1.107
9.657	12.7	103	28	1.0545	21.005	11	107	23	1.0208	31.337	10.1	93	22	1.0305
9.679	24.8	103	45	1.2584	21.017	9.2	107	82	0.4068	31.378	10.3	93	24	0.9389
9.714	14.6	105	28	1.1725	21.047	24.7	107	34	1.485	31.425	8.8	90	21	0.9165
9.752	13.5	105	26	1.1058	21.075	12.9	107	36	0.7812	31.467	11.6	93	24	1.092
9.763	26	105	91	0.6336	21.109	28.2	105	30	1.9924	31.507	13.8	93	25	1.148
9.79	16.7	103	38	0.9774	21.131	11.6	105	45	0.6732	31.548	8.6	95	24	0.7503
9.826	14.2	105	28	1.0224	21.169	13.4	105	27	1.102	31.594	8.9	95	22	0.8418
9.849	28.3	105	44	1.2926	21.189	32.6	105	49	1.308	31.638	10	90	22	0.8888
9.885	18.3	105	27	1.404	21.224	12.4	107	28	1.057	31.683	9	90	22	0.8325
9.917	11.2	103	31	0.8512	21.267	20.1	105	24	1.5093	31.729	11.2	90	22	1.0488
9.932	35.4	103	70	1.0575	21.301	10.4	105	30	0.833	31.773	9.6	86	22	0.9328
9.962	17.6	101	33	1.146	21.339	11.9	105	26	0.9804	31.816	9.4	88	23	0.9288
10.007	11.2	103	22	0.972	21.356	28.5	105	60	0.9639	31.848	14.6	90	32	1.0496
10.041	15.7	101	30	1.0744	21.386	17	105	33	1.101	31.908	6.6	90	16	0.894
10.081	16.4	97	25	1.288	21.421	15.7	105	29	1.1235	31.953	6.6	84	23	0.6525
10.115	13.7	93	29	0.9724	21.436	24.4	105	71	0.8235	31.998	10.4	80	22	0.8955
10.159	11.2	90	23	1.0208	21.486	12	107	20	1.07	32.037	10.9	78	26	0.8775
10.202	10.3	86	23	0.9417	21.518	25.4	111	31	1.424	32.082	10.3	82	22	0.954
10.244	8.3	80	24	0.7854	21.553	15.5	107	28	1.162	32.123	11.9	84	24	1.066
10.284	14	74	25	1.152	21.593	12.3	105	25	1.024	32.169	9	80	22	0.897
10.324	8.9	76	24	0.82	21.62	28.1	103	36	1.6308	32.243	5.4	84	14	0.8584
10.376	9.5	76	19	1.0712	21.648	10	105	36	0.7364	32.292	10.2	80	20	0.9555
10.425	9.4	74	20	0.9947	21.685	23.8	107	27	1.591	32.334	10.5	78	24	0.8652
10.473	10.3	78	21	1.056	21.722	13.4	107	28	1.1359	32.374	11.1	78	25	0.912
10.52	9.5	82	22	0.9541	21.764	11.2	107	24	1.0122	32.417	9.1	74	23	0.8944
10.558	9.9	84	26	0.8322	21.784	24.6	107	49	1	32.458	10.4	74	25	0.984
10.61	9.3	82	19	0.9412	21.816	13.4	105	32	0.912	32.494	10.6	74	28	0.9468
10.645	12.3	82	29	0.924	21.856	25.7	107	25	1.852	32.532	7.8	74	26	0.7942
10.674	11.9	78	35	0.8584	21.889	14.2	109	30	1.1055	32.573	4.7	78	24	0.5945
10.705	9.1	76	32	0.7223	21.915	7.7	109	38	0.6032	32.618	7.2	76	22	0.8235
10.756	8.9	72	19	1.0353	21.929	42.4	109	71	1.1018	32.663	6.9	70	22	0.7875
10.799	10.3	70	24	1.1008	21.964	10.5	107	29	0.8785	32.704	7.7	68	24	0.7954
10.837	10.9	72	26	1.0412	22.002	13.2	107	27	1.064	32.742	7.1	68	26	0.7068
10.876	10	74	26	0.975	22.018	33.5	107	60	1.0592	32.785	5.4	74	24	0.6278
10.925	9.5	78	21	1.0731	22.053	13.7	109	29	1.057	32.838	5.5	74	19	0.7102
10.967	10.6	78	24	1.0584	22.089	16.7	109	28	1.2312	32.886	4.9	70	21	0.624
10.991	6.8	76	41	0.5472	22.099	28.8	109	94	0.555	32.927	6.9	68	24	0.7093
11.014	16.7	76	44	0.736	22.136	11.9	109	27	0.9324	32.981	4.5	68	19	0.6588
11.054	9.8	78	25	0.888	22.181	16.5	109	22	1.125	33.024	6.3	70	23	0.6966

