LABORATORY INVESTIGATION OF A SIMULATED INDUSTRIAL TASK PRE- AND POST-ERGONOMICS INTERVENTION

BY

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THESIS

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ABSTRACT

The focus of the present study was on the investigation of the effects of an intervention strategy on an industrial task *in situ* and a simulation of the same task within a laboratory setting.

The task of offloading crates from a truck at a local business was simulated in a laboratory setting for rigorous analysis. The effect of an ergonomically sound intervention on selected physical, physiological and perceptual variables was evaluated in a test - retest experimental set-up using 28 young, healthy male students. Each of the two experimental conditions lasted for 16 minutes. In the pre-intervention task subjects were required to transfer the crates from one point to another by sliding them along the floor. During the execution of the post-intervention task responses to reductions in the stacking height and modifications of the working method were evaluated.

Results obtained for spinal kinematics during the simulated industrial task indicated a high biomechanical risk, due to large ranges of motion, high velocities and accelerations in the sagittal and transverse planes. The heavy workload of the task was also evident in elevated physiological responses (HR, R_F, V_T, VE, VO_2, RQ, EE) and perceptual ratings (RPE, Body Discomfort). Assessment of the intervention strategy revealed that the ‘high risk’ industrial task was reduced to ‘moderate acceptable’, with measurements of spinal kinematics, physiological and perceptual variables being significantly reduced. An *in situ* re-assessment of the workers’ responses to the intervention also elicited reductions in heart rates and perceptual ratings compared to the original task.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

It is a paradox that despite the exponential increase in mechanization and automation the problem of musculoskeletal disorders due to manual materials handling (MMH) remains a major area of concern around the world (Dempsey and Hashemi, 1999; Marras, 2000). Not only are governments spending an enormous amount of money on workers' compensation claims and medical treatments, but general production losses due to absenteeism, lost work time and poor quality of work also amount to billions (Ayoub and Mital, 1989; Ciriello and Snook, 1999; Ciriello, 2001). Aside from the monetary losses, one should not forget the physical pain and psychological suffering that individuals with work-related musculoskeletal disorders (WMSDs) have to endure. Unfortunately, despite extensive scientific research in various disciplines, MMH remains the number one cause of WMSDs. Buis (1990) reported that attempts to control manual handling injuries in Australia through screening and training have been in vain and occupational MMH injuries continue to account for 60-70% of lost time. In the United States, Mital and Ramakrishnan (1999) found that none of the extensive efforts to contain MMH risks had reduced the severity of WMSDs; in fact, the numbers have either remained constant or even increased. Statistics from Great Britain also show horrendous figures of workers affected by occupational musculoskeletal disorders and the resulting costs of these injuries to industry (Health and Safety Commission, 1991).

If the problem of WMSDs is so severe in developed countries (DCs), the question arises as to how much worse it is in industrially developing countries (IDCs). According to O'Neill (2000), the greatest contrast between IDCs and DCs is the amount of materials moved manually every day, be it in the manufacturing, construction or agricultural sector. It is common knowledge that financial restraints, particularly amongst small- to medium-sized businesses, which make up the majority of industries in IDCs, prevent companies from investing extensively in automated equipment and machinery. Hence human input is still required to perform excessively demanding tasks under sub-optimal working conditions and usually in extreme environmental climates. Workers in IDCs have been observed lifting loads greater than their own body weight, and stacking bricks at frequencies between 17 and 22 lifts per minute, hence moving 60-70 tons every day in extremely hot and humid conditions (Charteris and Scott, 2001). These are not isolated cases; heavy manual labour in the Third World remains the dominant pattern of work in most work sites. Unfortunately, poorly maintained or mostly non-existent databases regarding the epidemiology of work-related musculoskeletal disorders hinder any in-depth investigations into this problem. Loewenson (2001) pointed out that reporting systems in Southern Africa possibly underestimate the true occurrence of occupational diseases and injuries as much as 50-fold, which might be the reason why workers in IDCs do not receive the specialized attention they so desperately need to tackle the problem of WMSDs.

South Africa has a workforce of about 14 million economically active adults. Statistics provided by Jeebhay and Jacobs (1999) indicate that musculoskeletal disabilities, affecting mainly the hands and the back, are amongst the five most common occupational diseases. The Compensation Fund Report (1997) reveals that workers' compensation claims in South Africa exceeded R 2 billion in 1997, and time lost due to accidents exceeded 21 million man-days. This is due to each fatality or 100% disability being the equivalent of 6000 lost man-days. These statistics regarding costs and man-days lost are only due to accidents and / or incidents resulting in fatalities or extreme disabilities; excluded are the daily aches and pains that are often not reported and are difficult to attribute to a single cause, the most typical example being non-specific low back pain. It is unfortunate that job insecurity among South African labourers prevents them from reporting sub-optimal working conditions, excessive work demands and health problems (Charteris and Scott, 2001; Loewenson, 2001).

When discussing the problems affecting worker well-being one should go beyond the eight-hour work shift. O'Neill (2000) explained that poverty, poor education, malnutrition, violence, unemployment and overpopulation contribute to the physical, physiological and psychological burdens that workers in IDCs have to deal with on a daily basis. In isolation these issues are generally manageable with relatively little strain. However it is the compounding effect of these various factors at home and at work that pushes workers to their physical and mental limits. The overall result is that weak workers with poor physical work capacities usually have to perform the most strenuous jobs for very little financial rewards (Scott, 2003). Labourers who are continuously challenged to their limits will ultimately show signs of fatigue, discontentment, discomfort, pain and injuries (Dempsey, 1998). In fact, analyses by Dempsey and Hashemi (1999) on workers' compensation claims have shown that strains and sprains accounted for 57% of compensation claims, indicating that the majority of MMH claims were related to overexertion. Apart from the ill-effects on the workers' well-being, overexertion can also lead to decreased work performance. Strict quality criteria and on-time deliveries of the right quantities are the set targets in most industries. Decreased work performance leads to a failure of achieving these goals, which, in the view of highly competitive international markets, is reason enough to cut business ties. Occurrence of such a scenario in several industries will eventually result in a lack of economic growth and poor gross domestic product, as is evident in many IDCs. This in turn has a detrimental effect on the population as a whole, and the negative spiral that has emerged is difficult to reverse (Shahnavaz, 1987).

Within such a negative scenario developing countries are unable to fulfil their potential. There clearly is a need for ergonomics interventions in industries to improve the current situation and to slow down and ideally reverse the negative spiral that has emerged in IDCs (Scott, 2003). An ergonomics study should be regarded as "part of a larger process within the company, designed to combine efficiency and profitability with the general well-being of the workforce" (Haines and McAtamney, 1995). This requires optimising the relationship between the workers' physical and physiological capabilities and the task demands within their organizational and environmental context. Compatibility between these interactive components will not only improve worker safety and well-being, but also aid the company in reaching its productivity targets. Achieving this, Scott (1993) emphasized, requires in-depth knowledge of the workforce's morphological, physical and mental capabilities. Neglecting these, particularly in countries such as South Africa where numerous ethnic groups with varying physical characteristics and cultural lifestyles exist, could cause greater stress on the workers and result in effects contrary to those desired.

Regardless of whether in developed countries or in the Third World manual materials handling (MMH) remains one of the main focal points of general concern. In IDCs the extremes of the MMH task demands, environmental conditions and the generally poor physical and physiological capacities of the workforce require even greater attention from ergonomists, as an incompatibility between job requirements and worker capabilities will result in overtaxing the workers and poor production performance, ultimately failing to achieve company targets with staff concerned or product output.

Unfortunately, despite extensive research in the area of MMH, little has been achieved to promote worker well-being and improve industrial productivity in IDCs. Kilbom (1988) and Westgaard and Winkel (1997) argued that the greatest downfall of ergonomics is the distinct divide between research and application. Ergonomics is an applied science, and yet research results from the laboratory have rarely been transferred into the field, nor have most of the biomechanical, physiological and psychophysical models developed been validated *in situ*. There is hence a great need for ergonomics intervention research, particularly in IDCs, where ergonomics still is relatively unknown. Not only would it bring the concept of ergonomics to the people, it would also enable the verification of the interventions' suitability *in situ* and the quantification of the benefits of ergonomics input. Another point to be taken into consideration is the fact that the majority of ergonomics research occurs in developed countries. As the workforce in IDCs differs from workers in DCs in morphology, physical and mental capabilities and lifestyles, the interventions and guidelines devised in the First World will in all probability be unsuitable to the labourers in the Third World.

Of all the MMH ergonomics research conducted, lifting and lowering have probably received the greatest attention. Not only do they comprise 69% of all MMH tasks (Ciriello *et al*., 1999), they also contribute significantly to low back pain and upper extremity disorders. Particularly in financially handicapped countries, such as IDCs, limited mechanization demands that humans perform lifting and lowering activities involving excessively heavy objects, moved at high frequencies and in awkward postures, hence increasing the likelihood of injuries and accidents, and aggravating existing musculoskeletal disorders (MSDs).

It is therefore evident that despite the extensive research conducted in the past there remains a great need for more specific research and application. It is for this reason that the focus of the current research project was a small local bottle-sorting enterprise, where the majority of tasks consisted of manual lifting and lowering activities of crates off a truck. The aims were to identify specific manual materials handling problems within this Eastern Cape industry and to devise and implement suitable intervention strategies. By using a combination of field and laboratory work this ergonomics intervention project focussed on the changes in physical, physiological and perceptual responses to quantify the resulting benefits of the suggested intervention strategy.

STATEMENT OF THE PROBLEM

It is evident from the literature that ergonomics research takes place predominantly in the laboratory. Limited research has combined field and laboratory studies, taken theoretical solutions into industries and re-evaluated these in the field setting. The lack of implementation and verification of laboratory-based results within the field makes it impossible to determine whether theoretical interventions provide ideal practical solutions. The aim of the current research project was to identify a specific MMH task within a selected small Eastern Cape industry and to conduct a basic *in situ* analysis on the workers' responses to a selected task. Simulation and extensive pre- and post-experimentation of the observed field activity in the laboratory served to devise a suitable low-cost intervention strategy to be implemented within the original business. Finally, the effectiveness of this intervention was evaluated in the field by re-assessing the workers' responses.

RESEARCH HYPOTHESIS

By conducting a multifaceted investigation into a simulated industrial task it was expected that the proposed intervention strategy would result in reductions in spinal stresses, metabolic cost, perceived exertion and body discomfort.

STATISTICAL HYPOTHESES

The various tests of the above expectation, that the proposed intervention would improve working conditions, were framed in the following null hypotheses.

1. Spinal kinematics would remain unchanged at the highest and lowest levels of the stacked crates after implementation of the intervention strategy.

a) H_o: $\mu SK(6)_{Pre} = \mu SK(4)_{Post}$
H_a: $\mu SK(6)_{Pre} \neq \mu SK(4)_{Post}$

b) H_o: $\mu SK(4)_{Pre} = \mu SK(4)_{Post}$
H_a: $\mu SK(4)_{Pre} \neq \mu SK(4)_{Post}$

c) H_o: $\mu SK(1)_{Pre} = \mu SK(1)_{Post}$
H_a: $\mu SK(1)_{Pre} \neq \mu SK(1)_{Post}$

Where: Pre = Pre-intervention assessment
Post = Post-intervention assessment
SK = Spinal kinematics at the various levels (L) (including displacement, velocity and acceleration in the sagittal and transverse planes).
‘L’ for pre-intervention condition: Level 6 (highest crate);
Level 4 (third crate from the top);
Level 1 (lowest crate)
‘L’ for post-intervention condition: Level 4 (highest crate);
Level 1 (lowest crate)

2. Physiological responses would not differ between the two experimental conditions.

a) H_o: $\mu CV_{Pre} = \mu CV_{Post}$
H_a: $\mu CV_{Pre} \neq \mu CV_{Post}$

b) H_o: $\mu RR_{Pre} = \mu RR_{Post}$
H_a: $\mu RR_{Pre} \neq \mu RR_{Post}$

c) H_o: $\mu MC_{Pre} = \mu MC_{Post}$
H_a: $\mu MC_{Pre} \neq \mu MC_{Post}$

Where: CV = Cardiovascular responses (including heart rate and VO_2)
RR = Respiratory responses (including breathing frequency, tidal volume and minute ventilation)
MC = Metabolic cost (including energy expenditure and respiratory quotient)

3. Perceptual responses would not change between the two experimental conditions at the initial and final collection interval.

a) H_o: $\mu PR(i)_{Pre} = \mu PR(i)_{Post}$
H_a: $\mu PR(i)_{Pre} \neq \mu PR(i)_{Post}$

b) H_o: $\mu PR(f)_{Pre} = \mu PR(f)_{Post}$
H_a: $\mu PR(f)_{Pre} \neq \mu PR(f)_{Post}$

Where: PR(i) = Perceptual responses during the initial collection interval
PR(f) = Perceptual responses during the final collection interval

DELIMITATIONS

A local bottle-sorting business, where lifting and lowering activities dominated the workers daily routine was approached to become involved in the current research project. A general survey of the industry and task analyses of the working routines allowed the identification and prioritisation of four problem tasks, of which the most physically taxing activity was chosen for in-depth analysis. *In situ* assessments of the task demands focussed on heart rate and perceptual responses during a regular working day. The same task was then simulated in the laboratory and rigorously assessed.

The experimentation phase in the laboratory was delimited to using healthy male student volunteers aged from 18 to 26 years and with a stature between 1700 mm and 1850 mm. The independent variables were restricted to stacking height of the crates and working method; and because it is a universally accepted fact that handling frequency significantly reduces stresses on the body, it was not included as a manipulated variable in order to identify the effect of reductions in the stacking height and elimination of the sliding action on the subjects' responses.

The experiment focussed on physical, physiological and perceptual responses pre- and post-intervention. Dependent variables were delimited to spinal ranges of motion, velocities and accelerations in the sagittal and transverse planes of movement, reflecting the biomechanical stresses imposed on the spine of the subjects; heart rate, oxygen consumption, respiratory frequency, tidal volume, minute ventilation, energy expenditure and respiratory quotient indicated the physiological stresses experienced, while Ratings of Perceived Exertion and Body Discomfort were selected to reflect the perceptual strain experienced by the subjects.

Together with the participatory input from employer and employees an intervention strategy was developed, which was evaluated in the laboratory and subsequently introduced to the original industry and implemented albeit with some modifications. The workers' responses to the altered task were re-assessed using the same methodology and equipment as for the initial *in situ* evaluation.

LIMITATIONS

Although every effort was made to rigorously control as many impinging variables as possible, the following factors did pose limitations to the current study and should be taken into consideration when examining the results.

During the initial assessment in the bottle-sorting business the labourers worked out in the open, hence climatic conditions could have had an impact on the initial *in situ* assessment, as differences in heat and humidity could not be controlled for. An unexpected change of venue however occurred between the first and the final *in situ* assessments and, as a result of the new venue providing undercover workspaces, exposure to environmental stressors such as extreme heat, cold and rain was reduced. Even though the basic set-up and work processes remained similar, the situational change could have had an impact on the workers' post-intervention responses.

Subject selection in industry was limited to the industrial workers who always performed the offloading task under investigation in the current study. Subjects for the laboratory experiments were also not randomly selected, as the researcher relied on student volunteers to participate in this project.

From pilot studies the duration of each experimental condition was set at 16 minutes. With task demands however proving to be excessive, a build-up of fatigue was inevitable, therefore limiting extrapolations of physical, physiological and perceptual responses to longer durations.

The industrial workers differed noticeably from the laboratory subjects in terms of health, work capacity, socio-economic background and experience. These, plus ethnic and cultural differences between the Black Xhosa workers and the mainly White student volunteers could not be controlled, nor could lifestyles and pastime activities. Extrapolations of responses to changes in the task characteristics from one population to another are therefore limited.

CHAPTER II

REVIEW OF RELATED LITERATURE

INTRODUCTION

The ongoing research into work-related musculoskeletal disorders (WMSDs) has done little to alleviate the problem in industries around the world. In developed countries the post-industrial trends, which have lead to increased automation and robotics, have contributed significantly to reducing the amount of heavy manual labour amongst workers, but have achieved very little to reduce the prevalence of musculoskeletal disorders (Buis, 1990; Mital and Ramakrishnan, 1999; Marras, 2000). If the problem of WMSDs is so severe in developed countries and limited improvements have been accomplished despite decades of research and intervention attempts, the problem is suspected to be even greater in industrially developing countries (IDCs), which include more than three-quarters of the world's working population (Shahnavaz, 2000).

In IDCs manual materials handling remains the dominant pattern of work. Daily, workers move tons using only their bodies to lift, lower, push, pull, hold, carry and even throw materials. Mital (1999) found that employers in IDCs continue to rely on manual labourers as they are not financially able to invest in automated equipment, do not have the space available for machinery or the diversity of tasks is too great to be performed by a machine. Unfortunately it is the workers who have to make up for these shortcomings, even though it often means overtaxing their musculoskeletal and cardiovascular systems. The lack of regulations and legislation in IDCs results in workers having to perform unreasonable tasks under difficult conditions, often for longer than the accepted eight-hour work shift.

Historical political issues have led to the majority of the South African population being uneducated or semi-skilled, and most workers are left with no choice but to be part of a large group of manual labourers who often have to work under sub-optimal conditions. In most cases poor economic growth prevents employers from paying their labourers more than minimum wages, which means little investment into housing, often kilometres away from the workplace, inadequate dietary intake and poor health (Shahnavaz, 1987; O'Neill, 2000; Scott, 2002a). Long travelling distances to and from work, often by foot, and poor nutritional and health status generally (now amplified with the HIV/AIDS pandemic) significantly reduce the workers' physical and physiological capacities before they even begin with their physically demanding jobs. At the workplace sub-optimal workspace layouts, poor process design, bad working postures, unpleasant environmental conditions and inappropriate organization of work contribute to increasing physical and physiological fatigue, which in turn increases the likelihood of accidents and musculoskeletal injuries (MSIs). Additionally, increases in production pressures and rapid changes in production systems not only impose excessive physical and physiological, but also perceptual stresses on the workers. The resultant discomfort, pain, dissatisfaction and inability to perform up to the employers' expectations eventually leads to high worker turnover, absenteeism, poor labour relations, strikes, poor product quality and low quantities (Jafry and O'Neill, 2000). The resultant low productivity puts a company at a distinct disadvantage, particularly in terms of international competitiveness. Poor productivity among South Africa's factories also translates into poor national economic growth, which in turn aggravates the workers' general quality of life. As one damaging factor initiates and leads to another, the negative spiral intensifies and becomes increasingly difficult to reverse.

Contrary to impressions that ergonomics is a luxury for rich countries, it is in IDCs that ergonomics has an enormous role to play by breaking this vicious cycle (Bao and Shahnavaz, 1989). The key for this lies with improving productivity. Even a small increase in productivity will lead to nominally higher incomes, which will help the workers improve their nutrition, housing and educational status. This will have positive impacts on their health, increasing their working capacity, which in turn will improve productivity. Baptista and Moro (2001) pointed out that ergonomics interventions are able to improve the quality of work life, which will lead to an improvement in the individuals' overall quality of life.

Essentially, it is all about the *proper use of manpower*. Improving productivity "is not about making people work harder, it is about equipping, organising and motivating people to work more effectively" (Greenborough, 1980). In a complex context such as the South African one, Candler (1993) emphasized a holistic approach to devising interventions. Not only do practicing ergonomists require a profound knowledge of the work capacities and cognitive differences of the various ethnic and cultural groups, but also insight into the nature of the industry that requires ergonomics input. No ergonomics intervention can be successful if not considered together with managerial strategies, production systems and production requirements. Solutions, particularly in IDCs, need to be 'tailor-made', as they could otherwise turn out to be more of a disservice to the company and its workers than goodwill (Gurr *et al*., 1998).

Whatever the cause, any incompatibility in the human-task-environment system will result in inefficient work, fatigue and injuries among the labourers, and low product quantity and poor product quality for the company. According to Ayoub and Mital (1989) and Dempsey (1998), the key to improving an inefficient system, that is harmful to both employee and company, is to understand the cause and effect relationships, and to consider the total effect of positive and negative influences. Analysing any manual materials handling system therefore requires investigations into its four main components:

1. Worker characteristics
2. Task demands
3. Environmental factors
4. Organizational factors

WORKER CHARACTERISTICS

Probably the most difficult component to investigate in any MMH system is the human operator. Although the prime focus in ergonomics is the worker's strength and physiological capacity, Smith (2001) pointed out that an individual's work capacity is determined by genetic, psycho-social and environmental factors. It is this nature - nurture interaction that is a challenge in all human research as it results in substantial variability among individuals, thus complicating the development of intervention strategies, which will be of benefit to all workers involved.

Morphology

The assessment of a worker's morphology is an essential part of any ergonomics analysis as these measures are important determinants of the individual's work capacity (Ayoub and Mital, 1989). Stature, body proportions, ratio of body fat to lean muscle mass and bone density will all influence an individual's responses to manual work. Assessments of these variables are particularly important in IDCs as very little is known about the morphological characteristics of the indigenous working population. Due to the absence of local databases in South Africa, manual handling guidelines that were originally established for the European population continue to be used in IDCs, despite obvious limitations.

Considerations of basic physical measurements are important in workstation design and workspace layouts, as Southern African workers tend to have longer extremities, and yet are shorter in stature than their European counterparts (Wagner and Heyward, 2000). Comparisons of Pheasant's (1996) anthropometric databases of European and American males with Tobias' (1990) measurements of Black Southern African males revealed that the latter group is on average 50 mm shorter than the former population. This difference is even greater when comparing European males with Coloured South African males from the Cape Peninsula (Steyn *et al.*, 1990). Although being shorter may be advantageous for low working heights, as less of a stoop is required than for taller individuals, higher working surfaces will place considerable stress on the shorter workers' upper extremities and backs.

Body weight plays an important role in the relationship between the labourers' strength and manual materials handling capacities. During manual handling workers do not only have to carry, lift or lower the mass of an object, but also the weight of their heads, arms and trunks, which account for approximately 75% of body mass (Williams and Lissner, 1962). Carrying excessive body weight, particularly fatty mass, places considerable stresses on the skeletal system, mainly on the lower back, therefore rendering the individual prone to low back problems. Any additional load also increases the metabolic expenditure rate, which means that for the same job heavier workers will be more physiologically stressed than their lighter counterparts (Ayoub and Mital, 1989).

A study by Wagner and Heyward (2000) on the body composition of Black Africans showed 5-7% more lean body mass and a greater mineral density in bones compared to White subjects from similar socio-economic backgrounds. However the socio-economic divide between Black and White people in South Africa is still very distinct, and many Black people particularly in rural areas continue to live on or even below the breadline and adequate nutritional intake is rare. In a malnourished state the body tends to resort to muscular proteins and skeletal minerals as energy sources, leaving the worker's musculoskeletal system in a frail state. At the same time however many South Africans are undergoing the transition from rural to urbanized lifestyles. Traditional foods of rural Black people are low in fat and high in unrefined carbohydrates and dietary fibre, but Bourne *et al*. (1993) noticed that fat, salt and sugar consumption tended to increase and physical activity decrease with urbanization, hence raising the risk of obesity and cardiovascular diseases.

Ergonomists in South Africa are therefore faced with the challenge of designing workplaces and work processes and devising interventions for people with large variations in morphologies and wide ranges of ethnic and lifestyle factors.

Strength Capacity

Muscular strength is arguably the single most important factor determining an individual's ability to perform manual labour. As strength is a muscle's maximum ability to overcome an external force, the capabilities of muscle groups in the arms, legs and back determine the workers' abilities to deal with the demands of the common manual tasks of lifting, lowering, carrying, holding, pushing, pulling and throwing.

Strength expression is multifaceted with physiological determinants ranging from the muscle's cross-sectional area, its location in relation to bony levers, the ratio of fast-twitch to slow-twitch fibres and the innervation of nerves to the body's overall aerobic capacity. According to McArdle *et al*. (1996) human skeletal muscle can produce between 16 and 30 N of force per square centimetre. Hence, the larger the muscle's cross-sectional area, the greater the force that can be exerted. From their study of body composition differences between Black and White individuals, Wagner and Heyward (2000) found that the Black people had a greater tendency towards mesomorphy, probably due to a greater secretion of growth hormone, and hence a greater strength capacity. Not to be forgotten though is that in the Third World context inadequate nutrition inhibits muscle development, and that Black workers might be relatively weaker than individuals from the more affluent population. At the same time, however, rural workers generally tend to be more physically active and the work conditioning effect may result in a greater strength capacity than in sedentary workers. The law of specificity states that only the muscles specific to a certain activity will undergo increases in size. The difficulty lies in determining whether the muscle strength gained by physical labour, outweighs the loss of muscle mass due to malnutrition.

Muscular work can be static or dynamic in nature. Static work is any activity that requires muscles to contract at a constant force over an extended period of time. This leads to the compression of blood vessels, decreased oxygen delivery to the muscles, reduced strength exertion and increased strain, discomfort and pain (Mital *et al*., 1997). The work performed not only depends on muscular strength but also the ability of the surrounding structures, such as ligaments, tendons and articular cartilage, to withstand external forces. Depriving these structures of essential blood supply weakens them, rendering the skeletal system even more vulnerable to the hazards of manual work. Particularly a weak back is prone to musculoskeletal problems associated with heavy manual labour. It is for these very reasons that static activities, such as holding while standing or walking, or stooping while working should be avoided. Concentric and eccentric muscle contractions on the other hand are dynamic and therefore more favourable than the isotonic contractions during static work. Confined working spaces forcing workers to adopt awkward postures often require the labourers to exert static strength. However, a lack of strength could also force labourers to adopt alternative awkward working techniques to cope with the work demands, which might exacerbate the problem, resulting in a negative spiral. Muscular fatigue is highly probable during an eight-hour shift of manual labour, as overstimulation causes muscle contractions to become progressively weaker until they eventually cease. The efficiency of the cardiovascular system to remove waste products and to supply the muscle with oxygen and nutrients also decreases, hence increasing the risk of MSIs.

It is common in ergonomics assessments to obtain ‘maximum voluntary contractions’ from subjects or industrial workers as a measure of their maximum strength capacities. However, Ayoub (1992) and Dempsey (1998) remarked that, although previous prediction equations for MMH capacity have relied on static measures of strength, these tend to underestimate forces and moments as they ignore the additional loads imposed by dynamic actions. Obtaining dynamic measures might therefore be a better predictor of physical capacity, even though obtaining these clearly is more complex (Andersson, 1985).

Aerobic Capacity

For any manual materials handling task, it is not only important that the workers have the strength capacity to handle heavy loads, but that they are also able to sustain a specific work output over a period of time. Working shifts tend to be eight hours or more in duration and the Basic Conditions of Employment Act of South Africa states that workers must have a 60-minute break for every five hours of work (Department of Labour, 1997). As this leads to a virtually continuous working pattern, workers require a certain minimum physical work capacity (PWC) in order to maintain the required work pace throughout the work shift. Smith (2001) defined this PWC, also known as aerobic capacity or VO_{2max} , as the “maximum levels of physiological exertion that can be achieved by an individual“. It is commonly accepted that working at 33% of an individual’s VO_{2max} can be sustained for an eight-hour working day, with little risk of overexertion (Smith, 2001). However, Ayoub (1992) as well as Dempsey (1998) and Bot and Hollander (2000) cautioned that aerobic capacity is task specific, and that performing at 33% of the individual’s aerobic capacity determined on a cycle ergometer or a treadmill, might be too great for tasks demanding input from the upper extremities. The PWC is also dependent on the worker's general health status. Labourers come from many different regions in southern Africa and they therefore differ in their state of nutrition, habitual activities and endemic diseases, which in turn affect their aerobic capacities.

Overexertion of any physiological system leads to fatigue. Local fatigue refers to the inability of a muscle or muscle group to sustain a certain work rate, whereas whole body fatigue is the inability of the cardiovascular and pulmonary systems to continue supplying the body with oxygen and nutrients and removing waste products. According to Basmajian (1967) and Åstrand and Rodahl (1986) general indicators of fatigue include a decline in mental alertness and motivation, a reduction in work output and endurance time, weaker and slower muscular contractions, localized pain, increases in lactate accumulation and core temperature and increased respiratory, circulatory and neuromuscular functions. Heart rate, cardiac output, ventilation rate and oxygen consumption (VO_2) rise at the onset of an activity and increase with increasing task demands. Åstrand and Rodahl (1986) explained that once the workers have settled into a working rhythm and the oxygen uptake equals the oxygen requirement of the working tissues, the above-mentioned physiological measures reach a plateau or 'steady-state'. However, at some point fatigue does set in and with it a phenomenon known as 'physiological drift', where physiological responses gradually rise again and could lead workers to the limits of their PWC (Patton *et al*., 1991). When the stage is reached where no further increases in these physiological measures are possible, individuals are making full use of their aerobic capacity.

The conclusion that can be drawn is that individuals with greater strength and a larger aerobic capacity are better prepared for prolonged and heavy manual work than physically and physiologically weaker persons (Mital *et al*., 1997). Genaidy *et al*. (2001) suggested that muscularly stronger individuals would be more suitable for heavy loads, whereas workers with large aerobic capacities might be more appropriate for fast-paced tasks. Again, the challenge of ergonomists in IDCs is to offer interventions that are suitable for a large range of individuals. In addition, the differences in lifestyles and health status indicate that manual handling guidelines established for European populations may not necessarily be appropriate for workers in the Third World.

Psychological Factors

Even though it is not an ergonomist’s task to derive any conclusions about the workers’ psychological state, acknowledgement of psychological and perceptual aspects is of essence, as the focus of ergonomics is on the *human factor*. Humans are emotional beings, hence their personalities, fears, attitudes, motivations and perceptions have a direct effect on the manner in which an activity is executed. Often workers in IDCs are already in a fatigued state when they arrive at work. Poor socio-economic backgrounds, inadequate nutrition, overexertion, lack of sleep, conflicts and worries result in low work capacities and poor motivation. Together with mental and / or emotional fatigue this physical exhaustion contributes to low arousal and lack of attention, hence accelerating the onset of real and perceived exertion. Reduced sensory stimuli, sluggish central information processing and being physically unprepared for situations demanding quick or accurate reactions generally result in poor work performance and an increased risk of accidents occurring. Extremes of perceived exertion will lead to stress, which arises when individuals feel they are no longer able to cope with the set work demands. Manual labourers in IDCs are also often regarded as being inferior and only good enough to perform menial tasks. It is thus not surprising that this lack of respect, together with poor organization, poor incentives, inadequate communication with supervisors and colleagues, plus a negative working ambience contribute significantly to overall work stress.

Ayoub and Mital (1989) pointed out that physical, physiological, mental and emotional factors determine the workers’ “end-point” of performance and that pushing the workers to the extremes of their various capacities, including the psychological, could have undesirable repercussions. Assessment methods of perceptual responses to the demands of work, such as Ratings of Perceived Exertion and Body Discomfort, will be discussed at a later stage.

Training and Experience

Prerequisites for safe and efficient manual materials handling are workers who are physically and mentally prepared for the task. Particularly in IDCs, where workers have low work capacities, work-hardening programmes are a simple, yet effective means of preventing musculoskeletal disorders, as they lead to improvements in strength and aerobic capacities (Ayoub and Mital, 1989). Kroemer and Grandjean (1997) and Mital *et al.* (1997) also pointed out that training has great educational value. As even basic education amongst the general population in industrially developing countries is poor, the benefits of training programmes include common skills, knowledge on the procedures and processes, safe manual handling techniques, as well as gaining the ability to identify and cope with general task demands and hazards (Kroemer and Grandjean, 1997). The same authors emphasized that familiarity of a task increases with experience and it is for this reason that experienced workers are able to perform tasks with greater mechanical efficiency, more precise movements, better concentration and visual control and reduced perceived exertion than new workers.

The existence of these specialized capacities needs to be considered during laboratory and field research, as student volunteers, usually with limited MMH experience, are the most common subjects partaking in laboratory experiments, whereas in industry measurements usually occur on the workers themselves. The use of the research results on the responses of volunteers and applied to industrial workers should be used with caution. Although comparisons of the workers in Ciriello and Snook's (1983) research and the student subjects in a study by Jiang *et al*. (1986) showed similar maximum acceptable weights (MAW) and heart rate responses for lifting, lowering and carrying tasks at various frequencies, Mital and Manivasagan (1983a) found that regardless of the lifting frequency, experienced male industrial workers were able to lift 6 kg more than inexperienced students. In similar studies, Mital and Ilango (1983) and Mital (1985) confirmed that job experience increased the MAW for lifting and carrying tasks. A familiarization period for volunteering subjects should hence be considered.

Other Factors

Apart from morphological and physiological variations between ethnic groups, *cultural considerations*, such as differences in language, religion, cognition and perception also exist. Morals, ethics and cultural customs could influence the way a task is performed; a job that might be perceived as reasonable in one culture might be completely unacceptable in another. Understanding differences in perceptions and interpretations of basic requirements are crucial to preventing misunderstandings, which are likely to result in accidents, improper operation of machinery and poor product quality. However, unless immersed in a particular culture for a considerable amount of time this aspect of human variability is extremely difficult to understand. Nevertheless, O'Neill (2000) stresses that cultural considerations should be an integral part of ergonomics investigations, particularly in industrially developing countries, as it affects relationships between human performance and its controlling variables, sensory functions and perceptions, and cognitive processes and mental models, hence influencing psychophysical responses to an activity.

TASK CHARACTERISTICS

Task characteristics refer to the elements that describe specific manual handling activities and that affect the manner in which workers go about lifting, lowering, pushing, pulling, carrying and holding materials. Although the focus of this research project was on lifting and lowering tasks, manual materials handling activities in industries rarely consist of a single task, but rather occur in combinations of various sub-tasks. Mital (1999) and Mital and Ramakrishnan (1999) highlighted the fact that little attention has been paid to designing and analysing tasks which include diverse manual handling activities. According to Ciriello *et al*. (1999) the difficult part of analysing combination tasks is that the task parameters differ between various jobs and that even within a certain job, the task characteristics do not necessarily remain constant. Jiang *et al*. (1986) proposed that the only way to analyse a combination of MMH tasks is to analyse each component in isolation and from that determine the limiting factor in the activity.

Load

Object weight is probably the most researched task characteristic in MMH, mainly due to the negative effects of heavy loads on the musculoskeletal system. With increasing loads the stresses on the musculoskeletal and cardiovascular systems are amplified, accelerating the onset of fatigue and the workers' perceptions of exertion.

Health and safety representatives in industries often request handling guidelines, specifically with regard to maximum loads, which may be handled by most people without excessive weariness or MSI risks. Although extensive research has been conducted in search of the 'ideal' load, there is no single maximum acceptable weight (MAW). Instead, it is the combination of load and other task characteristics that eventually results in fatigue and / or musculoskeletal disorders. The MAW is extremely task specific as variations in postures, working heights, frequencies, couplings, work space, object size and shape amongst others, influence the workers' capabilities of handling objects (Ayoub and Mital, 1989; Sanders and McCormick, 1993).

Physical, physiological and psychological responses also differ between specific MMH tasks. Ciriello and Snook (1983) and Davis *et al.* (1998), for example, found that that lowering consistently exhibited greater MAWs than lifting, and Ciriello (2001) reported that the MAWs of combined tasks were significantly less than the MAWs of the individual components. It is from this research and a previous study by Ciriello *et al*. (1990) that the conclusion was derived that the limiting factor of combination tasks was the component with the lowest acceptable weight. The same authors also found that it was the lifting activity that had the lowest MAW, compared to lowering and carrying tasks, but when assessing the three tasks in combination, MAWs were 19% lower than for the individual lifting activity.

Pheasant (1991) stated that the "maximum safe weight" is a range of masses, rather than a single load. As depicted in Figure 1 this 'safe' weight begins with a risk threshold, the point at which a marked increase in manual handling risk occurs, and ends at a maximum cut-off point, after which the manual handling risks become unacceptable. It is particularly in this "zone of steadily increasing risk" that the workers' physical and physiological weaknesses, together with other task characteristics need to be taken into consideration.

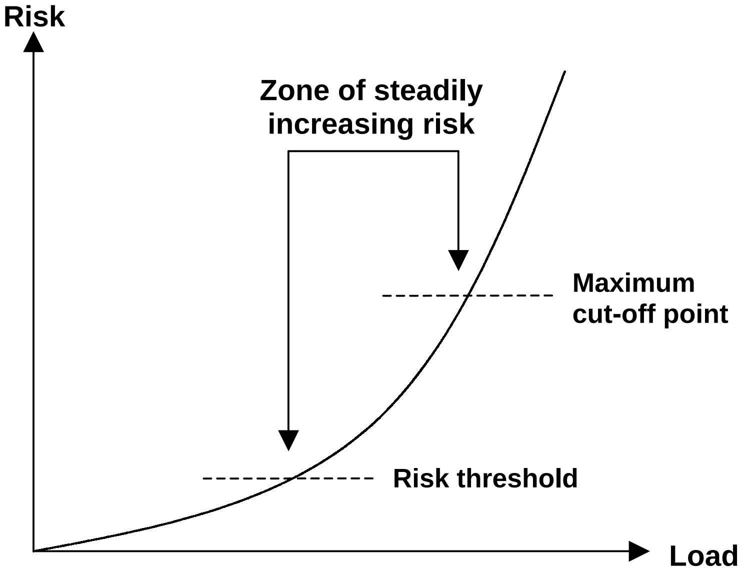


Figure 1: Hypothetical risk curve, depicting the zone of "maximum safe weight" (adapted from Pheasant, 1991).

According to Nicholson (1989) and Buckle *et al*. (1992), however, there seems to be a distinct discrepancy between 'acceptable' lifting limits, which are the limits that workers are willing to handle, and 'safe' lifting limits, which fall in line with the biomechanical and physiological criteria of what is considered potentially unsafe to exceed. Guidelines put forward by the National Institute of Occupational Safety and Health (NIOSH) set the 'recommended weight limit' (RWL) for a 'standard' lift under ideal conditions at 23 kg, after which the compressive forces on the spine exceed the 'safe' limit of 3400 N (Waters *et al*., 1993). However, 'acceptable' loads seem to be far greater than the 'safe' limits. Genaidy *et al*. (1998) had subjects assign different verbal cues to various loads and found great variations of perceptions of heaviness, particularly between loads of varying degrees of 'heavy'. The results showed that male subjects classified the NIOSH RWL of 23 kg only as 'somewhat heavy', whereas the average maximum weight the subjects were willing to handle was around 63 kg. In IDCs, where there is a limited amount of automation, labourers are required to move loads manually. These loads often exceed ‘safe’ handling limits and sometimes even ‘maximal acceptable’ limits. LIFTRISK, devised by Charteris and Scott (1990), has extended the weight range to 42 kg as the maximum acceptable load, but it is important to note that, particularly in IDCs where the indigenous workforce generally has a low work capacity, such loads need to be assessed in conjunction with other task characteristics and the capacities of the workers handling them.

Frequency and Duration

Frequency, according to Marras *et al*. (1995) and Mital *et al.* (1997), is probably the most important task characteristic when considering the physiological cost necessary to execute the required activity. Heart rate, oxygen consumption and metabolic cost increase in a non-linear fashion with increasing handling frequencies, hence accelerating the onset of overall body fatigue. The fact that different tasks exhibit different responses at various frequencies needs to be considered in the analysis of combined activities. Mital *et al*. (1994) found that lifting tasks between 14 and 22 handlings per minute exhibited significantly higher heart rate and oxygen uptake responses than lowering tasks. The same authors also found that MAWs decreased by 15% and Ratings of Perceived Exertion increased with an increase in handling pace. Jiang *et al*. (1986) explained that physiological limitations play an important role in MMH activities, which are performed at high frequencies, due to the increasing significance of adequate physiological recovery, whereas both strength and physiological capacities have a mixed influence at low frequencies.

For repetitive lifting of 23 kg the National Institute of Occupational Safety and Health determined that the ideal lifting frequency is one lift every five minutes, and no more than 15 lifts per minute for very light loads (Waters *et al*., 1993). In IDCs such frequencies are unrealistic, as lift rates of more than 20 lifts per minute have been observed. It needs to be acknowledged that the lifting rate and RWL have a complex relationship. Not only is the ‘ideal’ frequency intrinsically mass-dependent (Scott *et al*., 1992), but Dempsey (1998) found that biomechanical, physiological and psychophysical experiments all yielded different recommended loads for various frequencies (Figure 2). He hence concluded that the RWL at a particular lifting frequency should be based on the most conservative value from the three approaches. This means that the biomechanical approach would be the most appropriate for determining ideal loads for low intensity tasks, the psychophysical approach for moderate frequencies and the physiological approach for highly paced lifting activities. As these trends are derived from lifting and lowering activities they might not necessarily apply to other MMH tasks. Waters *et al*. (1993) did emphasize though that the activity most affected by frequency is repetitive lifting, due to the recruitment of more muscle groups, hence resulting in larger energy cost, and that other tasks, such as carrying, pushing and pulling are less severely affected.

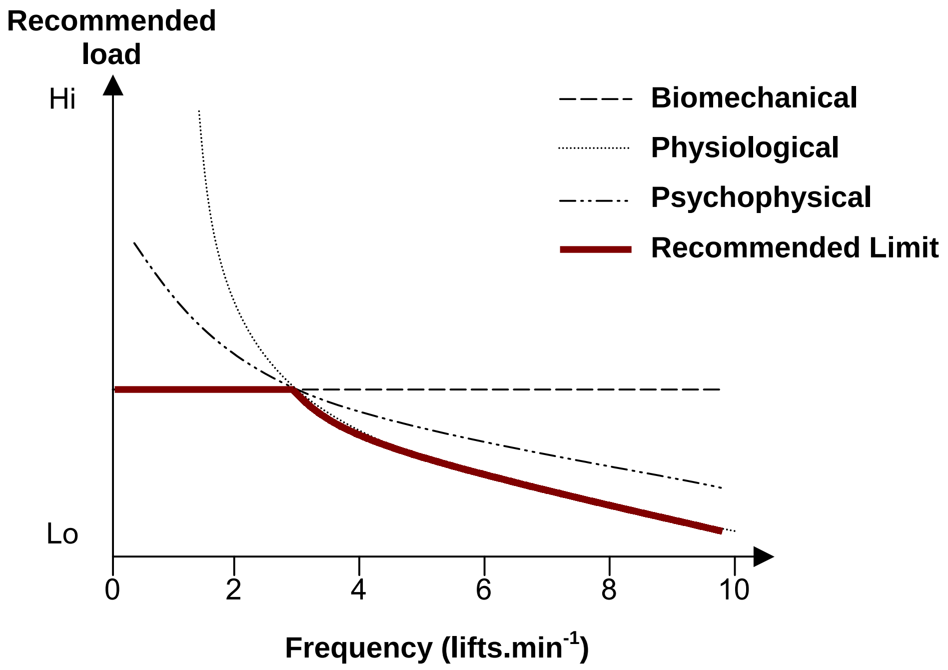


Figure 2: Conflicts among different design criteria for repetitive manual materials handling (taken from Dempsey, 1998).

Usually the *duration* of a working shift is an average of eight hours. For excessive working demands energy expenditure over such a period of time leads to a depletion of energy resources and a build-up of lactic acid, which eventually manifest themselves as general fatigue, muscular weakness and even localized discomfort (Ayoub and Mital, 1989). In a psychophysical experiment Mital (1983) found that MAWs were directly affected by the task duration and that MAWs decreased by 3.4% every hour during a 12-hour working shift. A particular concern, which arises with continuous lifting and lowering over an extended time period, is static fatigue. Although all MMH tasks are dynamic in nature, they do have a static component, such as isometric muscle contractions in the upper body, when holding a load during lifting or lowering tasks (Jiang *et al*., 1986). The NIOSH guidelines therefore recommend a duration of no more than one hour for repetitive lifting (Waters *et al*., 1993).