Time	VO2	HR	RR	VE	Time	VO2	HR	RR	VE	Time	VO2	HR	RR	VE
11.099	7.7	78	23	0.81	22.211	17.4	109	34	1.089	33.084	8.5	70	17	1.17
11.127	6.4	74	35	0.5124	22.239	7.6	109	35	0.2912	33.13	8.1	74	22	0.9522
11.161	13	72	30	0.9894	22.273	27.3	109	29	1.836	33.187	4.6	78	18	0.6726
11.213	8.3	68	19	0.8996	22.285	5.8	109	87	0.2472	33.232	5.2	74	22	0.63
11.245	9.1	72	31	0.7136	22.31	18.9	109	40	0.95	33.262	9.3	66	33	0.669
11.281	11.1	70	28	0.9756	22.346	23.5	111	27	1.5156	33.3	9	66	26	0.855
11.335	7.1	64	19	1.0098	22.375	18.6	109	35	1.2296	33.339	6	70	25	0.663
11.416	4.7	70	12	0.9801	22.412	11	109	28	0.9324	33.384	5	76	23	0.6255
11.474	6.9	68	17	1.015	22.437	29	107	39	1.565	33.43	5.7	72	22	0.621
11.52	9.9	70	22	1.0074	22.466	7.2	107	34	0.464	33.471	4	70	24	0.4961
11.589	5.3	68	14	0.8487	22.503	12.2	109	27	0.9731	33.502	6.5	68	32	0.5704
11.665	6.4	66	13	1.1172	22.517	42.1	109	72	1.0836	33.541	11.5	70	26	1.014
11.724	6.3	68	17	0.9322	22.544	22.9	109	38	1.2663	33.593	3.5	72	19	0.5252
11.783	6.2	70	17	0.9204	22.594	9.9	107	20	0.96	33.641	6	74	21	0.6624
11.828	6	70	22	0.7065	22.606	34.8	107	82	0.8484	33.703	4.9	68	16	0.6696
11.887	4.8	66	17	0.6549	22.634	15.4	105	35	0.9128	33.763	5	62	17	0.672
11.931	6.5	66	23	0.726	22.675	15.1	107	25	1.2218	33.802	3.7	62	26	0.4524
11.973	8.9	68	24	0.9534	22.686	32.3	107	87	0.7062	33.841	7	62	25	0.4212
12.013	10.9	70	25	1.164	22.717	22.3	107	32	1.4384	33.892	4.9	68	20	0.5916
12.047	8	74	29	0.7888	22.747	15.2	107	34	0.993	33.939	5.8	74	21	0.6157
12.101	10.8	80	19	1.7442	22.763	31.9	107	61	1.072	33.987	5.1	68	21	0.5808
12.159	2.8	86	17	0.377	22.799	13.8	107	28	1.1376	34.034	6.2	64	21	0.6439
12.185	18.3	88	37	1.0504	22.845	20.1	109	22	1.702	34.081	6.2	62	21	0.658
12.225	7.8	90	25	0.852	22.877	15.1	109	31	1.1072	34.13	6	62	21	0.6909
12.251	1.1	90	39	0.2912	22.911	15.1	109	29	1.0234	34.175	6	62	22	0.6615
12.266	32.7	90	66	1.059	22.943	25.4	107	31	1.7152	34.22	6.6	64	22	0.72
12.3	7.7	93	30	0.7174	22.967	12	107	43	0.7392	34.264	5.9	64	22	0.6776
12.341	15.1	93	24	1.4022	23.004	13.9	109	27	1.1174	34.31	5.8	66	22	0.7084
12.379	7.4	93	27	0.7638	23.019	31.2	109	65	0.9555	34.353	4.3	68	23	0.559
12.425	11.9	88	22	1.104	23.049	17.5	109	34	1.2	34.397	4.9	68	23	0.616
12.466	6.1	90	24	0.6888	23.085	13.9	109	28	1.1124	34.441	4.3	68	22	0.5808
12.491	3.9	93	40	0.43	23.101	29.5	109	60	1.0064	34.481	9.5	68	25	0.968