Frequency and duration are both temporal factors in manual materials handling that cannot be assessed in isolation, especially as combinations of various MMH tasks occur more frequently than individual handling activities. An increase in one parameter should hence warrant a decrease in the other, and adjustments to work rate and duration should be in keeping with physiological criteria. Unfortunately, the pace and duration are often set by either machines, the shift's overall daily production target or the duration of the shift or work processes, leaving the workers little flexibility to pace themselves according to their capabilities. Although redesigning work processes and introducing mechanical aids can reduce the severity of musculoskeletal stresses and fatigue, Mital *et al*. (1997) cautioned that they cannot prevent them entirely. This calls for the need for job rotation or rest allowances, which should be determined according to the task intensity, cardiovascular and muscular demands and the labourers' work capacities.

Distance – vertical and horizontal

According to Ayoub and Mital (1989) and Marras (2000) two types of forces act on the musculoskeletal system. External forces are generally the effect of gravity acting on the load and body parts, whereas internal forces, such as muscle contractions, intra-abdominal pressure and passive forces from connective tissues are created to support the external load. However, due to the mechanical disadvantage the body tissues have to work at, the internal forces usually exceed the external ones, thus increasing the likelihood of overexerting the musculoskeletal system (Pheasant, 1991). Particularly excessive vertical distances, as with high or low working surfaces, and horizontal distances due to far reaches, amplify the forces acting on the body.

Vertical distances either affect the upper extremities for excessively high, or the lower back for extremely low working heights. Hoozemans *et al.* (1998) pointed out that high working levels place the arms and shoulder region at a considerable risk, particularly in combination with twisted postures and static loads. Apart from taxing the relatively gracile muscles of the upper extremities, lifting or manipulating objects above shoulder height has circulatory implications, as blood has to be pumped against gravity to the working muscles. Less efficient oxygen transport will result in less effective force production and an earlier onset of fatigue (Chaffin and Andersson, 1991). With excessively low working heights the increasing angles of trunk inclination are accompanied by an anterior shift of the worker's centre of gravity. The dramatic increases in the shearing forces on the lumbar spine are the result of the erector spinae having to create a torque large enough to maintain balance, while moving the weight of head, arms and trunk plus the mass of the object in a controlled manner.

In terms of energy expenditure, Sanders and McCormick (1993) pointed out that the metabolic cost of lifting objects off the floor is greater than lifting them from 'ideal' heights, due to the additional effort of lowering and raising the body. Acknowledging the 75% of body weight (HAT), which has to be lifted in addition to the external load, there will be an elevation in the energy cost. As a general rule of thumb working heights should not be lower than knuckle height or exceed the shoulder level. The NIOSH equation has therefore set the minimum level from which an object should be lifted, at 750 mm above floor level (Waters *et al.,* 1993). The NIOSH equation and psychophysical studies conducted by Ciriello and Snook (1983) and Ciriello (2001) also demonstrated that a vertical lifting distance of 250 mm produced larger MAWs than distances greater than 250 mm. However, in a study on the effects of vertical height and distance on lowering tasks, Ciriello (2001) found no differences between the MAWs of lowering objects from knuckle to floor level, and from shoulder to knuckle height.

Working situations in IDCs often require lifting loads from pallets on the ground and stacking objects beyond shoulder level, which is why in LIFTRISK stooping heights range from 150 mm to 720 mm and stretching heights from 720 mm to 1700 mm (Charteris and Scott, 1990). Even though 720 mm corresponds to the knuckle level of the average South African worker, working heights need to be assessed in conjunction with the workers' morphology. Stature, in particular, influences the 'ideal' working height; taller subjects will be more stressed during extreme stoops, whereas shorter labourers will experience greater strain with extreme working heights.

The *horizontal distance* of the load in relation to the worker is, according to Sanders and McCormick (1993), the most significant factor affecting compressive and shearing forces on the L5/S1 disc. The further away an object is situated from the labourer, be it due to awkward shape, size or unsuitable handling technique, the further the worker has to reach to hold the load. Far horizontal reaching distances cause an increase in trunk flexion angle and an anterior shift in the centre of mass, which offsets the worker's balance. The resultant torque required by the erector spinae muscles, to prevent the body from toppling over, significantly increases the shearing forces on the spine (Knapik *et al*., 1996). When increasing the horizontal reach distance from 400 mm to 600 mm Lavender *et al*. (1999) observed a 17% increase in sagittal plane moments acting on the spine, which is indicative of a greater risk to the musculoskeletal system. Apart from the increases in disc forces, spinal and muscular strain, Knapik *et al*. (1996) also found that energy expenditure increased the further the load mass was from the individual's centre of gravity.

Objects are seldom simply lifted and lowered. In addition to lifting or placing a load, a certain degree of horizontal displacement is often required. Specific placement of an object onto a pallet or shelf involves a vertical lift of the load, while simultaneously moving it in a horizontal direction. Figure 3, taken from Charteris and Scott (1990), illustrates the relationship between vertical and horizontal factors and their effects on MMH risks. The vectors are indicative of the movements. Motions from A to B and A to C depict vertical and horizontal movements respectively, whereas a movement from A to D is a combination of the two, as explained in the scenario above. Numbers 1 to 10 represent the increasing strain on the body and the associated MMH risk. Not only do spinal shearing forces increase, but so does the muscular strain in the back and upper extremities, hence accelerating of the onset of fatigue.

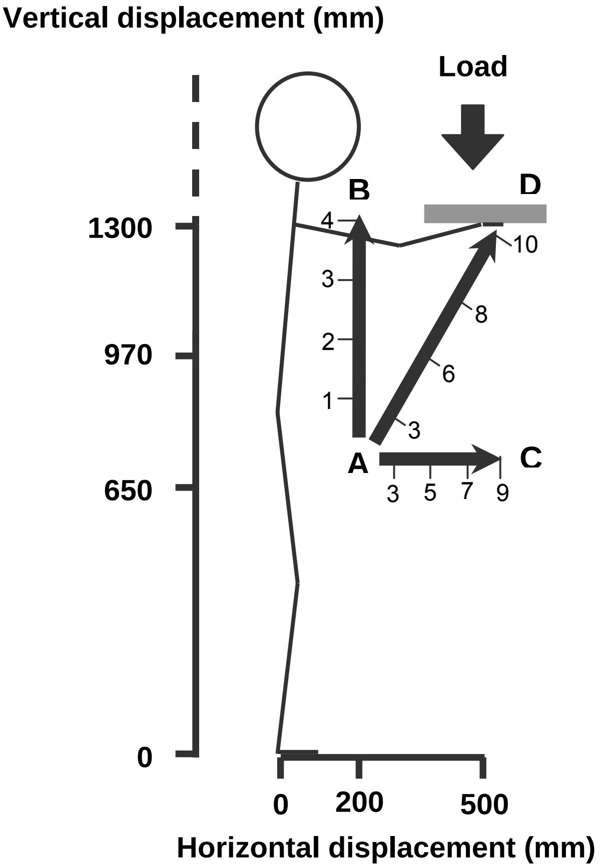


Figure 3: Varying degrees of MMH risk with combinations of vertical and horizontal distances (adapted from Charteris and Scott, 1990).

Symmetry

“Nowhere, and on no health or safety criterion, is asymmetric MMH held to have any advantages over symmetric handling” (Drury *et al.,* 1989). However, the majority of tasks in industries continue to be asymmetric or at least contain an asymmetrical component. Drury *et al.* (1989) explained that asymmetry in manual materials handling can occur either by handling a load in one hand as opposed to two, twisting of the torso, a natural response to reduce effort, or through asymmetric hand positions and asymmetrically loaded boxes. What all these have in common is that they cause lateral and rotational deviations of the spine, resulting in an unevenly loaded musculature, hence increasing the stresses on the musculoskeletal system. Any asymmetrical handling disturbs the body’s balance by moving the centre of gravity towards the perimeters or even outside the base of support. To prevent themselves from falling over the workers have to adopt awkward working postures, thereby straining the musculoskeletal system. Mital and Manivasagan (1983a) found that the greater the offset of the centre of gravity from the mid-sagittal plane, the more physically stressful the subjects perceived the task to be, and the lighter the maximum acceptable weights became. Waters *et al.* (1993) added that asymmetrical lifting reduced the MAW by as much as 39% compared to symmetric lifts. Drury *et al*. (1989) and Gallagher (1991) also pointed out that the energy cost during asymmetrical lifting, lowering and carrying is substantially greater than when executing these tasks symmetrically. Any asymmetry is therefore classified as undesirable.

Working Postures

Ayoub and Mital (1989) defined *working posture* as the body's configuration while executing a task. Standing, sitting, stooping, stretching, kneeling and squatting are some of the most common working postures, but do not necessarily occur in isolation, as variations and combinations of these often occur during the course of an activity. The more the body deviates from its natural anatomical alignment, the greater the stresses on the musculoskeletal and cardiovascular systems become. The result is an increased risk in musculoskeletal injuries, particularly when spending more than 45% of the workday in non-neutral working postures (Stuebbe *et al*., 2002). Extremes of trunk inclination, particularly during lifting and lowering tasks are undesirable, not only because of the muscular effort required to maintain the position, but also due to the shearing forces acting on the intervertebral discs of the lower back. Working postures also influence the physiological responses, which occur during the course of an activity, as well as the ability to exert forces to perform a specific activity (Pheasant, 1996). Overhead work, for example, can lead to problems of the neck, arms and shoulders, as the gracile muscles in the upper extremities are less capable of great force production and also fatigue faster. In his simulation of mining activities, Gallagher (1991) found that lifting capacities were lower in a kneeling posture than lifting from a stooped position and that oxygen consumption for the latter condition was significantly greater.

Although proper use of workspace is essential, among the smaller industries in IDCs the amount of space available depends on the company's financial status, which is often relatively limited. Badly designed and cramped workplaces and workstations with a poor workflow force workers to adopt awkward working postures and techniques, which often have to be maintained for long durations. Gallagher (1991) pointed out that the greater the muscular effort required to maintain a posture, particularly during static work, the greater the energy expenditure and the earlier the onset of muscular fatigue. Field studies by Stuebbe *et al*. (2002) also revealed that postural and cumulative biomechanical stresses were highly correlated with musculoskeletal injury rates. In such cases, modifications in organizational issues such as job rotation would be a solution, as it is relatively easily implemented and allows the workers to recover from excessive task demands.

ENVIRONMENTAL FACTORS

Workers do not perform their activities in a vacuum, but in a specific environmental context and are hence subjected to heat, cold, humidity, noise, poor light, pollution and vibration to a greater or lesser degree. Parsons (2000) stated that these continuous influences acting on the human body produce physical and physiological strain, which can lead to discomfort, annoyance and subtle but direct effects on performance and productivity, as well as on worker health and safety. In IDCs particularly, the effects of inappropriate environmental conditions at the workplace on physical and mental responses, and on productivity are exaggerated by the labourers' poor socio-economic conditions.

According to O'Neill (2000) most countries located close to the equator are developing countries. It is in these areas that the workers need to be protected from environmental *heat stress*, particularly during heavy manual materials handling. Sanders and McCormick (1993) explain that the combination of heat and high humidity renders the body's most important cooling mechanism, the evaporation of sweat, less effective. The ensuing dehydration not only increases physiological exertion, but also results in performance decrements. Snook and Ciriello (1974) and Kilbom (1995) found that a loss of only 1% of body weight, through sweating, leads to a decreased physical work capacity and hence a deterioration of performance. Besides the physiological changes, body discomfort and perceived exertion also contribute to the performance decrements. It is therefore crucial, particularly during the summer months in IDCs, that workers have water sources nearby and are encouraged to regularly drink small amounts of fluid to maintain optimum hydration levels.

Finally, *pollution* at the workplace, be it grime, dust or smoke, can severely affect the workers' health and safety and lead to decreases in motivation, job satisfaction and general work performance. Proper "housekeeping" not only avoids excessive dirt and waste in and around the workplace, eliminating stumbling or slipping hazards, but also serves to provide a quick and easy overview of the state of the production, materials, tools and machinery. In a workstation, which only contains the tools, machines and materials necessary to perform a certain job, and where every item has its set place, workers spend less time searching for materials or tools and are able to quickly and efficiently identify and deal with problems that may arise.

ORGANIZATIONAL FACTORS

Even though the focus of problems associated with manual materials handling is on the compatibility (or lack thereof) between worker and task characteristics, there is no doubt that the overall organizational culture and worker involvement are as important as reducing the labourers' exposure to mechanical stressors (Westgaard and Winkel, 1997). This component of the ergo-system involves organizing and managing the company's production system, tools and personnel in such a way that it leads to an optimisation of the workers' efficiency, as well as that of the entire system. According to Hendrick (1991) the benefits of an effective macroergonomics design include improved productivity, safety, comfort, employee motivation and quality of work life.

One way to assess the overall situation is to involve all parties: employer and employees. This requires a leadership style that allows a two-way communication process between workers and management, and the active and responsible involvement of the workers in decision-making processes relevant to their jobs, workplace, systems and organization. Maciel (1998) discovered that benefits of such a managerial style were improvements in product quantity and quality, increased job satisfaction and decreased work-related stress. Getty and Getty (1999) maintained that establishing a participatory ethos could lead to valuable input from the workers regarding improvements of workstations and processes, leading to further productivity improvements.

Other basic principles that lead to more effective work organization and a better worker involvement include role clarity, feedback and goal setting. Not only do the goals of the company need to be considered, but also the workers' motivations to achieve these targets. Maciel (1998) emphasized that motivation among workers is a prerequisite to achieving a participative approach, and that incentives and reinforcement of good results through praise and rewards increase the workers' motivation. Finally, adjustments in the organizational set-up to include teamwork, adequate rest periods, multi-skilling and job rotation would not only help to reduce the exposure to extreme stressors, but also provide stimulation and introduce diversity to the daily routine.

TASK ANALYSIS TOOLS AND THEORETICAL MODELS

Task analysis techniques, according to Stammers and Shepherd (1995) are either used during the design stages of a system, or to assess and evaluate an existing one. In their quest to finding limits of task demands and establishing guidelines researchers have adopted four different approaches: epidemiological, biomechanical, physiological and psychophysical (Jiang *et al*., 1986; Marras *et al*., 1995) and it is only the integration of all four approaches that can truly shed some light on the complexity of the workers' responses to various task demands, environmental and organizational conditions. By using one of these approaches or combinations thereof, researchers have developed various models and assessment methods, not only to understand the human limitations associated with manual materials handling, but also to determine high-risk jobs in industries.

NIOSH Guidelines

Probably one of the most recognized MMH guidelines are the manual handling limits devised by the National Institute of Occupational Safety and Health (NIOSH) in the USA. These guidelines, which were developed for lifting and lowering tasks, are based on biomechanical, physiological and psychophysical research and take a range of tasks characteristics into consideration. These include frequency, duration, vertical reach, horizontal stoop or stretch, distance moved, couplings and symmetry. According to Waters *et al.* (1993) the recommended weight limit (RWL) is based on how much 90% of males and 75% of females can handle under ideal conditions, but as the task characteristics degenerate, this RWL is devalued. The maximum acceptable weight (MAW), which is three times the amount of the RWL, can only be handled safely by 25% of males and less than 1% of females.

The greatest criticism of this assessment method however is that the equation is too restrictive and the resulting RWLs are not realistic in industries. In their psychophysical study Elfeituri and Taboun (2002) found that the resulting RWLs were considerably lower than the loads accepted by the study's participants. Comparisons of various methods for establishing load-handling limits by Nicholson (1989) also showed that psychophysically determined weight limits were about 10% greater than the NIOSH RWL. Several authors cited by Elfeituri and Taboun (2002) point out that more than two-thirds of all MMH tasks would have to be redesigned if they were to adhere to the NIOSH guidelines. Particularly the recommended lifting frequency and horizontal distance were said to be unrealistic and impractical to implement. Additionally, weight limits that apply to the American population, might not necessarily apply to the Southern African workforce. However, in the universal comparison of handling tasks the NIOSH equation serves as a useful indicator of the relative risk involved in the selected MMH activities and their various components.

LIFTRISK

Many assessment methods, including the NIOSH guidelines, are limiting at a worker's level. Mital and Ramakrishnan (1999) pointed out that little research has focussed on establishing population capability profiles for MMH tasks. Particularly in IDCs the indigenous populations' work capacities should receive special attention to determine a possible worker-task mismatch. It is for this reason that Charteris and Scott (1990) devised LIFTRISK, a basic computer-based expert system identifying possible risk factors in lifting tasks. Based on the physical capacities of the Southern African workforce, this assessment method evaluates the individuals' work capacities and the task demands in isolation, as well as in relation to each other, identifying any possible mismatch between the two. Mass, lift-rate, reaching distances, stooping distances and stretching heights are considered in the task evaluation, whereas worker age, arm strength, back strength and aerobic capacity determine operator related risks. LIFTRISK analyses the task and operator parameters in combinations to yield a task-inherent risk factor, a predisposed operator rating and an overall situational risk rating; the higher the score, the greater the risk. As these factors interact in complex ways, LIFTRISK finally calculates a weighted situational risk factor, taking factors such as sex and stature into account, and provides a prioritised identification of high risk factors, which allows the users to target specific risks for basic intervention strategies.

Despite their popular use Buckle *et al*. (1992) called for the necessity to evaluate the effectiveness of the guidelines, together with their assumptions and limitations. Marras *et al*. (1999) also cautioned that only few of the many theoretical assessment methods have been evaluated for sensitivity and effectiveness of controlling low back disorders (LBDs). The NIOSH guidelines, for example, assume that the lift performed is a smooth motion with an unrestricted working posture and optimal environmental conditions (Chaffin and Andersson, 1991). Similarly, assumptions made by LIFTRISK are that only four task parameters and four operator parameters are sufficient to provide accurate risk ratings. However, even though no assessment method is perfect due to the magnitude and complexity of the operator-task parameters, each method does have certain strengths and should be chosen accordingly and used circumspectively and with modifications according to the specific situation. Despite their shortcomings, the value of such theoretical models lies with their contributions to establishing standardized guidelines and to allowing universal comparisons to be made.

OVERALL COMPATIBILITY

It is evident that only by amalgamating various means of analysing the specific situation that advances in manual materials handling practices can be made. In their conceptual model for studying human movement Charteris *et al.* (1976) emphasized the need for an “interdisciplinary, holistic approach”. Any movement, be it locomotory, manipulative or communicative in nature, brings about changes in the internal (physical and physiological) and external environment, and is not properly elucidated unless analysed as such. However, it is also evident from the above descriptions of the various worker, task, environmental and organizational characteristics, that addressing any ergonomics related problems in detail requires a considerable amount of input, which may not always feasible, due to restrictions in finances, equipment or time. The focus is therefore reduced to the selected factors most relevant to the study.

As manual labour is more prevalent in IDCs compared to industrialized countries, the occurrence of musculoskeletal disorders, particularly of the lower back, will arguably be much greater, despite limited statistical evidence. Further assessment of spinal kinematics within an IDC context is therefore essential to clarify this particular problem in the developing world. Another area of prime focus in IDCs is the preservation of metabolic energy, as poor nutritional status and living conditions result in low physical work capacities of the local workforce. Tasks with energy requirements exceeding the labourers’ daily intake result in exertion, as well as health and performance decrements. It is for these reasons that the focus of the present research project was on spinal kinematics, metabolic cost and perceived exertion and discomfort.

Spinal Kinematics

The biomechanical hazards of MMH activities are inherent in many industrial jobs. Particularly lifting and lowering tasks place enormous stresses on the musculoskeletal system, specifically on the vertebrae and soft tissues of the lumbar spine. Marras (2000) explained that biomechanical models are based on a load-tolerance relationship, which assumes that injuries occur when a quantifiable load placed on the musculoskeletal system during work exceeds the threshold for tissue damage. The forces imposed on the L5/S1 joint of the spine are external forces due to the effects of gravity acting on the object or body segments, plus the internal forces created by muscle contractions, intra-abdominal pressure and passive forces from connective tissues (Ayoub and Mital, 1989; Marras, 2000).

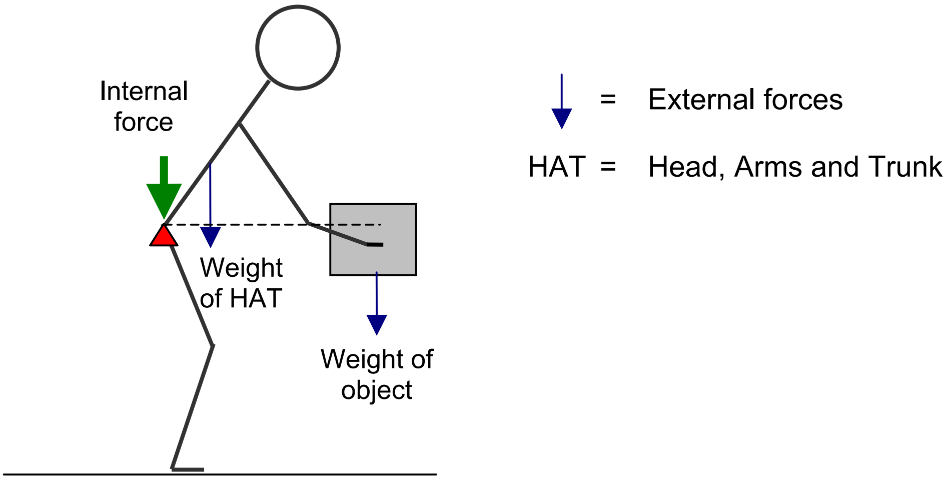


Figure 4: Relationship between internal and external forces acting on the lumbar spine (adapted from Marras, 2000).

Andersson (1985) pointed out that in order for a worker to handle a load, the internal moments have to equal the external moments. However, the nature of the lever system, as depicted in Figure 4, is one of a mechanical disadvantage, which requires internal forces to be significantly greater than the external ones, therefore increasing the mechanical stresses acting on the spine. Marras (2000) argued that although the key to assessing spinal loads is to accurately account for the internal forces, the assessment of these during natural ‘free-style’ lifting is a major limitation.

The internal and external loads imposed on the spine result in forces, which can be compressive, shearing or torsional in nature, depending on working technique, posture, working heights, symmetry, load handled and vibration. However, probably most important in influencing spinal forces are trunk position and the range of motion through which the spine moves. According to Marras *et al*. (1995) many ergonomics investigations in the past have been limited to static assessments of spinal forces, as dynamic trunk motions have been difficult to measure. Tsuang *et al*. (1992) however found that static analyses ignore the inertial forces that are brought about by the accelerations of the load and the body segments and therefore tend to underestimate peak moments particularly at the L5/S1 level for various loads at different velocities, compared to dynamic analyses. These authors, together with Marras *et al.* (1995) and Marras (2000) emphasize the importance of dynamic and three-dimensional evaluations of trunk motions. No movement occurs in a single plane; hence in any spinal assessment the combination of the compressive, shearing and torsional forces should be considered together with trunk moments and velocities. To enable researchers to quantify three-dimensional trunk movement during any working situation, Marras and colleagues developed the Lumbar Motion Monitor (LMM), which will be described at a later stage.

When standing in an upright position the main forces imposed on the spine act in a vertical direction, due to the combined mass of the head, arms, trunk and load handled, and are therefore compressive in nature. Any motion from the vertical however, be it trunk flexion or lateral bending, increases the moments acting on the lumbar spine, therefore resulting in increased shearing forces and a significant reduction in spinal tolerance to both internal and external forces (Marras, 2000). Basic biomechanical principles illustrate that as trunk flexion increases, the worker’s centre of gravity moves towards the perimeters of the base of support, hence increasing the load arm, whereas the effort arm remains unchanged. This results in an increased production of the internal forces to balance the external moment, amplifying the shearing forces. An experiment by Kumar (1999) demonstrated that during lifting activities of a 22 kg box from the ground to a shelf at 1250 mm height, compressive forces of the L5/S1 joint increased with increasing trunk extension from 3600 N at hip level to around 4300 N at the height of the shelf. Conversely, anterior-posterior shear forces progressively decreased from about 5500 N to just below 3000 N at the height of the shelf. In both cases, however, the inertial forces during the 'take-off' stage exceeded the forces measured during any other stage of the lifting action, resulting in compressive and shearing forces of around 5000 N and over 6000 N respectively. In addition, Chang *et al*. (1999) emphasized that changes in the joint angle alter the length-tension relationship of the muscles and therefore the functional ranges of the joint. A study by Marras *et al.* (1995) also revealed that flexion flattens the lumbar spine, rendering lumbar erector spinae muscles inactive. As a result the intervertebral discs and posterior spinal ligaments have to carry the load, therefore making them more susceptible to torsional and shearing forces (Kippers and Parker, 1984; Marras *et al.*, 1995). Although much attention is paid to the flexion of the spine, Adams *et al*. (1980) argued that during hyperextension it is the supraspinous and interspinous ligaments, which are exposed to these stresses. As torsional and shearing forces are less well tolerated than compressive forces, the risk of musculoskeletal disorders is significantly increased.

During comparisons of lifting and lowering tasks Davis *et al.* (1998) found significantly greater anterior-posterior shearing forces for lifting, whereas lowering objects showed greater compressive forces on the lumbar spine. The reason for this, according to McKean and Potvin (2001), is that lumbar and knee flexion are greater during lifting, whereas pelvic flexion is greater for lowering tasks. They also discovered greater mean and peak erector spinae activation for lifting compared to lowering. Waters *et al.* (1993) defined the maximum acceptable compressive force on the spine to be 3400 N. On the other hand, maximum acceptable shearing forces, established by McGill (1997), range between 750 N and 1000 N, indicating that shearing forces are less well tolerated than compressive forces.

In addition, asymmetries in manual handling add a torsional force to the compressive and shearing forces already acting on the lower back. From their experiments Lavender *et al.* (1999) found that during lifting tasks, which involved twisting the upper body, the transverse moments in the spine were three times greater than the twisting moments observed during lifting and turning tasks, where the subjects pivoted by moving their feet. Ayoub and Mital (1989) are among the many researchers who consider this rotational component to be the most harmful of motions to the spine. During extreme twisting actions trunk torque production was found to decrease with increased rotational displacement (Marras and Mirka, 1989). These decreases in trunk strength and force production are the reason why Waters *et al*. (1993) and Elfeituri and Taboun (2002) found a considerable decrease in the MAW for any asymmetrical activities.

It is not only the position of the trunk that affects the forces acting on the spine, but also maximum load moment, maximum lateral velocity, maximum sagittal velocity, average twisting velocity and lifting frequency (Marras *et al*., 1995; Marras, 2000). In their study of more than 200 employees in the automotive industry, Norman *et al.* (1998) found that peak shear forces, peak torso flexion velocity and lumbar moment were good indicators of biomechanical risk factors relating to the reporting of low back pains. Research conducted by Marras *et al*. (1995) on over 400 industrial lifting tasks showed that velocity was an even greater risk indicator than displacement, range of motion or acceleration. Experiments by Lavender *et al*. (1999) not only indicated a 19% increase in sagittal bending moments in the spine for increasing loads (from 10% to 20% body weight), but also a 16% increase in the sagittal plane moments with increasing lifting velocities. Increasing loads and working pace were also found to increase lateral bending moments during sagittally symmetrical lifts, lifting and twisting tasks, as well as lifting and turning activities. Davis *et al.* (1998) reiterated that increasing velocities result in increasing anterior-posterior shearing and compressive forces during lifting and lowering activities respectively. Trunk strength also decreases with increasing rotational velocities, as was evident in the decreasing peak EMG activity and peak torque values recorded by Kumar *et al.* (2003). Even though various researchers perceive different parameters to the greatest predictor of low back disorders, the complexity and multivariate nature of spinal kinematics requires assessing risk factors in combination with each other.

Metabolic Cost

When performing physical work, the human body is not only required to move itself while maintaining a controlled posture, more often than not it also has to move or transport other objects (Kilbom, 1995). When such demands are imposed on the body it reacts with a complex series of cardiovascular, respiratory and metabolic responses, and, depending on the individual's physical work capacity, the efficiency of these responses determines the amount of strain the body can cope with. However, poor nutritional status, ill health and the presence of dormant cardiovascular diseases could adversely affect the workers' performance efficiency during heavy manual labour, as it contributes to fatigue and ultimately leads to exhaustion.

The use of heart rate monitors is a popular means to determine the degree of physical exertion. Not only is there minimal cost involved, it is also non-invasive, data collection can occur continuously and over a long period of time, and it has repeatedly shown reproducible relationships (Vuori, 1998). However, constant fluctuations in heart rates occur due to changes in breathing rate, blood pressure, hormones, various actions of the sympathetic and parasympathetic nervous systems and emotional states, as well as working postures, environmental influences and health status', complicating the analysis of heart rate responses due to a specific activity alone. Kapitaniak (2001) explained that despite the great variations in heart rates due to intra-individual differences, the majority of people display average resting heart rates between 60 and 90 beats per minute ($bt.min^{-1}$). With activity, these values rise and eventually reach a maximum when the intensity of the activity becomes excessive and the heart cannot contract any faster. Excessively high heart rates are associated with insufficient ventricular filling and inadequate contractions of the cardiac muscle and therefore reduced oxygen supply to the working muscles (Tortora and Grabowski, 1996). This results not only in cardiovascular fatigue, but also muscular weakness, which is why maintaining heart rates at an acceptable level is important during prolonged physical labour.

In his article on the measurement and assessment of dynamic work, Kilbom (1995) stated that heart rate responses during prolonged work of up to 90 bt.min^{-1} only indicate a light cardiovascular strain, whereas 90 to 110 bt.min^{-1} indicate moderate, 110 to 130 bt.min^{-1} heavy and 150 to 170 bt.min^{-1} extremely heavy strain. Åstrand and Rodahl (1986) suggested that heart rates ranging between 90 and 130 bt.min^{-1} should be the upper limit for continuous work, whereas Kumar *et al*. (2000) reported acceptable heart rates between 104 and 114 bt.min^{-1} for palletising tasks. Evidently such measurements are dependent on the type of manual work performed as well as the sequence and combination of the tasks. Kapitaniak (2001) reported greater heart rate increases for arm work than for leg work, and a study conducted by Mital *et al*. (1994) revealed heart rates of 155 bt.min^{-1} for lifting and 144 bt.min^{-1} for lowering activities. Ciriello *et al*. (1990) stated that heart rates for combination tasks were between 4 to 10 bt.min^{-1} higher than performing the individual components in isolation. Kumar *et al*. (2000) and Kapitaniak (2001) also pointed out that uncomfortable postures, postural constraints and static work lead to heart rate increases.

During any physical activity the demand for oxygen increases as effective muscle contractions during physical labour can only occur with sufficient oxygen supply and an appropriate energy source. Aerobic metabolism sets in for long-term activities at moderate intensities, relying on oxygen for the process of breaking down lipids to release large amounts of energy. As one litre of oxygen is equivalent to approximately 20 kJ or 5 kcal of energy, oxygen consumption (VO_2) can be used to calculate the energy cost (Jorgensen, 1985; Howley, 2001), which, according to Åstrand and Rodahl (1986), should not exceed 21 kJ.min^{-1} for long-term activities. Sanders and McCormick (1993) pointed out that oxygen consumption at rest is below 0.5 L.min^{-1}, but can increase up to 5 L.min^{-1} for extremely heavy work, usually witnessed in endurance athletes. Again, this depends on the type of activity performed, as the amount of energy expenditure is dependent upon the amount of muscle groups active during a task performance (Kapitaniak, 2001). De Looze *et al*. (1994) for example found that for the same amount of mechanical work, lifting yielded greater energy expenditures than lowering activities. Mital *et al*. (1994) also reported that for psychophysically determined MAWs subjects worked at about 57% of their maximum aerobic capacity (VO_{2max}) for lifting tasks, but at only 43% of VO_{2max} during lowering activities. This is an average oxygen consumption of 2.01 $L.min^{-1}$ and 1.81 $L.min^{-1}$ respectively.

Once aerobic metabolism has set in and measurements of oxygen consumption remain constant, physiological responses are said to be in ‘steady-state’, as demand and supply are balanced. Generally, heart rate, cardiac output, ventilation rate, minute ventilation (VE) and oxygen consumption rise at the onset of an activity and increase proportionally to the task demands. These increases are linear, provided the work rate is below the ventilatory threshold. Work rates above the ventilatory threshold result in a non-linear increase between VO_2 and VE (Péronnet *et al*., 1987) and occur at about 60-75% of VO_{2max} or an oxygen consumption of about 2.5 $L.min^{-1}$ (McArdle *et al*., 1996). The ventilatory equivalent, which is the ratio of minute ventilation to oxygen consumption (VE/VO_2), is usually around 25 L of air breathed for every litre of oxygen consumed for submaximal steady-state activities (McArdle *et al*., 1996).

As soon as the work intensity increases to such an extent that the build-up of lactate in the blood becomes too great to be removed and the oxygen demand exceeds its supply, the body is forced to revert to anaerobic energy sources (Ayoub and Mital, 1989). According to Kilbom (1995), anaerobic metabolism occurs during heavy dynamic exercise, where the demands are greater than 50% of the individual’s maximum capacity for oxygen consumption, or more than 10% of maximum muscle strength during static activities. Once the anaerobic threshold is reached, the work intensity can only be sustained for a limited amount of time, as muscular fatigue and perceptions of exertion increase rapidly until the individual’s physiological end-point is reached. Jiang *et al.* (1986) found that for a combination of MMH tasks the most strenuous individual activity usually is the limiting factor. However, during prolonged activities of a sub-maximal nature a phenomenon called “physiological drift” is likely to occur. According to Patton *et al.* (1991) this gradual increase in physiological responses, particularly oxygen consumption, is caused by a combination of increases in body temperature and pulmonary ventilation, accumulation of blood lactate, reductions in mechanical efficiency and a shift in substrate utilization. This can result in individuals working at increasing levels of their maximum work capacity and eventually leads to their end-point of performance.

Recovery largely depends on the rate at which the circulatory system can make up for the oxygen debt and remove lactate. Kumar *et al*. (2000) showed that during the recovery phase following a three hour palletising task, metabolic cost and heart rates showed a rapid exponential decrease in the first five minutes, which then tapered off to resting values. These authors also found that metabolic recovery was almost complete after about 10 minutes of rest, and that no significant differences in the recovery heart rate and oxygen consumption were found between 10 minutes and 35 minutes of rest.

Energy cost during work should always be assessed in relation to the labourers' maximum work capacities. In order to obtain a standard of reference, Kilbom (1995) suggested supplementing occupational measurements with a sub-maximal or maximal exercise test. From this it can then be determined at what percentage of an individual's VO_{2max} capacity work is being performed, and more effective interventions to reduce fatigue and MSD risks can be implemented. According to physiological criteria, oxygen consumption for an eight-hour working day should not exceed 1 $L.min^{-1}$ for male workers (Ciriello and Snook, 1983) or be more than 33% of the individual's maximal aerobic capacity (Smith, 2001). Jorgensen (1985) too, set the limit for mixed physical handling tasks over an eight-hour day between 30 and 35% of VO_{2max}. However, Legg and Myles (1985) pointed out that the physiological responses of a VO_2 test on the treadmill or cycle ergometer differ from the responses during lifting and lowering tasks, as the former has a rhythmic dynamic component, whereas the latter has brief periods of high power output and a relatively long static component. They argued that this was the reason why, in their psychophysical study on lifting tasks, subjects only worked at intensities of 21% VO_{2max}. Similarly, by adjusting the MAWs which Mital's (1983) subjects were required to lift for a 12-hour period, working intensities were an average of 23% of maximum aerobic capacity. The same author also stated that work intensities of 50% of VO_{2max} could not be sustained for more than one hour without excessive fatigue.

Psychophysical Responses

Perceptual responses during any working task are as important in understanding human effort, as are other physical and physiological measures (Borg, 1982; Westgaard and Winkel, 1997). The perception and interpretation of signals from the body's internal environment, as well as the individual's drive and motivation determine the final end-point of performance. The need to quantify subjective estimates of effort, such as perceived exertion, resulted in the development of psychophysical rating scales. Of the many rating scales available to assess perceptual responses Borg's scale for Ratings of Perceived Exertion (1970) and Corlett and Bishop's (1976) Body Discomfort Scale remain the most suitable and most commonly used for ergonomics assessments.

Ratings of Perceived Exertion

Borg, a physiologist, was amongst the first researchers in the 1960s to recognize the need for subjective measures to rate physical work capacity and performance. He proposed that signals elicited from the cardiovascular and respiratory systems, peripheral muscles, joints and the central nervous system are integrated into a 'gestalt' perception of exertion; a good indicator of the degree of physical strain experienced by the workers. The most commonly used scale for Ratings of Perceived Exertion (RPE) is a 15-grade rating scale ranging from an almost resting state, with an assigned value of 6, to maximum exertion perceived by an individual, with a value of 20 (Borg, 1982). Attached to these ratings are verbal anchors, ranging from "very, very light" to "very, very hard", making ratings easier and more comprehensible (see Appendix B). Great care must however be practiced when administering the RPE scale to ensure that subjects are familiar with its concept and correct usage. This caution is particularly relevant in IDCs where the majority of industrial workers are semi-literate and might not be familiar with the concept of such a scale.

The mechanisms behind perceived effort are however not yet clearly understood. Robertson (1982) suggested that local factors, involving sensations of strain and / or discomfort in the periphery, generally the muscular system, provide the primary signals for perceived effort. Davis *et al*. (2000), too, found that direct muscle force sensations were the main factors influencing psychophysically determined MAWs, whereas spinal loading, i.e. the compressive and shearing forces on the spine, played a less important role. Central factors, including heart rate, pulmonary ventilation, respiratory rate and oxygen uptake, act as amplifiers and balance the local strain with the metabolic demand. In terms of cardio-respiratory responses Robertson (1982) claimed that heart rates contribute as strongly to perceived exertion as oxygen consumption and pulmonary ventilation. Davis *et al.* (2000) supported this argument that the amount contributed by central factors, such as minute ventilation and VO_2 towards perceived exertion, increases with increasing workloads. It is hence common in the administration of RPE that subjects provide a rating for 'Central' perceived exertion, as well as 'Local' RPE in the periphery.

What makes the RPE scale so popular as an indicator of physical strain is its correlation with physiological measures, particularly heart rate. Multiplying the scale values by 10 yield possible corresponding heart rate values from 60 to 200 $bt.min^{-1}$ and as work progressively increases so the Ratings of Perceived Exertion steadily increase as well. Due to the high correlation between heart rate and oxygen consumption Robertson (1982) found that at less than 50% of VO_{2max}, work was perceived to be 'light'. 'Moderate' work between 50 and 70% of VO_{2max} became less tolerable, and work intensities greater than 70% of VO_{2max} were perceived as 'heavy' and intolerable. However, such correlations have been heavily debated. MacKinnon (1999) reported a good correlation between RPE and heart rates for sweeping tasks, but a poor correlation during load carriage. Mital and Manivasagan (1983b) were unable to find correlations between Local RPE for the arm during one-handed carrying tasks and the obtained heart rates. In his review, Robertson (1982) also found no correlation between different load carriage systems, but did cite a correlation between heart rate and RPE for lifting weights. Legg and Myles (1985) on the other hand showed that while performing lifting tasks for an 8-hour day their subjects' Ratings of Perceived Exertion increased significantly during the morning and continued to rise in the afternoon despite constant heart rates and oxygen consumption. Borg (1982) however cautioned not to take the 'RPE x 10 rule' too literally, as the influences of age, sex, type of activity, environmental factors and psychological factors, such as anxiety and motivation, might distort the relationship between heart rates and RPE. Kumar and co-workers confirmed that perceptions of task demands are influenced by “the ‘nature’ of the psychophysical instruments, the appropriateness of psychophysical scales, as well as much more complex cognitive factors involving personal expression of effort” (Kumar *et al*., 2000, p.689).

Body Discomfort

In 1976 Corlett and Bishop devised a scale used for the ratings of discomfort in local body parts. The reasoning behind the Body Discomfort scale is that discomfort is an indicator of the incompatibility between worker capabilities and task demands, and therefore a predictor of possible musculoskeletal injuries resulting from sub-optimal working postures or repetitive tasks. In the adapted version the “body map” is divided into 28 parts and comes with a 10-point Lickert scale ranging from “minimal discomfort” to “extreme discomfort” (see Appendix B). Subjects are required to identify the specific area(s) of discomfort on the diagram and provide a rating of the intensity of the discomfort on the scale. Similar to the RPE scale, the principle behind the body discomfort scale is that discomfort is the summation of multiple unpleasant sensations received via the special senses from different body areas, resulting in a ‘gestalt’ perception of overall discomfort (Corlett and Bishop, 1976). Kumar *et al*. (2000) did point out though that perceptions of task demands are subjective evaluations, and are therefore influenced by more than biomechanical and physiological factors.

Despite many companies’ insistence that they cannot afford to make their workers comfortable, experiments by Corlett and Bishop (1976) showed that by improving comfort through task and machine redesign, performance was improved, as was the work-rest ratio, due to the reduction of non-working time. Companies, they argued, could therefore not afford not to make their workers comfortable.

ERGONOMICS INTERVENTION RESEARCH

As an applied science, ergonomics should not be isolated to the laboratory, but be brought out into the ‘real’ working world. The divide between ergonomics as an academic discipline versus ergonomics as an applied science is particularly noticeable in industrially developing countries, where, despite good research conducted in the laboratories, only limited amounts of the results are applied to industries (Scott, 2001). Even though all industries could benefit from ergonomics input, Jafry and O’Neill (2000) emphasized that in IDCs ergonomics interventions have focussed primarily on large-scale industries, whereas smaller businesses have been neglected. This is very much the situation in South Africa, where small businesses make up the majority of South African industries and probably are in the greatest need of ergonomics input.

In order to achieve the two-fold objective of ergonomics, namely the improvement of worker health and well-being and the improvement of the organization’s productivity, ergonomics intervention research seems to be the best means to bridge the gap between theoretical knowledge and practical application. *Ergonomics intervention research* is defined as “a field study with ergonomics interventions designed to provide answers of general interest, i.e. applicable to work places other than those included in the study” (Westgaard and Winkel, 1997). As straightforward as this might sound, these authors pointed out that of the 89 intervention studies they reviewed, only a fraction could claim to be high quality ergonomics intervention research. Not only does the overall purpose of the intervention study have to be taken into consideration, particularly during the project’s planning stages, but Kilbom (1988) and Westgaard and Winkel (1997) emphasized that the greatest downfall of ergonomics interventions has been poor follow-up studies and / or a lack of quantifying the benefits of the counter-measures implemented. This could possibly be one of the reasons not only for the failure of ergonomics to contribute significantly towards reducing the incidence of WMSDs, but also for the limited acknowledgement given to ergonomics in IDCs. It has also resulted in an inability to draw conclusions on the success or failure of interventions and their cost-effectiveness. Scott (2002b) stated that the majority of ergonomists are good at identifying problems, but not solving them and that there is a greater need for test - retest research to be performed in the field to verify that the interventions implemented have produced quantifiable beneficial outcomes.