12.513	29	93	44	1.0318	23.132	15.4	109	33	1.1005	34.509	5.6	68	36	0.5152
12.552	9.8	90	26	0.9009	23.159	13.3	109	37	0.783	34.545	4.7	70	28	0.5292
12.598	13.2	90	22	1.2466	23.186	27.9	111	37	1.4985	34.59	4.5	76	22	0.5625
12.637	12.9	93	25	1.0959	23.235	11.7	105	20	1.1662	34.636	4.4	74	22	0.5658
12.663	0.8	95	39	0.247	23.273	24.7	103	26	1.9228	34.681	5	68	22	0.5805
12.683	31.4	97	49	1.136	23.31	9.1	103	28	0.8029	34.726	5.4	66	22	0.603
12.716	11.2	97	31	0.858	23.354	16.1	107	23	1.3332	34.782	5.5	66	18	0.7224
12.76	11	99	22	1.1044	23.387	17.9	107	30	1.1748	34.83	10.4	64	21	1.2048
12.788	15.7	99	36	0.9576	23.429	15.4	107	24	1.2264	34.873	5.4	66	24	0.6536
12.828	9	99	25	0.82	23.441	25.7	105	86	0.6792	34.925	3.7	70	19	0.5616
12.843	30.9	99	67	0.885	23.476	17.9	107	28	1.1935	34.986	4.2	70	16	0.6588
12.877	13.9	99	30	1.0506	23.508	15.8	109	31	0.9856	35.038	3.4	68	19	0.5304
12.916	7.1	99	25	0.6864	23.522	26.6	109	72	0.7798	35.076	9.9	66	27	0.8398
12.93	22.1	99	72	0.7588	23.555	19.8	111	30	1.3035	35.124	6.4	64	21	0.8064
12.958	18.5	99	37	1.12	23.592	16.7	113	27	1.2321	35.183	5.6	66	17	0.8083
12.996	7.9	101	26	0.6232	23.6	37.8	111	128	0.5104	35.229	7.3	68	22	0.8234
13.014	33.6	101	53	1.1736	23.636	15.9	111	28	1.2132	35.27	4	68	24	0.5084
13.049	14.8	99	29	1.1375	23.67	13.1	113	29	0.9112	35.327	4.1	68	17	0.5871
13.079	8.9	99	34	0.621	23.687	9.9	113	61	0.5338	35.424	3.6	64	10	0.7857
13.098	28.3	99	52	1.178	23.716	25.8	113	35	1.4587	35.481	5.2	68	17	0.7239
13.126	12.8	99	36	0.7756	23.753	15.4	113	27	1.1544	35.53	4.7	66	20	0.637
13.163	9.2	101	27	0.7918	23.776	27.7	113	44	1.334	35.572	8.3	64	24	0.8946
13.175	29.8	101	81	0.6948	23.821	13.9	111	22	1.1115	35.613	5.7	64	25	0.7052
13.214	14.9	101	26	1.1934	23.847	14	113	38	0.7956	35.683	3.6	74	14	0.581
13.265	17	101	20	1.4586	23.865	36.7	113	58	1.3266	35.747	3.7	70	16	0.6016
13.301	12.7	101	28	0.954	23.894	21.4	113	34	1.363	35.805	5.1	64	17	0.7424
13.345	17.7	103	23	1.3816	23.926	18.1	113	31	1.2448	35.845	6.4	68	25	0.696
13.38	15.9	103	28	1.1585	23.943	28.7	113	57	1.0931	35.944	6.8	70	10	1.9206
13.427	18.2	101	22	1.5886	23.978	15.4	113	29	1.197	35.985	2.4	74	24	0.3772
13.459	13.5	101	32	0.992	24.007	14.8	115	34	0.9309	36.045	2.2	70	17	0.42
13.509	17.3	101	20	1.46	24.039	16.2	113	32	1.0688	36.109	1.3	66	16	0.3264
13.569	9.6	105	17	0.906	24.075	15.4	109	28	1.1304	36.16	3.7	60	19	0.4947