Marras (2000) is one of many researchers highlighting the need for high quality intervention studies, as these are a powerful tool for the assessment of possible LBD causes and control thereof. However, even though an intervention might have been successful from a company's point of view, it might not be rated highly as an ergonomics intervention study, as it has not fulfilled certain criteria. The following "quality criteria" put forward by Westgaard and Winkel (1997) ensure that the experimental set-up, statistical analyses, methodology and procedures of the study do not present limitations that might effect the internal and external validity of the study:

- Large enough sample sizes and random selection of subjects to ensure a fair representation of the population investigated
- Proper statistical analyses
- Reliability and sensitivity of variables to determine relevant and significant cause - effect relationships
- Inclusion of a control group or repeated measures on the same subjects for comparative purposes
- Adequate observation period with follow-up measurements to ensure the sustainability of the intervention strategy
- Proper documentation of the interventions and intervention processes to provide insight into the purpose, processes and results

Devising interventions that will contribute to the desired goal(s) can only occur after the establishment of the objectives of the study, a thorough assessment of the problem and experimentation with carefully selected variables. Westgaard and Winkel (1997) put forward three broad categories of ergonomics interventions that can be derived from the experimentation process:

1. 'Mechanical exposure interventions' aim at reducing physical stresses through the redesign of workplaces or technical interventions.

2. ‘Production system interventions’ refer to changes in the organizational set-up, e.g. work-to-rest ratios or the introduction of job rotation to prevent unilateral stresses, or stresses on a particular muscle group.
3. ‘Modifier interventions’ focus on changes affecting the workers directly, rather than the working environment. These include personal protective equipment, work hardening exercises or training on proper lifting techniques.

The recommendations following from the initial data analysis vary according to the problem’s severity and their financial and technical feasibility (Haines and McAtamney, 1995). Even though Westgaard and Winkel (1997) claimed that production system interventions and modifier interventions have the best chances of success, mechanical exposure interventions are the easiest to implement and to sustain, as they do not depend as much on the workers’ or company’s willingness and compliance to work with the intervention measures, as the other two intervention approaches do. At the same time however, mechanical exposure interventions tend to be the most expensive of the three, as they involve physical changes to the workplace, tools or machines. In cases, where larger, more expensive interventions are impossible, short-term, low-cost measures should be aimed at. Scott (1997), Kogi (1997) and Zalk (2001) all emphasized that these “no-cost / low-cost” interventions at a micro-level are possible in IDCs despite economic and technical constraints, and that even the smallest interventions could have noticeable benefits for workers and industries as a whole.

Regardless of the intervention approach taken, probably the most important component of implementing a successful ergonomics intervention program in IDCs is participatory involvement from both workers and management, as it addresses physical and physiological, as well psychosocial factors in the workplace (Kogi, 1997; Zalk, 2001). Workers not only know their workplace and work processes best, they are also the ones who ultimately have to accept and work with the interventions implemented. Managers, on the other hand, are the ones to approve the proposed changes and also to provide financial funding for alterations of the workplace. At the same time, not all problems can be solved instantly and it is therefore essential to instil a culture of continuous improvement in the workplace.

Not only will this prevent problems from becoming too large and unmanageable, but will also automatically lead to an ethos of self-help amongst the workers.

The question that then arises is whether ergonomics intervention strategies applied in developed countries, particularly concerning organizational issues, stand a chance of success in IDCs, where, in many cases, not even the basics of ergonomics are understood. Not adhering to the 'quality criteria' of ergonomics intervention studies could lead to low external validity so that results cannot be transferred to other settings, or effective interventions could be 'lost' due to their lack of documentation. The type of intervention employed also depends on the finances available, as well as the willingness of the workers, unions and management to accept the proposed suggestions. All these factors contribute to the complex and multi-facetted nature of ergonomics interventions research.

LABORATORY VS. FIELD RESEARCH

Limited literature exists on laboratory vs. field research, despite the long-standing question whether experimental results obtained *in situ* are comparable to those obtained in the laboratory. This issue is however difficult to solve, as conducting research projects in the laboratory and in the field have their respective advantages and disadvantages.

According to Oborne (1995) and Westgaard and Winkel (1997) the main drawback of conducting experiments in the field is that experimental conditions can be less rigorously controlled than in the laboratory, often due to countless extraneous factors out of the researcher's control, such as environmental factors, strikes, changes in the production processes, the nature of the work performed, the facilities, as well as variability from the workers themselves, i.e. work experience, physical differences and preferences as to how the work is performed (Allread *et al.*, 2000). In the laboratory experimental treatments, situations, even the subjects themselves can be controlled and individual variables of interest can be studied in isolation to obtain 'true' responses to a specific situation. This artificial reconstruction of the working situation, however, puts the external validity of the results into question. By the very nature of empirical research numerous extraneous factors are controlled or cut out in ‘cold’ laboratory research, and could thus render the outcomes unreliable and solutions ineffective in reality. Interventions devised in the laboratory need to be scrutinized before implementation in industry to ascertain that they will be as successful in the ‘real world’ as they were in the laboratory. Investing time and money into interventions that do not bring about the desired results, or worse, have a negative impact on the industry, could be disastrous.

On the other hand, collecting data in industrial settings can be time-consuming, expensive and a disruption to production processes. Zalk (2001) however emphasised that it is essential that data be gathered in the field under actual working conditions in order to quantify the workers’ exposure to various stressors, both before and after implementation of an intervention strategy. According to Allread *et al.* (2000) this requires no more than three employees and three repetitions of each task by an employee. Apart from disruptions being minor, they found that despite the small sample size there was no significant reduction in the standard errors of trunk kinematic measurements with more subjects and repetitions.

In most field studies subjects are the workers themselves and therefore have a certain amount of training and experience in handling the tasks, whereas in laboratory experiments, the subjects tend to be volunteers. To be applicable to industries Oborne (1995) claimed that experimenting with the workers themselves is the better option, although not always viable. Volunteers, he claims, are inexperienced and often do not understand the consequences of their actions. They do not have salaries to worry about, nor are they affected by manager relationships, negative work ambiences, job dissatisfaction, stress or other impinging factors that may affect the labourers positively or negatively. Particularly psychosocial factors influencing the workers’ responses to task demands need to be taken into consideration as they are necessary for devising interventions that will be effective within the respective industrial context, but at the same time could distort ‘true’ responses to particular treatments. Oborne (1995) also questioned whether the experimental situation itself does not provoke responses different to the ‘norm’ in the day-to-day activities *in situ*. Regardless of the subjects used, or whether the research was conducted in the laboratory or in the field, the entry of the experimenter with foreign equipment and probing questions is likely to alter the individuals’ responses during the experimental observation.

Despite the many complex factors and interactions involved in the assessment and improvement of a work situation, combinations of field and laboratory work are the best means to conducting effective ergonomics intervention research. Assessment of the actual problem in its industrial context is essential for the establishment of certain parameters necessary to simulate the selected tasks in the laboratory, where extensive experimentation can occur. Bao and Shahnavaz (1989) stated that although ergonomics is an applied science and much of the research has been limited to the academic field, it is the task of today’s ergonomists to take scientific findings out of the laboratory and to apply the theoretical solutions in the field.

CHAPTER III

METHODS

INTRODUCTION

A small bottle sorting enterprise was approached and asked to participate in the current research project. The business collects empty bottles from pubs and bottle stores in the greater Grahamstown area and brings them to the warehouse where crates filled with the bottles are offloaded, sorted into their categories, cleaned of bottle rings and tops and finally palletised to be sent back to the respective breweries and distilleries. The reasons for choosing this particular business were work processes that were dominated by lifting and lowering activities at a high frequency and awkward working postures.

Initially, a general observation period at the bottle sorting business prior to the testing sessions served to familiarize the researcher with the general set-up, array of tasks, workflow, work methods and the workers themselves. It also aided in identifying high-risk tasks that would require investigation and were in need of ergonomics intervention. Informal interviews conducted with the manager answered questions regarding organizational issues, such as working hours, production demands, worker incentives and future plans. Thereafter, basic measurements of workspace dimensions, task requirements, plus the workers' demographic and anthropometric characteristics, heart rate and perceptual responses were recorded in order to identify and prioritise problem tasks.

Offloading the truck was identified as the process in most need of ergonomics intervention. The offloading process occurs two to three times a week for a duration of approximately one hour and generally involves four to five workers who form a line from the truck to the pallets. The crates with the empty bottles are passed from one worker to another until finally the last workers stack the crates onto pallets, as is illustrated in Figure 5.

Figure 5: ‘Chain’ formed by workers during the offloading process.

Although two offloading methods were observed, the one identified as being more physically demanding was selected for investigation in the laboratory. It involved one worker, positioned on top of the truck, sliding the crates along the loading surface to the end of the truck. A second worker standing on the ground received and passed (or threw) these crates from the truck on to the last two workers, alternating between them, who then stacked the crates onto the pallet (Figure 6). Once a pallet was full, it was removed by a forklift and the same process continued to fill the next empty pallet. The remaining two workers were either involved in driving the forklift or in counting the crates that were being offloaded.

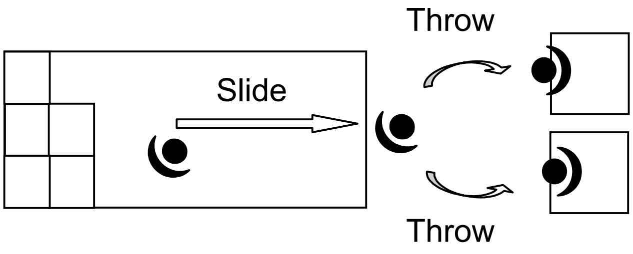


Figure 6: Diagram depicting the workflow for the selected working method.

In order to quantify and compare the intervention results, some basic measurements of the workers’ responses were conducted on site at the bottle sorting business. The labourers chosen were the ones performing the task that was considered to be the most strenuous, namely *sliding* the crates along the truck's loading surface as can be seen in Figure 7. The labourers were given a detailed explanation on the purpose of the research project, the procedures and the equipment, including the psychophysical rating scales to be used. The language barrier was overcome by translating certain issues, which the workers did not understand into Xhosa, their home language, to prevent any misunderstandings. Once the labourers were satisfied with everything, they gave their verbal consent to participate.

(a) (b)

Figure 7: Illustrations of workers on the truck reaching for (a) the highest crate and (b) sliding it along the loading surface.

As the workers had never been involved in research of this kind, several trial runs on separate occasions were required to habituate them. Allowing the labourers to familiarize themselves with the equipment and also the procedures would ensure natural responses and increase the reliability of the experiment and its results. Initially, only a heart rate monitor was used, which was strapped to the workers and left to record for the entire duration of the offloading process. Later the psychophysical rating scales were introduced. Once the researcher was satisfied that the workers were comfortable with the equipment and procedures, an 'official' testing session was conducted. Again a Polar Accurex Plus Heart Rate transmitter and wristwatch were fitted to the workers and the procedures were repeated. Resting heart rates were measured for two to three minutes and the labourers were then instructed to go about their tasks as usual. Heart rates were recorded throughout the entire offloading duration, and handling frequencies were also obtained. Once the offloading process had been completed the workers were presented with an English and a Xhosa version of the RPE scale to rate Central and Local exertion in the back and upper extremities, as well as a Body Discomfort Map and Scale to point out any areas of discomfort experienced.

PILOT RESEARCH

Prior to the laboratory experimentation phase several pre-pilot and pilot studies, based on the initial evaluation in the field, were conducted in the Ergonomics Laboratory of the Department of Human Kinetics and Ergonomics at Rhodes University. These preliminary simulations of the selected industrial task served to refine the testing protocol and establish the suitability of the equipment to be used, as well as the variables measured. The main focus during these pilot studies was determining the duration for the two experimental conditions. Results obtained by measuring heart rate and psychophysical responses of four subjects performing each condition for a duration of 20 minutes showed that the physiological as well as the perceptual responses had reached a plateau by the second collection interval, nine minutes into the activity. As no significant differences were found between the heart rate and RPE responses at minute 15 and minute 20, the duration of each task was finally set at 16 minutes, allowing the researcher to conduct four sets of measurements at four-minute intervals for each experimental condition.

EXPERIMENTAL DESIGN

The investigation of the selected industrial task included two experimental conditions: one simulating the industrial scenario (pre-intervention), and the other (post-intervention) was conducted to assess the effect of the ergonomics intervention.

The laboratory set-up was based on the data collected within the industrial setting. There the mass of a crate filled with empty bottles averaged 10 kg and working frequencies averaged 12 lifts per minute. The same working heights measured in industry were used in the laboratory set-up. The pre-intervention condition was based on the industrial data, whereas the post-intervention condition was devised using basic ergonomics principles. Theoretical models, LIFTRISK and the NIOSH lifting equation, were also used in the development of the intervention strategy.

This straightforward pre-test / post-test set-up allowed the researcher to evaluate the effectiveness of the proposed ergonomics interventions. These results were then discussed with workers and management of the bottle sorting enterprise to develop an intervention most suitable to the business. This was presented to the management together with the results of the laboratory experiments to be implemented. Once the interventions had been put into practice and the workers had enough time to get accustomed to the changes, a re-evaluation of the labourers' physical and psychophysical responses to the tasks was conducted.

SUBJECT CHARACTERISTICS

Due to the combination of field and laboratory work, two different groups of subjects were involved in this research project. As the basic morphological data of the industrial workers in Table I showed little variation amongst each other, three of the six labourers were selected as subjects for the initial and the final assessment stages in the industry. Although no medical examination was conducted, the workers claimed to be healthy on the day of testing. They were then required to wear heart rate monitors to obtain 'resting' and 'working' heart rates in order to estimate their energy cost *in situ*.

TABLE I: Basic demographic and anthropometric data of industrial workers (n=6) and laboratory subjects (n=28).

	Industrial Workers			Laboratory Subjects		
	Mean	**SD**	**CV**	**Mean**	**SD**	**CV**
Age (yr)	26.33	3.27	12.42	21.04	2.20	10.47
Mass (kg)	63.33	5.76	9.09	75.80	10.04	13.28
Stature (mm)	1701.67	24.01	1.41	1781.07	40.89	2.29
Body Mass Index	21.86	1.80	8.23	23.87	2.87	12.02
Back Strength (kg)	-	-	-	99.67	24.15	24.23
Grip Strength (kg)	42.83	4.40	10.27	41.32	10.58	25.62
Experience (yr)	3.92	2.80	71.43	-	-	-

SD = standard deviation; CV = coefficient of variation (%)

For the laboratory experiments twenty-eight healthy male students between the ages of 18 and 26 years volunteered to act as subjects. They represented different ethnic groups of the local demography, and their basic demographic and anthropometric data included age, stature, body mass, grip strength and back strength (Table I). As stature is known to have a substantial effect on the stresses in the spine during lifting and lowering (Ayoub and Mital, 1989), it was deemed necessary to limit the subjects' stature to range between 1.70 m and 1.85 m. Again, no medical examination was conducted, but the subjects claimed to be healthy with no history of low back pain, cardiovascular or respiratory problems that could put them at risk or present any limitations to the study.

All subjects were informed of the nature of the study. In the case of the industrial workers this was translated into Xhosa and verbal consent was given. Volunteers for the laboratory experiments gave their verbal and written consent to the research protocol (see Appendix A), which was approved by the Rhodes University Ethics Committee.

INSTUMENTATION AND TREATMENTS

Mirka *et al.* (2000) emphasized that in order to identify the sub-tasks that may pose a risk to the workers there is a need for multiple assessment tools, particularly in jobs with highly variable biomechanical demands. Apart from the more sophisticated equipment described in detail below, use was also made of tape measures, response counters and stopwatches.

ANTHROPOMETRIC PARAMETERS

Body Mass

Body mass of industrial workers was measured to the nearest 0.5 kg using a portable Seca scale. Laboratory subjects however were measured to the nearest 0.1 kg using a calibrated electronic Toledo Scale. The labourers were weighed wearing their work overalls, whereas the volunteers wore light comfortable clothing. Both groups removed their shoes before being weighed.

Stature

Stature of the industrial workers was obtained using a tape measure. Laboratory subjects were measured using a Harpenden stadiometer. All subjects were required to stand upright and barefoot with their heels against the tape measure / stadiometer and the head erect looking ahead. Stature was measured from the floor to the vertex in the mid-sagittal plane.

PHYSICAL PARAMETERS

Strength Capacity – Dynamometers

Muscular strength is arguably one of the most important features required during manual materials handling. In the case of the bottle sorting business, where lifting and lowering crates dominated the workday, grip strength and back strength measurements were of essence. For this TKK Smedley's dynamometers were used.

Grip strength was measured three times for each subject to obtain a maximum reading. Standard procedure for measuring grip strength included adjusting the hand dynamometer for grip width. Then, standing upright in a comfortable stance, with the hand dynamometer held in the dominant hand above the head, the dynamometer was gripped as forcefully as possible with the arm smoothly moving anterior-inferiorly. The maximum reading was then recorded.

For measurements of back strength subjects were required to sit on the ground with their legs extended and the feet pushing against the base of the back strength dynamometer placed against the wall. Subjects were required to pull the handle as forcefully as possible, using only the back muscles to exert the force. This method of measuring back strength was chosen over the upright torso lifting strength test position as described by Chaffin *et al.* (1978) in order to avoid the possibility of strain to the back musculature. For the same reason only one back strength measurement was taken.

Lumbar Motion Monitor

The Chattecx^{TM} Lumbar Motion Monitor (LMM) is an exoskeleton of the spine, replicating the vertebral column's three-dimensional movement. It is modelled after the spine, containing numerous T-sections, which are connected via wires, similar to vertebrae being connected via ligaments. The wires lead to four potentiometers at the base of the LMM, which change voltage as the wires are twisted and / or stretched, enabling measurements of instantaneous position, velocity and acceleration of the trunk during flexion, extension, lateral bending and twisting motions (Marras *et al*., 1992). Voltage outputs are transmitted via an umbilical cable to an analog-to-digital converter and the signals are then processed and stored in a portable microcomputer.

Before fitting subjects with the LMM, the zero-calibration check was carried out with the LMM lying in its carrying case. Once this calibration had been performed the LMM was secured to the subjects using body harnesses; two semi-rigid plates strapped over the lumbosacral region of the pelvis and around the thorax at the level of the scapulas' inferior angles. As measurements of spinal motion are taken in relation to the position of the pelvis subjects were required to stand motionless in a comfortable stance, so that the LMM could be set to zero according to their spinal curvature. Thereafter, the activity under investigation proceeded.

PHYSIOLOGICAL PARAMETERS

Polar Heart Rate Monitor

For the purpose of obtaining a measure of cardiac strain, Polar Accurex Plus Heart Rate monitors were used. The Polar Coded Transmitter, which measures the heart's electrical activity, was fitted around the subject's chest with an elastic strap at the level of the inferior border of the pectoralis muscles and in line with the left ventricle situated slightly to the left of the mid-centre of the chest. A receiver worn as a wristwatch recorded the heart rate responses at 15-second intervals during the field testing sessions and pre-pilot studies. During the pilot studies and under the experimental conditions in the laboratory, the heart rate responses were transferred telemetrically to a microcomputer running the $K4b^2$ software.

Before any experimentation took place a relatively reliable resting heart rate was recorded and used as a 'reference' heart rate, because of the volatility of heart rate responses due to anticipation, movement, changes in breathing patterns and speech, amongst others. Particularly with the industrial workers who were not familiar with such technology, anticipation could have distorted resting heart rates. A habituation period was therefore arranged during which the experimenter explained the technology to the workers, fitted them with the heart rate monitors and left them to work as normal wearing the heart rate monitors for a duration of about two hours.

Metabolic Cost – K4b^2

The Cosmed® K4b^2 is a metabolic on-line system, which measures an individual's gas exchange breath for breath over a period of time. Each subject was required to wear a suitably sized facemask from which pipes lead to a portable unit, containing oxygen (O_2) and carbon dioxide (CO_2) analysers, as well as a sampling pump, UHF transmitter, barometric sensors and electronics. Powered by a battery, this portable unit was fixed to the subject's thorax via a harness. A receiver unit received the telemetrically transmitted data from the portable unit and allowed these data to be displayed on a portable microcomputer containing the appropriate Windows-based software. Heart rates (HR), tidal volume (V_T), breathing frequency (R_F), oxygen consumption (VO_2), minute ventilation (VE) and respiratory quotient (RQ) were the specific measurements assessed using the K4b^2.

Before using the K4b^2 on the subjects, room air calibration, gas calibration and flowmeter calibration were conducted. Room air calibration required sampling room air in order to update the O_2 and CO_2 analysers. Reference gas calibration required sampling a gas with a known composition, and flowmeter calibration was executed using even inspiratory and expiratory strokes from a three-litre syringe.

Figure 8: Subject preparation with the K4b^2 and Lumbar Motion Monitor.

PSYCHOPHYSICAL PARAMETERS

Ratings of Perceived Exertion

Borg's scale for Ratings of Perceived Exertion (1970) is one of the most commonly used psychophysical rating scales to assess the strain experienced by subjects. The scale, which ranges from a value of 6, for almost no strain, to 20 for maximal exertion was presented and explained in detail to all workers and volunteers (Appendix B). Ratings of Central exertion and Local exertion of the back and lower extremities were included. Even though all industrial workers were literate, they had a limited English vocabulary and were therefore presented with both an English and a Xhosa version of the RPE scale, either of which they could use to provide their personalized perception of exertion.

Body Discomfort Map and Scale

As discomfort can be regarded as an indicator of the incompatibility between a worker and a task, Corlett and Bishop (1976) developed the Body Discomfort Map. Even though the original Body Discomfort Map only provides a posterior view of 12 body parts, an adapted version including anterior and posterior views, 28 body parts and a 10-point rating scale ranging from 1 for minimal discomfort to 10 for maximal discomfort was presented to the subjects (see Appendix B). Again, the purpose of the Body Discomfort map and its rating scale was explained in detail to all subjects.

TREATMENTS

SESSION 1: INTRODUCTION AND FAMILIARIZATION

This session involved explaining the procedures to the subjects verbally and in writing. It also addressed any queries they might have had. Subjects were required to sign a consent form before basic data were collected. These included age, stature, mass, grip strength and back strength. Subjects then familiarized themselves with the tasks they would be required to perform, as well as the equipment that would be used. This brief habituation session served to put the subjects at ease and minimize any responses brought about by anxiety and anticipation, rather than the treatments.

SESSION 2: EXPERIMENTATION

This session included experimentation of the two conditions for the selected industrial task (pre- and post-intervention). The LMM was calibrated to each individual's natural spinal curvature while they were standing in a relaxed upright posture and the subjects were instructed to return to this position after every crate they handled. A rest period of at least 30 minutes was required between Conditions A and B. (Note: the terms 'condition', 'task' and 'pre- / post-intervention' will be used interchangeably).

Condition A:

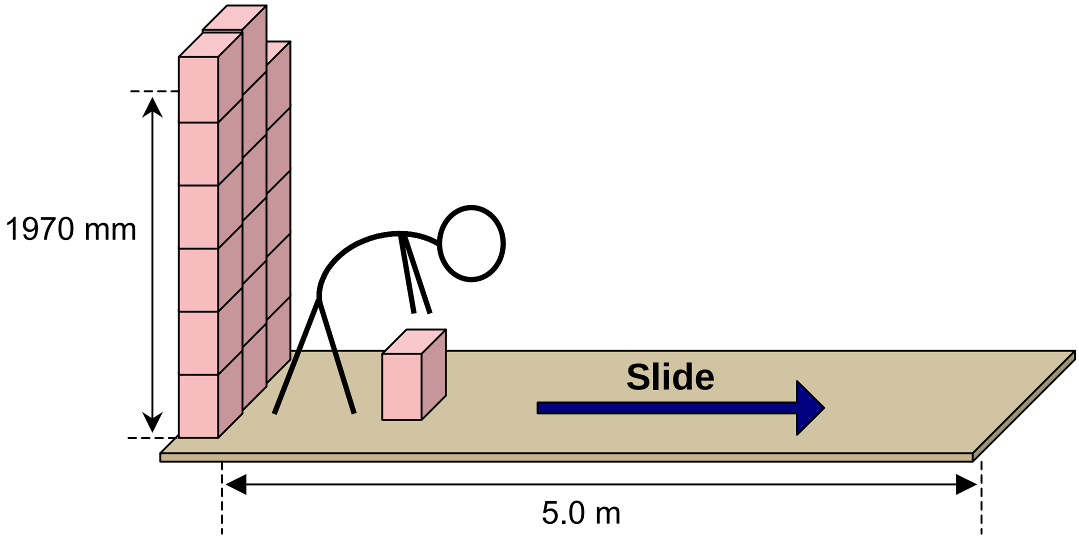


Figure 9: Representation of the workstation set-up for Condition A.

This condition represented what was observed and measured in industry. A five meter long piece of hardboard was placed on the floor representing the truck's loading surface. At one end the crates (dimensions: 400 mm long x 300 mm wide x 340 mm high), each weighing 10 kg, were stacked in three columns at six crates high, reaching a maximum grip height of 1970 mm. Subjects were required to lift each crate off the stack and slide it along the hardboard at five-second intervals, simulating the action as observed *in situ* (Figure 9). Once all crates had been removed from one end of the hardboard, subjects were given five seconds to walk to the other side, where an assistant had already stacked the crates, before sliding them back. This condition lasted for a period of 16 minutes. Physiological parameters were measured throughout the activity, whereas spinal kinematics were obtained at four 4-minute intervals relating to the working pattern. Subjects were also asked for their Central and Local Ratings of Perceived Exertion at regular intervals.

Condition B:

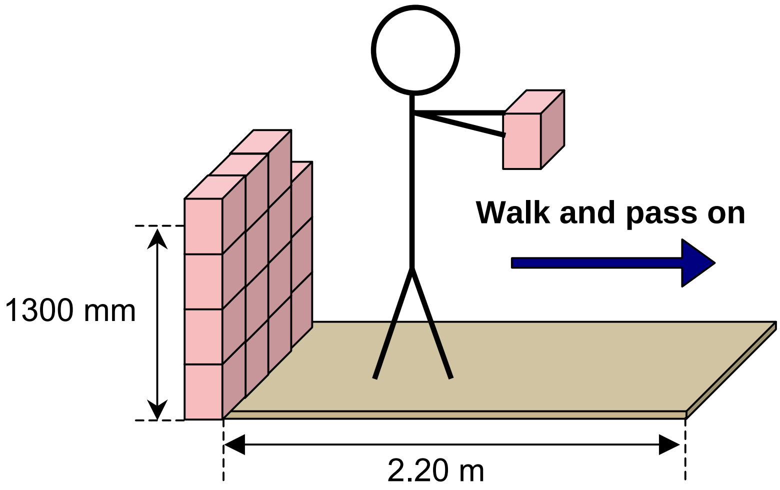


Figure 10: Representation of the workstation set-up for Condition B.

For this condition, the post-intervention activity, the work method was altered by reducing the stacking height of the crates to a maximum vertical reach of 1300 mm (four columns at four crates high), the subjects were no longer required to place the crates onto the floor and to slide them along, but had to carry the crates for two to three steps and hand them over to an assistant, who represented another worker in industry (Figure 10). Again, once all crates had been moved from one end, the subjects were given five seconds to walk to the other end before moving the crates back. This condition also lasted for a period of 16 minutes during which physical, physiological and psychophysical responses were obtained during the set intervals.

Devising the above intervention strategy required taking both theoretical and practical aspects into consideration, if the implementation was to be successful. To determine the effects that various changes in the workstation and work processes could have on the workers, theoretical models were utilized. At the same time however, the practicality of implementing the 'ideal' solution had to be considered. The intervention had to be easy to administer, be relatively cost-effective and have no negative impact on the business' productivity. With the aid of the theoretical models it was expected that by reducing the vertical height to four crates (1300 mm) and modifying the working method, the physical, physiological and perceptual stresses on the workers could be reduced significantly with hardly any disruption to the production and no financial input. Depicted in Figure 11 is the proposed re-organization of the workers, which eliminated the sliding action. The first worker would carry the crates and hand them over to a second worker, also positioned on the loading surface, who would then place the crates at the end of the loading surface for the remaining workers to palletise. Due to the universal acceptance of the significant contributions to reducing physical and physiological exertion the high frequency of the present activity was not altered. This allowed the researcher to identify whether the change in stacking height and working method would have the desired effect.

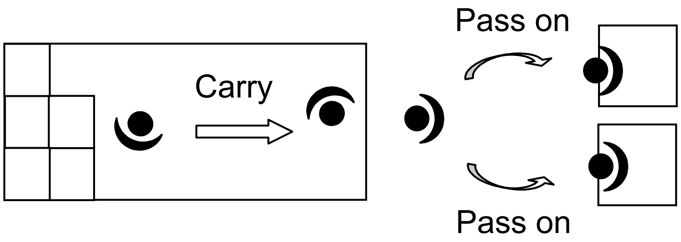


Figure 11: New proposed workflow.

EXPERIMENTAL PROCEDURES

Experimentation in the laboratory was conducted in the Ergonomics Laboratory of the Human Kinetics and Ergonomics Department at Rhodes University. Twenty-eight male volunteers participated in this research project and each subject was required to partake in two sessions. During the first session, the purpose of the study and the procedures were explained to all subjects verbally and in a written document, which they were expected to read (Appendix A). Once all queries had been answered to the subjects' satisfaction they were required to read and sign an informed consent form (Appendix A). Basic demographic and anthropometric data were then collected, including age, stature, mass, grip strength and back strength. Finally, a brief habituation session, which involved fitting the subjects with the Polar Accurex Heart Rate Monitor, the K4b^2 mask and the Lumbar Motion Monitor harnesses allowed the subjects to familiarize themselves with the equipment and the tasks they would be required to perform. The workplace parameters obtained in the industry were used to set up a similar workstation in the laboratory to simulate the selected task.

The second session involved experimentation of the selected industrial task pre- and post-intervention (Conditions / Tasks A and B respectively). The subjects received a short briefing regarding the procedures for the current session, particularly regarding the sequence of events as Conditions A and B were alternatively assigned in order to minimize the influence of fatigue (Figure 12). Thereafter they were fitted with the Polar Accurex Heart Rate Monitor, the K4b^2 and the Lumbar Motion Monitor. 'Anticipatory' values were obtained for two minutes before the testing commenced. Physiological responses were recorded for the entire 16-minute duration of the activity under each experimental condition, whereas 30-second measurements of spinal kinematics were obtained starting at minutes 3:30, 7:00, 11:00 and 15:30. As the task demands continuously changed during the course of the activity, due to the differences in crate stacking height, the researcher had to ensure that measurements of spinal kinematics started once the subjects reached for the top crate of a new stack during the above-mentioned intervals and ended once the last crate in the column had been moved to the other end. In total subjects moved 198 crates under each condition, a total of 1980 kg in

16 minutes. Measures of Central Perceived Exertion were obtained after minutes 2, 5, 9, 13 and after completion of the sub-task (minute 16), whereas Local Ratings of Perceived Exertion for the back and lower extremities were alternated. Back ratings were obtained during minutes 2, 9 and 16, and Local RPE for the lower extremities were measured during minutes 5, 13 and 16. At the completion of each condition recovery data were collected for three minutes and subjects were presented with a Body Discomfort Map and Scale to rate the three worst areas of discomfort and / or pain. A 30-minute rest period was required between conditions.

Condition A

Condition B

Figure 12: Subjects performing each of the two experimental conditions: (A) sliding the crates and (B) carrying them.

STATISTICAL ANALYSIS

All data were transferred to the STATSGRAPHICS (Version 6.0) statistical software. Basic descriptive statistical analyses were run on all relevant variables, providing general information regarding the sample’s responses (see Appendix C for example).

Paired t-tests were then conducted to compare the physical, physiological and perceptual responses between the two experimental conditions. The significance level was set at p<0.05, providing a confidence level of 95%. This only allowed 5% chance of rejecting a true hypothesis (Type I error). The sample size of 28 subjects limited the probability of a Type II error (failing to reject a false hypothesis).

Kinematics: Statistical analyses on physical parameters obtained from the Lumbar Motion Monitor were limited to selected crate levels, depicted in Figure 13. Spinal kinematics between the experimental conditions were compared at the highest and lowest levels of each condition (A:6 vs. B:4 and A:1 vs. B:1 respectively), as well as between crates A:4 and B:4.

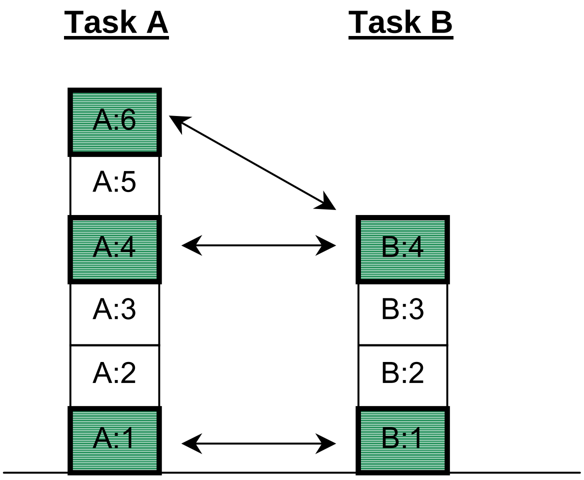


Figure 13: Selected levels of crates chosen for comparison.

Physiological: Statistical tests were run on the physiological parameters using the mean values obtained from 'anticipatory' measurements, the entire duration of each activity and the final recovery minute.

Psychophysical: Analyses on the psychophysical responses were limited to the first and the last measurements obtained for Central and Local RPE, whereas analyses for Body Discomfort relied on basic descriptive statistics.

CHAPTER IV

RESULTS AND DISCUSSION

INTRODUCTION

Researchers involved in ergonomics intervention studies are confronted with several obstacles, the most obvious being the disruption of the labourers' normal working routines. The observation process alone, and especially together with the introduction of measuring equipment in any *in situ* investigation, is very likely to influence workers consciously or subconsciously into adopting work methods different to those usually employed (Oborne, 1995). Adding to the acknowledged difficulties of field research, in industrially developing countries (IDCs) the culture and language differences of the various ethnic groups as well as the great educational divide between most manual labourers and researchers complicates the simplest of procedures, such as a clear understanding by the workers about the research study, the equipment used and the activities to be performed.

Yet the need for ergonomics intervention studies and practical and viable solutions is crucial, not only because of the excessive work demands and the poor physical condition of most manual material handlers in IDCs, resulting in an early onset of fatigue and therefore greater risks of accidents and injuries, but also because of the need for Third World industries to keep up with the productivity of those in developed countries. It is for these reasons that, for the current research project, measurements in the field were kept to the minimum; sufficient to give the researcher the necessary information to simulate the selected activity in the laboratory and to conduct rigorously controlled investigations. A test - retest experiment was set up, measuring various physical, physiological and perceptual responses to the activity as it was performed in the bottle sorting industry and again after an intervention strategy had been introduced.

For ease of reference the biomechanical, physiological and perceptual results of this experiment are presented in separate sections. The final discussion entails the integration and holistic analysis of all responses. To address the research hypothesis, the simulated industrial pre-intervention task (Task A) is compared to the remodelled task (Task B) of the intervention strategy throughout the results and discussion section.

SPINAL KINEMATICS

The biomechanical stresses of manual materials handling on the musculoskeletal system have been well documented (Chaffin, 1988; Dempsey, 1998; Marras, 2000), and the spine is usually implicated. No ergonomics intervention study of MMH tasks would therefore be complete without an assessment of spinal motions. Such an investigation necessitates a three-dimensional analysis of not only displacement of the back, but also lumbar velocity and acceleration (Marras, 2000). As described in the methodology, in the original activity (Task A) the responses to lifting crates 1 (lowest), 4 and 6 (highest pre-intervention) were chosen for analysis, whereas for Task B, post-intervention responses to working with crates 1 (lowest) and 4 (highest post-intervention) were included. The statistical analysis focussed on the sagittal and rotational kinematic variables, relative to range of motion, velocity and acceleration.

Sagittal Range of Motion

The effect of the intervention strategy on spinal displacement in the sagittal plane was assessed using the entire range of motion (ROM) undergone by the back with every crate handled, as anticipation and discomfort could have lead to the variations in flexion or hyperextension while standing up between each lift. Range of motion was calculated as the sum of trunk displacement from the upright starting position to the points of maximum hyperextension and of maximum flexion, either during the initial contact or the final placement of the crate.

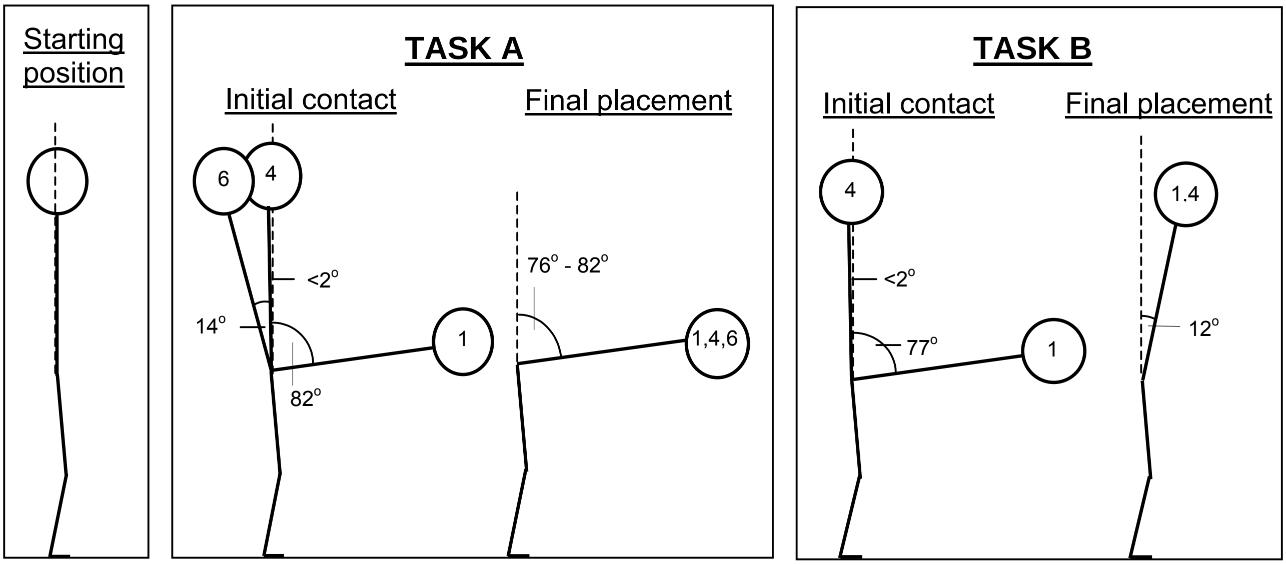
TABLE II: Spinal ranges of motion in the sagittal plane (means with standard deviations in brackets, % = coefficient of variation).

Levels	***Sagittal spinal ranges of motion (degrees)***	
	Task A	***Task B***
Crates A:6 vs. B:4	91.4 (6.7) 7.3%	13.6 (5.9) 43.2% *****
Crates A:4 vs. B:4	77.6 (6.9) 8.9%	13.6 (5.9) 43.2% *****
Crates A:1 vs. B:1	82.4 (5.5) 6.6%	78.4 (11.6) 14.8%

* denotes significant difference ($p<0.05$) between Task A and Task B

The improvements achieved in terms of reducing sagittal ROM by implementing the intervention strategy are evident from the data in Table II. When moving the top crates for each of the experimental conditions (A:6 and B:4 respectively) the measurements obtained for spinal range of motion revealed a statistical difference with a ROM of 91^{o} pre- and only 14^{o} post-intervention. Range of motion when handling crate A:4 was marginally reduced to 78^{o}, but was still significantly greater compared to crate B:4. However, there was no difference in the ROM when the crates at floor level were moved; these were measured at 82^{o} and 78^{o} under Conditions A and B respectively.

In their study on the biomechanical risk factors for occupational-related lower back pain, Marras *et al*. (1995) classified a ROM of 34^{o} as a 'high risk' factor. When standing in an upright position the main forces imposed on the spine due to the combined mass of head, arms, trunk and load handled act in a vertical direction and are therefore compressive in nature. Any sagittal motion from the vertical, such as the extreme stretching and stooping observed in Task A, significantly increases the moments and shearing forces acting on the lumbar spine, and according to Marras (2000), will reduce spinal tolerance to both internal and external forces. As shear forces are less well tolerated than compressive forces, the risk of musculoskeletal disorders in Condition A was significantly greater than in Condition B, in which a simple adaptation in the working height and method resulted in more natural anatomical and less hazardous working postures.



(a) *(b)* *(c)*

Figure 14: Sagittal motion from (a) the upright starting position, and (b; c) initial contact with the crate to the final placement of the crate under both experimental conditions.

(Numbers in figures' "heads" represent levels of the crates)

(a) (b)

Figure 15: Extreme spinal hyperextension and flexion when (a) reaching for the highest crate and (b) sliding it along the floor under Condition A.

In both tasks the height of the initial contact with the crate varied depending on the stacking level, whereas the final placement under each condition remained unchanged throughout the duration of the activity. The diagrams in Figure 14 indicate the extent of hyperextension or flexion in the initial and final positions of the selected crates under each of the two experimental conditions. Handling the crate at a height of 1.97 m caused most of the subjects to hyperextend to an average of 14°, particularly the shorter subjects (shortest subject: 27°), as is evident from Figures 14b (initial contact) and 15a. Flexion from the upright position was similar for all crates in Task A, when recordings of between 76° and 82° were obtained while sliding the crates along the floor (Figures 14b (final placement) and 15b). Similarly, the extreme stoop to lift the bottom crates in Task B resulted in an average sagittal displacement of 77°. However, the intervention of passing the crates to another worker, rather than sliding them along the floor, reduced the flexion for the final positioning of the crate in Condition B to 12°; a reduction of at least 63°. According to the risk classifications devised by Marras *et al*. (1995), measurements which fell into the ‘high risk’ category during Task A (more than 8° for maximum extension and 20° for maximum flexion), were rated ‘low risk’ after implementation of the intervention strategy; the only exception being the deep stoop of B:1 when lifting the lowest crates as is illustrated in Figure 14c (initial contact).

Marras (2000) also emphasized the importance of noting how often subjects are forced to adopt extreme working postures, for, as he pointed out, MSDs tend to arise from cumulative stresses rather than from one major MMH event. In the present study hyperextension occurred only in Task A when subjects lifted the highest crate off each column, as is evident from Figure 16a. The same graph illustrates that under the same condition subjects also had to adopt a stooping posture to at least 76° of flexion with all crates in order to slide them along the floor. In Condition B however, the only extreme body position was one stoop to 77° of flexion in every four crates moved (the lowest crate of each stack), as is evident from Figure 16b. By decreasing the amount of sagittal flexion, as was achieved with the intervention strategy, the cumulative stresses on the lower back were reduced. Therefore, according to the principles put forward by Marras *et al*. (1995), the risk of low back disorders was also significantly lowered.