Time	VO2	HR	RR	VE	Time	VO2	HR	RR	VE	Time	VO2	HR	RR	VE
13.609	22.4	105	25	1.76	24.108	11.4	105	30	0.7986	36.207	6.2	60	22	0.6815
13.631	18.9	105	46	0.8734	24.141	12.7	101	31	0.8811	36.264	9.1	64	17	1.2027
13.682	51.3	105	80	3.5241	24.176	10	95	29	0.756	36.32	4.2	70	18	0.644
13.723	14.1	105	24	1.1849	24.208	14.3	90	31	0.9376	36.391	3.7	68	14	0.6532
13.765	22	105	24	2.0622	24.244	13.3	86	28	0.9864	36.457	3.7	66	15	0.6006

APPENDIX J

QUESTIONNAIRE DATA

Pre-study Questions	**Yes**	**No**
Pre-test Abdominal Belt Use:	4	8
Time to last use of belt	2.2 years (n = 4)	
Period of last use of belt	2 months (n=3) 20 minutes (n = 1)	
Do you *think* it helped in lifting/handling heavier loads?	3	1
Do you *think* it helped reduce strain on your body?	4	0
Awareness of abdominal belts and their applications	2.83	
Do you *think* a belt would aid in lifting more weight?	7	5
Do you *think* a belt would aid in lifting more weight with less strain on your body?	5	7
Common conceptions about abdominal belt	*Prevents accidental back injuries (n = 1)*	

Post-Sub-session impressions	40 NB	40 WB	60 NB	60 WB	75 NB	75 WB
How do you rate the lifting task? (1-5)	2	2.2	3.0	2.6	3.8	3.7
Neck discomfort (1-5)	1.7	1.7	2.2	1.9	2.2	1.8
Shoulders discomfort (1-5)	1.9	2.0	2.2	2.0	2.3	2.4
Upper back discomfort (1-5)	1.8	1.8	2.1	2.1	2.1	2.2
Upper arm discomfort (1-5)	1.9	2.4	2.4	2.2	2.5	2.3
Mid-back discomfort (1-5)	1.7	1.7	1.9	2.0	1.7	2.3
Forearm discomfort (1-5)	1.7	1.9	2.2	2.3	2.3	2.8
Lower-back discomfort (1-5)	1.8	1.5	1.7	1.9	1.7	2.3
Upper-leg discomfort (1-5)	1.4	1.6	1.7	1.7	1.7	2.1
Lower-leg discomfort (1-5)	1.7	2.0	2.2	1.9	2.1	2.0
Feet discomfort (1-5)	1.9	2.2	2.6	2.2	2.8	2.7
How do you rate your overall fatigue? 1-5)	2.2	2.2	2.7	2.6	3.1	3.7
Neck fatigue (1-5)	1.5	1.7	1.8	2.0	1.9	1.9
Shoulders fatigue (1-5)	1.9	1.9	2.2	2.4	2.5	2.5
Upper back fatigue (1-5)	1.7	1.7	2.1	2.0	2.2	2.2
Upper arm fatigue (1-5)	2.2	2.2	2.7	2.7	3.0	2.7
Mid-back fatigue (1-5)	1.7	1.7	1.8	1.8	1.9	2.2
Forearm fatigue (1-5)	1.8	2.0	2.6	2.4	2.7	2.7
Lower back fatigue (1-5)	1.6	1.9	2.2	1.9	2.2	2.3
Did the belt aid in lifting? (1-5)		2.6		2.8		2.7
Did the belt restrict your movement during lifting? (1-5)		1.8		2.1		1.7
Did the belt affect your breathing? (1-5)		1.8		1.9		2.1
Was the belt uncomfortable to wear? (1-5)		2.4		2.3		2.3

<table>
<tr><td colspan="5">Post-Study belt use impressions</td></tr>
<tr><td colspan="4">Do you think a belt aids in lifting task? (1-5)</td><td>3.2</td></tr>
<tr><td colspan="4">Do you think a belt restricts movement during lifting tasks? (1-5)</td><td>1.9</td></tr>
<tr><td colspan="4">Did you think a belt affects normal breathing pattern? (1-5)</td><td>2.1</td></tr>
<tr><td colspan="4">Is a belt uncomfortable to wear? (1-5)</td><td>2.3</td></tr>
<tr><td colspan="2">Would you use the belt in a similar lifting task?</td><td>Yes- 7</td><td colspan="2">No- 5</td></tr>
<tr><td>Was this decision based on the current experience?</td><td>Current- 5</td><td>Earlier- 6</td><td colspan="2">Both - 1</td></tr>
<tr><td colspan="5">Comments on your use or non-use of belt</td></tr>
<tr><td>Negative</td><td colspan="4">Positive</td></tr>
<tr><td>Uncomfortable for long periods- 3
Breathing pattern effected- 1
Disuse will hurt- 1
Restricts free movement -3</td><td colspan="4">Helps lift heavier loads- 4
Comfortable with its use- 1
Supports lower back- 4
Helps maintain proper posture- 3
Helps in long duration activity- 1</td></tr>
</table>

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

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