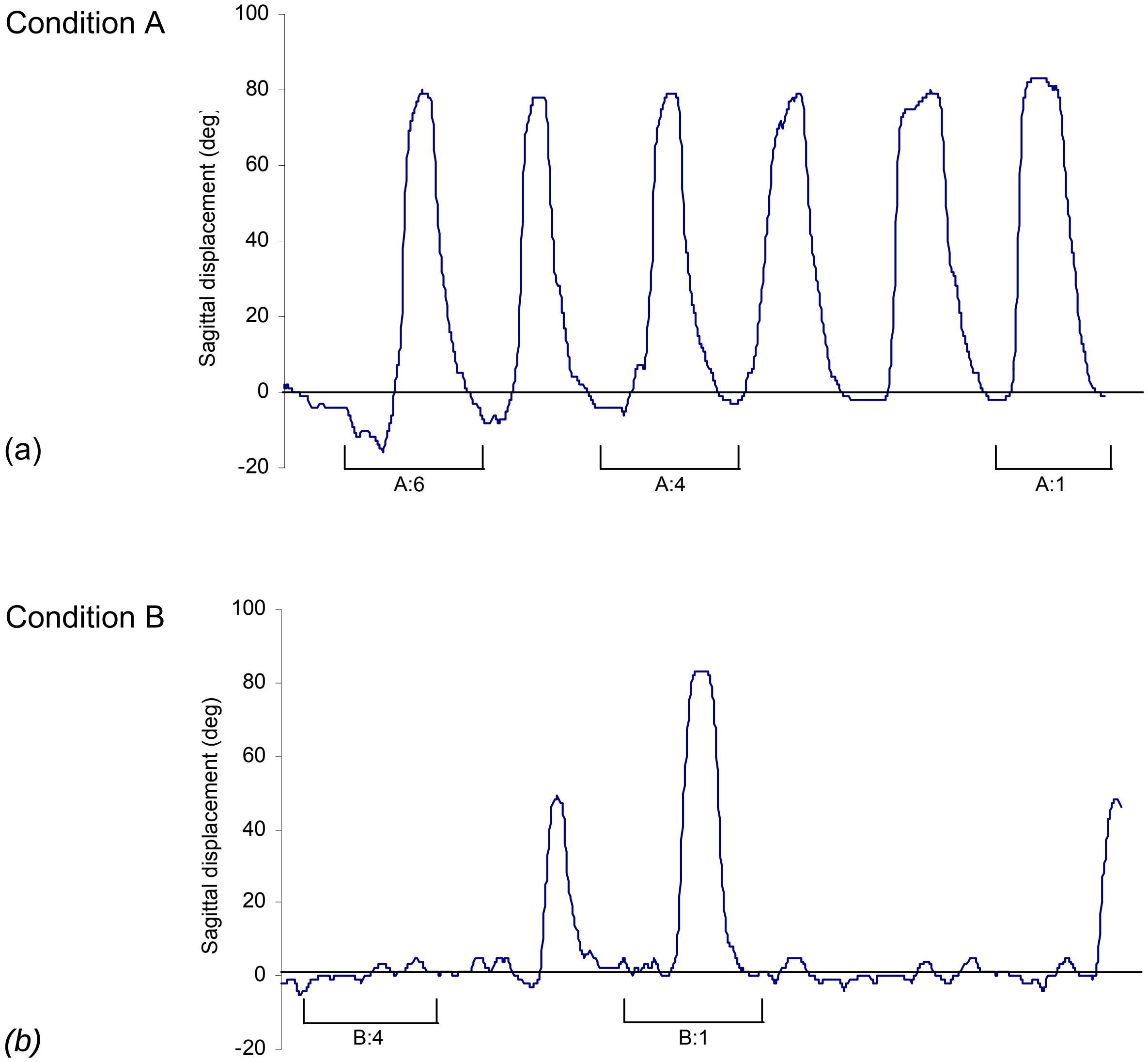


Figure 16: Typical patterns of sagittal trunk displacement.

Sagittal Velocity

Although the displacement of sagittal flexion and extension demonstrates an interplay between the compressive and shearing forces in the lower back, some researchers point out that velocity is the strongest predictor in the low back pain aetiology (Andersson, 1985; Tsuang *et al*., 1992; Marras *et al*., 1995). Due to the dynamic nature of both tasks in the present study and the extensive variability of the subjects' handling of the crates, peak spinal velocities for sagittal flexion and extension measured during the experiments were analysed and are presented in Table III.

TABLE III: Peak spinal velocities in the sagittal plane (means with standard deviations in brackets, % = coefficient of variation).

Levels	**Peak spinal velocities (deg.s^{-1})**			
	Flexion		**Extension**	
	Task A	**Task B**	**Task A**	**Task B**
Crates A:6 vs. B:4	194.3 (32.4) 16. 7%	36.4 (18.0) 49.4% *****	127.9 (23.6) 18.4%	31.2 (9.4) 30.1% *****
Crates A:4 vs. B:4	166.5 (30.4) 18.2%	36.4 (18.0) 49.4% *****	130.9 (23.3) 17.8%	31.2 (9.4) 30.1% *****
Crates A:1 vs. B:1	214.5 (35.7) 16.6%	213.6 (56.2) 26.3%	117.2 (20.1) 17.1%	159.2 (35.5) 22.3% *****

* denotes significant difference ($p<0.05$) between Task A and Task B

Statistical analyses revealed significant differences in the maximum trunk flexion velocities between the highest level for each condition (194 deg.s^{-1} and 36 deg.s^{-1} for A:6 and B:4 respectively), and between crates A:4 (167 deg.s^{-1}) and B:4. These high flexion velocities measured under Condition A are indicative of greater stresses acting on the spine, as studies by Marras *et al.* (1984) and Davis *et al.* (1998) have shown that increasing velocities during lifting and lowering result in greater spinal loading. Similarly, peak extension velocities were significantly greater for crates A:6 and A:4 (128 deg.s^{-1} and 131 deg.s^{-1} respectively) compared to 31 deg.s^{-1} for B:4. Although studies by Davis *et al*. (1998) and Gottlieb (2000) concluded that the concurrent increases in co-activation of the trunk muscles serve to assist limb stability and prevent injury, Komi (1973) pointed out that muscular force production decreases with increasing muscle contraction velocities. This leads to concomitant increases in sagittal moments at the L5/S1 level (Tsuang *et* *al*., 1992; Lavender *et al*., 1999) and significant reductions in trunk torque (Marras *et al.*, 1984). As a result of the higher velocities in Condition A the lower back is more susceptible to compressive, shearing and torsional forces.

According to the risk groups established by Marras *et al.* (1995) maximum spinal velocities in the sagittal plane equalling or exceeding 59 deg.s^{-1} are classified as 'high risk'. During Condition A the peak sagittal velocities were about three times greater than the above-mentioned 'limit' and were the result of the extreme ranges of motion and the high handling frequencies. Moving one crate every five seconds through a range of motion of between 80 and 90 deg.s^{-1} requires fast trunk movements to complete the work-cycle in the time available. The decreases in the ROM that were achieved with the post-intervention condition for the top two levels of analysis therefore reduced the need for high flexion velocities. Conversely, flexion velocities for the lowest level did not differ significantly between conditions due to the similar ranges of motion, with a similar pattern observed for extension velocities; the exception being crate B:1, which exhibited a significantly greater mean extension velocity than A:1. This could be attributed to a perceived 'recovery period' in Task A, where the subjects had just completed the task of pushing the crate away and were standing up, ready to collect the next crate. In Task B the bulk of the work still lay ahead of the subjects as they had to lift the crate and carry it to hand to the next worker, hence the high speed of moving into the upright position.

Velocities during flexion were significantly greater than during extension, regardless of working method or crate height. These greater velocities are due to the conscious bending to collect the crates, as well as the gravitational forces acting on the body. Extension, on the other hand, was slower as a result of having to work against gravity.

Sagittal Acceleration

In any situation of dynamic handling of objects, such as the tasks under investigation, it is necessary to acknowledge that the velocity of the motion will not be constant. Any in-depth investigation should therefore include an analysis of the rate of change of velocity, as some researchers such as Andersson (1985) believe that this constitutes a significant risk factor in low back disorders. Measurements obtained for peak positive and negative accelerations of the spine are depicted in Table IV.

TABLE IV: Peak spinal accelerations in the sagittal plane (means with standard deviations in brackets, % = coefficient of variation).

Levels	**Peak spinal accelerations (deg.s^{-2})**			
	Positive Acceleration		**Negative Acceleration**	
	Task A	**Task B**	**Task A**	**Task B**
Crates A:6 vs. B:4	612.9 (189.8) 31.0%	248.8 (73.7) 29.6% *	733.6 (166.4) 22.7%	275.2 (136.5) 49.6% *
Crates A:4 vs. B:4	601.1 (166.5) 27.7%	248.8 (73.7) 29.6% *	651.4 (149.2) 22.9%	275.2 (136.5) 49.6% *
Crates A:1 vs. B:1	739.4 (216.0) 29.2%	836.6 (270.0) 32.3%	832.7 (166.4) 20.0%	841.7 (232.7) 27.6%

* denotes significant difference ($p<0.05$) between Task A and Task B

Statistical analyses of sagittal trunk acceleration revealed a pattern similar to that exhibited by sagittal velocity. Positive accelerations were significantly greater for the top two levels of analysis for crates A:6 and A:4 (613 deg.s^{-2} and 601 deg.s^{-2} respectively) compared to B:4 (249 deg.s^{-2}). Negative accelerations were also greater for Task A (734 deg.s^{-2} and 651 deg.s^{-2}) compared to 275 deg.s^{-2} during Task B. No statistical differences were however found between the two conditions at the lowest level for either acceleration.

The greater positive and negative accelerations induced by the top two levels in Task A were not unexpected. Larger ranges of motion and high velocities under this condition compared to the post-intervention task necessitated marked accelerations to fulfil the required task in the time available. Marras and Mirka (1989) demonstrated that increasing accelerations have similar effects on the lower back as increasing velocities. Dramatic decreases in trunk strength with increasing accelerations render the spine vulnerable to the compression and shearing forces acting on the spine. MacKinnon and Li (1998) also pointed out that the danger of great accelerations was the risk of 'jerking' actions on the back, which could lead to severe tissue trauma. According to the risk groups developed by Marras *et al*. (1995) maximum positive accelerations of 340 deg.s^{-2} and maximum negative accelerations of 95 deg.s^{-2} fall into the 'high risk' category. Measurements of peak positive and negative acceleration obtained during experimentation under Condition A were considerably greater than the 'high risk' classification. With the introduction of the intervention strategy, positive spinal accelerations were reduced by 59%, placing them into the 'low risk' category. Negative accelerations, however, remained in the 'high risk' category despite equally large reductions under Condition B.

Rotational Range of Motion

In many studies rotation within the spine has been cited a major contributing factor to low back pain aetiology (Marras *et al.,* 1995; Marras, 2000). It is unfortunate that, as Amell *et al*. (2000) argue, trunk rotation is almost inevitable during manual materials handling, as workers tend to position themselves asymmetrically in order to get closer to the object to be handled and place the upper extremities at a mechanical advantage, resulting in a rotational motion in the vertebral column.

Contrary to the expectation that transverse plane motion would be greater under Condition A, it was the post-intervention condition which displayed greater ranges of motion at all stacking levels selected for analysis. Total transverse displacement was measured at 27^{o}, 22^{o} and 18^{o} for crates A:6, A:4 and A:1 respectively, whereas ranges of motion of 27^{o} and 25^{o} were obtained for the highest and lowest crates under Condition B respectively. The differences between the two experimental conditions were statistically significant at all levels except at the highest level. As was the case in the sagittal plane, the greater the transverse deviation from an anatomically neutral position, the greater the stresses imposed on the intervertebral discs and surrounding ligamentous and muscular structures.

Marras *et al.* (1990) and Kumar *et al.* (1995) pointed out that during extreme twisting actions muscular control shifts from the collectively large erector spinae to the latissimus dorsi and the external and internal oblique muscles of the trunk, ultimately affecting trunk strength, force exertion capabilities and motor control. However, following instructions, subjects employed 'free-style' manual handling actions, which, due to the absence of restrictions, permitted a natural flow of movement and allowed subjects to turn their feet, as opposed to twisting their spines, therefore preventing extreme rotational movements in the back.

TABLE V: Transverse displacements to left and right (means with standard deviations in brackets, % = coefficient of variation).

Levels	**Transverse displacement (degrees)**			
	Left		**Right**	
	Task A	**Task B**	**Task A**	**Task B**
Crates A:6 vs. B:4	17.9 (5.8) 32.3%	12.6 (8.9) 70.8% *	9.4 (8.1) 85.6%	14.8 (4.6) 31.2% *
Crates A:4 vs. B:4	17.5 (5.3) 30.0%	12.6 (8.9) 70.8% *	4.4 (5.0) 113.3%	14.8 (4.6) 31.2% *
Crates A:1 vs. B:1	17.1 (5.5) 32.4%	15.5 (7.3) 46.8%	0.8 (3.6) 426.1%	9.7 (4.2) 42.9% *

* denotes significant difference ($p<0.05$) between Task A and Task B

Assessing the data for transverse displacement to the left and right sides (Table V), it became apparent that Task A displayed a significantly greater range of movement to the left side than Task B, with displacements ranging between 17° and 18° for Condition A as opposed to 13° and 16° for Condition B. This consistent twist to the left was due to the subjects stepping to the left foot to initiate the vigorous pushing action to slide crates along the floor. From observations it was evident that due to the unrestricted working postures in Task A subjects turned their feet and hips, which prevented their spines from being forced into extreme rotation. A greater transverse displacement to the right occurred under the post-intervention condition, which suggests that, although subjects moved their feet while turning, the natural movement of twisting the trunk might play an important part in initiating or leading the turning motion when changing direction.

Although Task B displayed a greater rotational range of motion, the combination of rotation and simultaneous flexion and extension in Task A could lead to greater stresses on the spine. Analysis of the data revealed that under Condition A rotation was at its greatest during maximum flexion as the subjects bent down to push the crates along the ground. During twisting motions the erector spinae play the role of stabilizers, but as the trunk musculature is already weakened by the extreme stooping motions and the virtually inactive erector spinae, the added torsional forces significantly increase the risk of injury. On the other hand, under the post-intervention condition the point of maximum rotation coincided with minimal flexion, thus reducing the risk to the spine despite slightly greater twisting ranges of motion.

Rotational Velocity

From the rotational velocities displayed in Table VI it becomes apparent that, as in the case of rotational displacement, the velocities when twisting to the left side in Condition A were significantly greater for the top two levels of analysis, and nominally larger for the floor level compared to Condition B. Measurements to the left side during the pre-intervention task ranged from 54 deg.s^{-1} to 67 deg.s^{-1}, and from 47 deg.s^{-1} to 48 deg.s^{-1} for the post-intervention scenario. With larger ranges of motion there is a greater need for high velocities to complete the movement in a given time. In the case of Condition A the greater velocities served to create enough momentum to slide the crates the entire 5 m along the floor. However, fast rotational movements result in great torsional stresses on the spine. Kumar *et al*. (2003) pointed out that increasing velocities pose a greater risk to the spinal ligaments, joint capsules and other soft tissues due to their resistance to movement patterns deviating from the neutral anatomical standing position. If the connective tissues undergo increasing deformation as a result of faster rotational velocities, the risk of trauma increases.

TABLE VI: Peak spinal velocities in the transverse plane (means with standard deviations in brackets, % = coefficient of variation).

Levels	***Peak spinal velocities (deg.s^{-1})***			
	Left		***Right***	
	Task A	***Task B***	***Task A***	***Task B***
Crates A:6 vs. B:4	67.1 (18.2) 27.2%	48.3 (14.3) 29.6% *****	47.5 (17.8) 37.5%	43.2 (13.9) 32.2%
Crates A:4 vs. B:4	61.9 (16.7) 27.0%	48.3 (14.3) 29.6% *****	40.1 (12.6) 31.5%	43.2 (13.9) 32.2%
Crates A:1 vs. B:1	53.5 (13.5) 25.3%	47.2 (13.6) 28.8%	34.8 (9.1) 26.1%	48.6 (10.6) 21.7% *****

* denotes significant difference ($p<0.05$) between Task A and Task B

Rotational velocities to the right side ranged from 35 deg.s^{-1} to 48 deg.s^{-1} and from 43 deg.s^{-1} to 49 deg.s^{-1} under Conditions A and B respectively. The only time rotation was significantly faster for the post-intervention condition was at the floor level. Again, the slower rotational movements of A:1 could be the results of a deliberate slowing down of the subjects to ease the pace between each lift. Most of the time however, it was responses to Task A which exhibited greater rotational velocities, with the result that the back musculature was weakened and the surrounding soft tissue structures had to carry the load, hence making them more susceptible to the torsional stresses.

Rotational Acceleration

Positive and negative trunk accelerations in the transverse plane remained constant throughout all levels of analysis (Table VII). Values for negative acceleration ranged from 266 to 299 deg.s^{-2} in Task A and from 309 to 323 deg.s^{-2} in Task B. Again, the only significant difference between the two conditions was at the lowest level; the result of time-pressured ‘stop-start’ actions. Peak positive accelerations were nominally greater under the pre-intervention condition, ranging between 293 and 333 deg.s^{-2}, whereas positive accelerations in Condition B were recorded at 289 and 300 deg.s^{-2}.

TABLE VII: Peak positive and negative spinal accelerations in the transverse plane (means with standard deviations in brackets, % = coefficient of variation).

Levels	**Peak spinal accelerations (deg.s^{-2})**			
	Negative		**Positive**	
	Task A	**Task B**	**Task A**	**Task B**
Crates A:6 vs. B:4	298.9 (102.6) 34.3%	308.9 (107.7) 34.9%	332.8 (118.1) 35.5%	288.7 (84.4) 29.2%
Crates A:4 vs. B:4	292.9 (86.2) 29.4%	308.9 (107.7) 34.9%	320.4 (125.8) 39.3%	288.7 (84.4) 29.2%
Crates A:1 vs. B:1	266.3 (60.2) 22.6%	322.8 (83.0) 25.7% *	293.2 (91.5) 31.2%	300.2 (100.8) 33.6%

* denotes significant difference ($p<0.05$) between Task A and Task B

Marras and Mirka (1989) pointed out that trunk flexion angles, asymmetry angles and velocities interact in very complex ways that make extrapolations difficult. The load-tolerance relationship described by Hoozemans *et al.* (1998) and Marras (2000) is defined as the ratio of the strength of the musculoskeletal structure to the mechanical stress imposed on it, which relates directly to the biomechanical risk of tissue damage. From the above results the beneficial effects of the intervention strategy in terms of spinal kinematics are evident. An unfavourable combination of range of motion, velocities and accelerations in the sagittal and transverse planes during the execution of the original *in situ* action clearly placed excessive mechanical stresses on the spine and surrounding tissues of the lower back, decreasing structural strength and therefore significantly increasing the risk of MSDs. Conversely, the analysis of the change of working method proposed in Task B clearly demonstrated a more favourable load-tolerance relationship.

PHYSIOLOGICAL RESPONSES

Heart Rate

Although heart rates are probably the most erratic of all physiological variables, they are accepted as being reliable indicators of the amount of cardiac strain (Vuori, 1998, Kapitaniak, 2001), provided the responses are analysed keeping the testing circumstances in mind (Kilbom, 1995). As cardiac responses are easily influenced by a variety of factors, seated resting heart rates of all 28 subjects were obtained on the day of the habituation session. On the day of the experiments, 'anticipatory' heart rates were monitored immediately prior to each of the two conditions in order to establish whether subjects were apprehensive about performing either task. Anticipatory, working and recovery heart rate responses are presented in Table VIII.

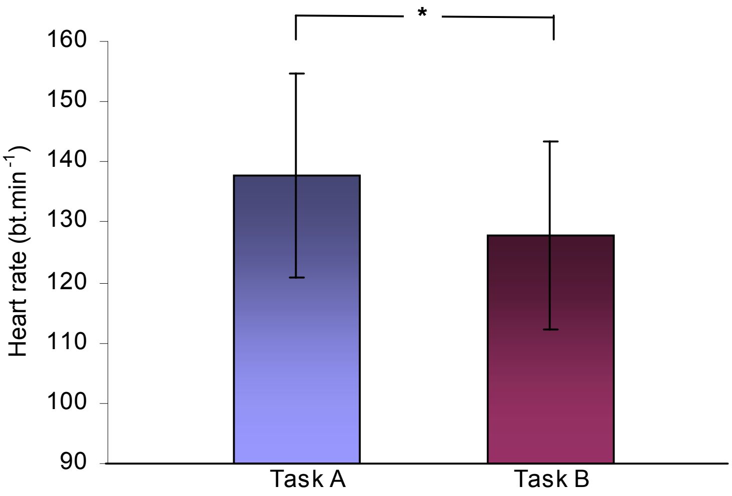
TABLE VIII: Anticipatory, working and recovery heart rate responses (means with standard deviations in brackets, % = coefficient of variation).

	Heart Rate (bt.min^{-1})	
	Task A	***Task B***
'Anticipatory'	77.7 (12.3) 15.8%	78.1 (11.6) 14.8%
'Working'	137.8 (17.0) 12.4%	127.8 (15.6) 12.2% *****
Recovery Minute 3	109.9 (18.6) 17.0%	102.4 (17.3) 16.9% *****

* denotes significant difference ($p<0.05$) between Task A and Task B.

For comparative purposes it should be noted that an average resting heart rate of 74 bt.min^{-1} was recorded for the selected industrial workers in the bottle sorting industry. The unfamiliar measurement and observational situation the labourers were exposed to could however have increased the likelihood of apprehension affecting their resting heart rate. Working heart rates averaged at 116 bt.min^{-1} for the entire duration of the offloading process, which lasted between 45 and 60 minutes. However, the labourers worked at varying frequencies, from zero and sometimes increasing to 26 crates per minute, where heart rates peaked at 167 bt.min^{-1}.

The subjects' mean anticipatory heart rate, collected for two minutes prior to the start of the activity, was elevated by an average of 15 bt.min^{-1} compared to their resting heart rate of 63 bt.min^{-1}, but did not differ significantly between the two conditions. McArdle *et al*. (1996) explain that neural and chemical actions, including hormones such as epinephrine and norepinephrine, cause these increases in heart rates in anticipation of activity.



* indicates a statistical difference at p=0.05.

Figure 17: Overall heart rate responses for Tasks A and B, the pre- and post-intervention conditions respectively (means and SD).

Extreme whole-body motions such as required for lifting actions increased the demand for blood required by the working muscles. Figure 17 demonstrates the positive effect of the intervention on overall working heart rate responses. Despite the noticeable inter-individual variability, as is evidenced in the high standard deviations (Table VIII), the mean heart rate responses for Task A (138 bt.min^{-1}) were significantly higher than those for Task B (128 bt.min^{-1}). Through the elimination of the extreme stretching and pushing actions the primary activity during Task B became carrying, which, according to research conducted by Mital *et al*. (1994) is less physically fatiguing than lifting or lowering. This, in all probability, reduced the circulatory demands of Condition B, despite there being no reduction in frequency.

Heart rate responses increased significantly during the first three minutes of both tasks and levelled off thereafter. According to Casaburi *et al*. (1987) and Smith (2001) a steady state is usually reached after 3-4 minutes of working at a constant workload. From the recorded heart rate responses a nominal progressive increase is however evident, with heart rates increasing from 134 bt.min^{-1} for Task A and 123 bt.min^{-1} for Task B (3.5 minutes into the activity) to 145 and 133 bt.min^{-1} just before termination of Tasks A and B respectively. Figure 18 illustrates that once the initial adjustment had been made to the imposed work load, the heart rates measured during Condition B were consistently 11 to 12 bt.min^{-1} lower throughout the entire collection period, again indicating that the different working methods of offloading the truck elicited an immediate apparent difference in cardiac responses, which was maintained through the entire duration of the activity.

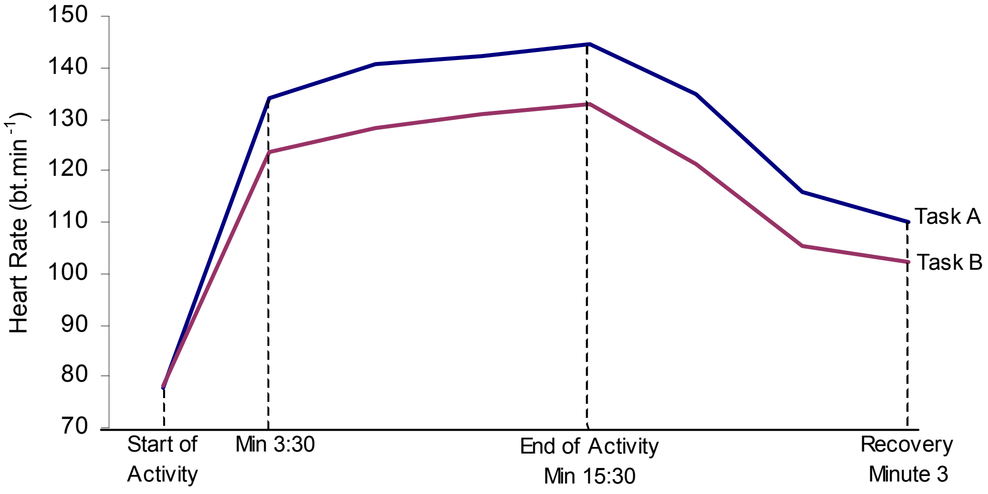


Figure 18: Progression of heart rate responses from anticipatory to recovery values.

According to the classification matrix of Sanders and McCormick (1993) a workload that elicits heart rates between 125 and 150 bt.min^{-1} is classified as 'heavy'. Although both tasks fall within this category, during Task A subjects were working in the middle range of the 'heavy' category, whereas during Task B subjects fell between the 'moderate' and 'heavy' categories. The difference in workloads between the experimental tasks is also apparent when taking the predicted physiological capacities into consideration. Subjects worked at an average of 69% and 64% of their age-predicted maximum heart rates under Conditions A and B respectively. Some subjects in Task A even worked above 90% of their predicted maximum, with one subject reaching 187 $bt.min^{-1}$ during the final minute of Task A, which was 94% of his age-predicted maximum heart rate. No such extreme elevations were evident during Task B.

During the first three minutes after termination of the activity mean recovery heart rates, presented in Table VIII, returned to 110 and 102 $bt.min^{-1}$ for Task A and Task B respectively. According to Brouha (1960), a change of more than 10 $bt.min^{-1}$ between heart rates for the first and the third recovery minute is considered as ‘normal’ (Kilbom, 1995). Although the heart rates were still considerably elevated three minutes after termination of the exercise, indicating a heavy workload, the subjects’ heart rates had decreased to 41% above anticipatory heart rates in Task A and to 31% above anticipatory values in Task B, suggesting that the time to fully recuperate from the activity was also reduced under the improved condition. Similar results were obtained from the industrial workers, although comparisons are only made tentatively due to the complex interplay between intensity and duration. The duration of the offloading process in the field was close to an hour with inconsistency in the frequency of lift. Recovery heart rates of the labourers did however follow the same trend as those of the subjects in the laboratory tests, with heart rates decreasing to 40% above resting values three minutes after termination of the activity.

Respiratory Responses

During physical activity the body’s increased need for oxygen supply and carbon dioxide removal manifests itself in immediate changes in ventilatory responses such as breathing frequency (R_F), tidal volume (V_T) and minute ventilation (V_E). As pulmonary ventilation is essential for aerobic energy metabolism, adequate changes in these respiratory variables are necessary for efficient physical performance (Åstrand and Rodahl, 1986).

The effects of anticipation, due to the stimulation of the respiratory neurons by the motor cortex and catecholamine secretion (McArdle *et al.*, 1996), are evident from the respiratory results in Table IX, with anticipatory breathing frequencies being elevated above the normative 12 br.min^{-1} to 16 br.min^{-1} for Task A and 17 br.min^{-1} for Task B. Similarly, tidal volumes were between 100 and 200 ml higher during the anticipatory period than the male average of 600 ml per breath (McArdle *et al.*, 1996). As a result, minute ventilation was elevated by 4.6 L.min^{-1} and 5.1 L.min^{-1} under Conditions A and B respectively.

TABLE IX: Respiratory frequency, tidal volume and minute ventilation (means with standard deviations in brackets, % = coefficient of variation).

	Respiratory Frequency (br.min^{-1})		***Tidal Volume (L.br^{-1})***		***Minute Ventilation (L.min^{-1})***	
	Task A	***Task B***	***Task A***	***Task B***	***Task A***	***Task B***
'Anticipatory'	16.2 (2.8) 17.6%	16.6 (3.5) 21.4%	0.7 (0.2) 28.7%	0.8 (0.2) 25.9%	11.8 (2.1) 17.9%	12.3 (1.8) 15.0% *****
'Working'	30.3 (5.6) 18.4%	28.5 (5.6) 19.8% *****	1.7 (0.3) 17.7%	1.6 (0.4) 23.6% *****	49.2 (6.1) 12.3%	43.3 (5.8) 13.4% *****
Recovery Minute 3	20.2 (5.1) 25.3%	19.4 (4.9) 25.3%	0.9 (0.2) 23.8%	0.9 (0.3) 30.6%	17.8 (2.6) 14.4%	16.3 (2.4) 14.5% *****

* denotes significant difference ($p<0.05$) between Task A and Task B.

Over the entire duration of the activity average values for breathing frequencies increased by 87% above 'anticipatory' values under Condition A and 72% under Condition B. Tidal volumes on the other hand rose by 143% and 100% for Tasks A and B respectively. The larger increases in breathing frequency and tidal volumes for the pre-intervention condition indicate that this condition was the more strenuous one. Significantly lower values for all respiratory variables give a clear indication of the beneficial effects of the intervention strategy. Further evidence is the decrease in breathing frequency from 30.3 br.min^{-1} to 28.5 br.min^{-1} and the reduction in tidal volumes from 1.7 L.br^{-1} to 1.6 L.br^{-1}. Minute ventilation, the product of tidal volume and respiratory frequency and an overall reflection of an individual's pulmonary ventilation, reached an average of 49.2 L.min^{-1} under Condition A, a 317% increase above anticipatory values, and 43.3 L.min^{-1} under Condition B, a 252% increase. These values, although classified as a 'very heavy' workload by Kroemer and Grandjean (1997), support the argument that Task B is physiologically less taxing than Task A.

The most substantial respiratory adjustments occurred within the first three and a half minutes, by which time both breathing frequencies had risen sharply, reaching average values of 29.1 br.min^{-1} for Task A and 27.8 br.min^{-1} for Task B. At the same time tidal volumes of 1.70 and 1.65 L.br^{-1} were recorded for Conditions A and B respectively. When heavy demands are placed on individuals fast adaptations in ventilation enable the body to minimize the oxygen deficit, quickly providing the working muscles with the oxygen required for aerobic metabolism. Over the duration of the activity responses in breathing frequency indicated a steady increase to 32 br.min^{-1} and 30 br.min^{-1} for the pre- and post-intervention conditions respectively. Tidal volumes, on the other hand, showed a reversed trend having decreased to 1.67 L.br^{-1} for Task A and 1.58 L.br^{-1} for Task B by the end of the activity. Åstrand and Rodahl (1986) and McArdle *et al*. (1996) pointed out that during light to moderate work ventilatory increases are usually attributed to a rise in tidal volume, whereas increases in breathing frequency become more important during heavy activities in an attempt to minimize the effects of carbon dioxide production and lactic acid build-up on the blood pH. Large tidal volumes indicate a more effective breathing pattern as greater volumes of air are moved into the lungs, whereas in the current case increases in breathing frequencies, but lower tidal volumes, indicate a more shallow breathing pattern. In such instances only a minimal amount of air reaches the alveoli and most remains in what is termed "dead space", accelerating the onset of fatigue (Åstrand and Rodahl, 1986). The results therefore suggest that with increasing muscular and cardiovascular fatigue a shift from moderate to heavy workload occurred, with the need for oxygen eliciting increases in breathing frequency, but at the expense of tidal volume. The progression of V_E values over the entire duration of the activity reveals a nominal increase, which was to be expected due to the greater increases in breathing frequency, compared to the decreases in tidal volumes. These changes over the 16-minute activity are not unusual for the selected respiratory variables, but might indicate a trend that could be exaggerated when performing the same activities for longer durations, as within an industrial setting.

Recovery respiratory responses showed a dramatic drop in the first minute before tapering off towards resting values during the following two minutes. Although all respiratory variables were still elevated above anticipatory values, the only significant difference between pre- and post-intervention tasks was in minute ventilation.

Oxygen Consumption (VO_2)

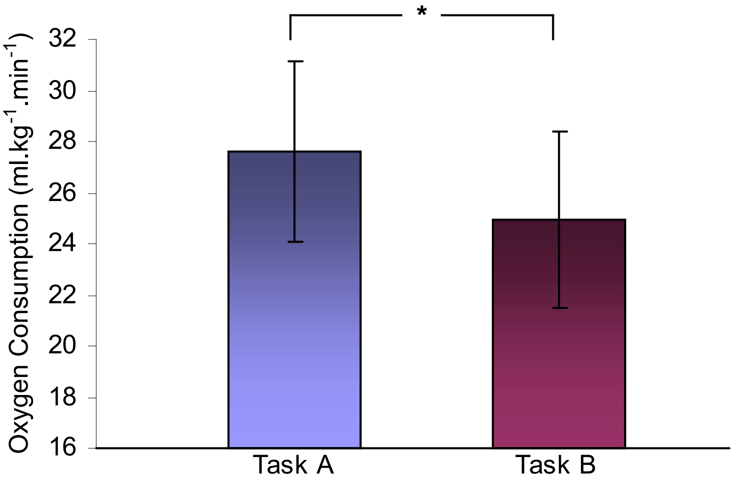
The increase in oxygen uptake during any activity is crucial for the metabolism of carbohydrates, fats and proteins to yield the energy necessary for the body to function optimally during times of physical stress. Furthermore, it is the capacity of the oxygen transportation and utilization systems that play an important role in the onset of fatigue and an individual's endurance capacity (Åstrand and Rodahl, 1986), although this point has been debated in the literature (Noakes, 1998). Jiang *et al*. (1986) pointed out that body mass plays a significant role in MMH, as increases in VO_2 are not only caused by the weight of an object being handled, but also by the worker's own body weight when lifting, lowering and carrying objects. The linear relationship between oxygen consumption and body mass thus allows for the analysis of VO_2 relative to body weight (McArdle *et al*., 1996). Relative and absolute oxygen consumption measurements are presented in Table X.

TABLE X: Relative and absolute anticipatory, working and recovery oxygen consumption (means with standard deviations in brackets, % = coefficient of variation).

	VO_2 (ml.kg^{-1}.min^{-1})		**VO_2 (L.min^{-1})**	
	Task A	**Task B**	**Task A**	**Task B**
'Anticipatory'	5.6 (0.6) 11.3%	5.8 (0.6) 10.2% *	0.4 (0.1) 18.66%	0.4 (0.1) 16.29%
'Working'	27.6 (3.5) 12.8%	25.0 (3.5) 14.0% *	2.1 (0.2) 11.04%	1.9 (0.2) 13.27% *
Recovery Minute 3	7.2 (1.2) 16.2%	7.1 (1.2) 17.6%	0.5 (0.1) 16.63%	0.5 (0.1) 16.32%

* denotes significant difference ($p<0.05$) between Task A and Task B.

Over the 16-minute experimentation period average oxygen consumption for the two testing conditions was recorded at 27.6 ml.kg^{-1}.min^{-1} and 25.0 ml.kg^{-1}.min^{-1} for Tasks A and B respectively, indicating a significantly lower physiological stress for the post-intervention working method (Figure 19).



* indicates a statistical difference at p=0.05.

Figure 19: Working oxygen consumption (means and SD).

While adequate oxygen supply is necessary to fuel the internal adjustments of the cardiovascular and respiratory systems, amongst others, to maintain homeostasis, the significant increase in oxygen consumption is attributed to the major muscle groups in the back, thighs and arms, which require large amounts of oxygen for optimal contractions. Apart from handling the 10 kg mass of the crates, lifting and lowering tasks also require movement of head, arms and trunk, which account for approximately 75% of total body weight (Williams and Lissner, 1962) and added, on average, 57 kg to the load to be lifted and lowered. Mital (1984) also found this to be the reason for the greater oxygen consumption when working between floor and knuckle height as opposed to working above this height. The results obtained in the current study support the findings of Mital *et al*. (1994), which demonstrated a greater oxygen cost for lifting and lowering activities compared to carrying. Reducing the stretching and stooping actions and introducing a carrying component to the task significantly lowered the energy cost for Task B.

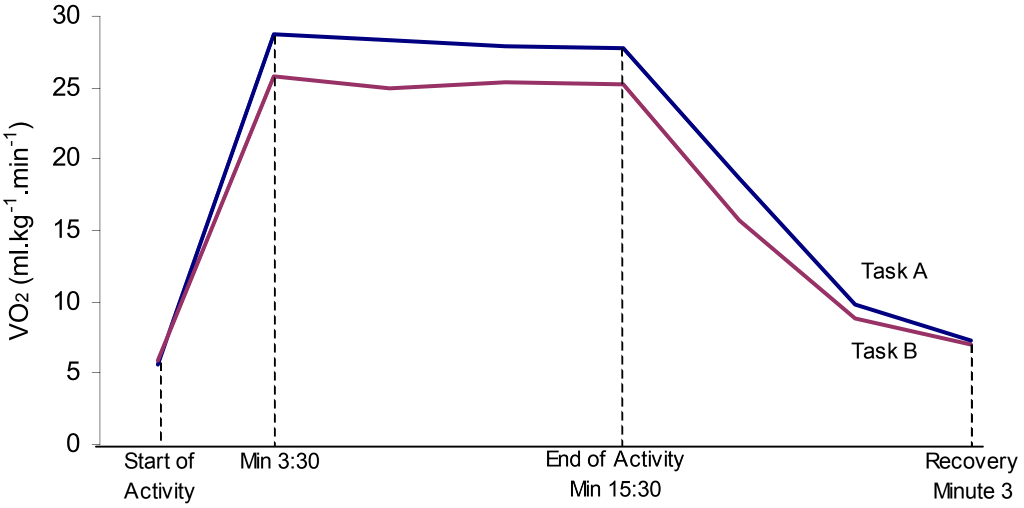


Figure 20: Steady-state curve for oxygen consumption from resting to recovery values.

Figure 20 shows that the greatest increase in oxygen consumption, similar to the other physiological variables, occurred in the first three minutes of the activity, with VO_2 values increasing five-fold for Task A, and 4.4 times for Task B compared to the anticipatory measurements. A review by Bangsbo (2000) revealed that this initial increase in oxygen consumption is not only due to increases in VO_2 of the cardiac and respiratory systems, but also due to an almost immediate increase in oxygen uptake by the working muscles, which reaches a maximum within 45 seconds. The significant difference in the VO_2 data between the two experimental conditions therefore suggests that the implementation of the intervention strategy had already reduced central, as well as muscular strain after only three and a half minutes of physical work. This difference was maintained throughout the duration of the activities.

Contrary to expectations, the progression of oxygen uptake from minute 3:30 to minute 15:30 indicated a nominal decrease. The levelling off and even nominal reduction of oxygen uptake over time points towards a steady physiological state where cardiac and ventilatory adaptations have reached a plateau and the body's demand for oxygen has been met (Åstrand and Rodahl, 1986). An explanation for the elevated VO_2 values recorded during minute 3:30 under both conditions is the attempt to make up the oxygen deficit. As the body adjusts its respiratory and circulatory systems to the sudden increases in oxygen requirements for aerobic substrate utilization (Åstrand and Rodahl, 1986) it 'overcompensates' before achieving balance, hence the initial elevated values. Another indicator that subjects had already reached steady-state by the first collection interval is the ventilatory equivalent. This ratio between minute ventilation and oxygen consumption is 25:1 at steady-state and greater when working in a non-steady-state (McArdle *et al.*, 1996). Ventilatory equivalent values of 22.4 for Condition A and 24.1 for Condition B were calculated for the first collection interval, and on average over the entire duration at 24.0 and 23.3 for Tasks A and B respectively.

Universally accepted classification tables categorize activities eliciting oxygen uptake between 1.5 and 1.8 $L.min^{-1}$ as 'heavy work' and VO_2 responses between 2.0 and 2.5 $L.min^{-1}$ as 'very heavy' (Sanders and McCormick, 1993). According to these tables, Task B falls into the former category, with an average oxygen consumption of 1.9 $L.min^{-1}$, and Task A falls into the latter category with a VO_2 of 2.1 $L.min^{-1}$. Caution must, however, be practised when applying such classifications. Not only is a person's physiological capacity determined by various factors such as level of training, age, sex and body size (Åstrand and Rodahl, 1986), it is also very task-specific (Dempsey, 1998). Although one could argue that conditioned industrial workers may be less physiologically taxed in the execution of Task A in this experiment, possible inadequate nutritional intake of the labourers could mean more limited aerobic capacities, as was found by Wyndham (1975) in respect of South African miners. The labourers would thus be working at a higher percentage of their maximum capacities. However, despite the high VO_2 values, which are not unexpected considering the high handling frequency of both tasks, it is evident that the suggested change in the handling pattern of the crates significantly reduced the physiological strain on the subjects.

Recovery oxygen uptake values show a substantial decrease over the three-minute recovery period (see Figure 20), which is a typical post-exercise response (Sedlock *et al*., 1989). By the third recovery minute VO_2 had decreased to 7.2 $ml.kg^{-1}.min^{-1}$ and 7.1 $ml.kg^{-1}.min^{-1}$ for Tasks A and B respectively (Table X). According to McArdle *et al.* (1996) the fast component of this excess post-exercise oxygen consumption (EPOC) can repay half the oxygen debt in the first 30 seconds of recovery, whereas the slow component of an individual's recovery depends on the intensity and duration of the activity and can delay the return to resting values by several hours. The delayed return to resting levels has several causes, including the replenishment of oxygen in the body, removal of anaerobic metabolites, such as lactic acid, differing levels of catecholamine concentrations and the elevated metabolism due to a higher core temperature (Sedlock *et al*., 1989; McArdle *et al*., 1996). The results indicate that the subjects' recovery VO_2 values were still elevated by 29% for Condition A and 22% for Condition B after three minutes of rest, and due to the high intensity of the activities it would be difficult to predict the time at which oxygen consumption would return to resting values. A study by Sedlock *et al.* (1989) revealed that exercise intensities affected both the magnitude and duration of the EPOC, whereas exercise duration only had an influence on the recovery time. In the current study this has implications for the recommendation of work-to-rest ratios, as work intensities and durations while offloading the truck *in situ* are not as rigorously controlled as they were during the laboratory experiments. However, as the results for oxygen uptake indicate, the working intensities of Task B are significantly lower than those of Task A, which in turn should have a positive effect on the workers' physiological recovery.

Energy Expenditure (EE)

The analysis of energy expenditure in this research project is of particular relevance to the field setting, due to the generally low work capacities of manual labourers in industrially developing countries. Overall energy expenditure results (Table XI) are presented in terms of energy expenditure in absolute terms, relative to body mass, as well as in terms of multiples of resting metabolic rate (MET).

TABLE XI: Overall energy expenditure of both conditions (means with standard deviations in brackets, % = coefficient of variation).

	Task A	***Task B***
EE (kcal.min^{-1})	10.1 (1.1) 10.4%	9.1 (1.2) 12.8% *****
EE (kcal.kg^{-1}.day^{-1})	194.0 (24.4) 12.6%	173.6 (23.5) 13.6% *****
MET	7.9 (1.0) 12.7%	7.1 (1.0) 14.0% *****

* denotes significant difference ($p<0.05$) between Task A and Task B.

The high energy cost displayed in Table XI is the sum of the energy required for the activity itself and that needed for moving the entire body, or parts of the body, particularly during weight-bearing activities such as walking and lifting (De Looze *et al*., 1994; McArdle *et al*., 1996). The results show that the recorded energy expenditures of 174 kcal.kg^{-1}.day^{-1} (10 kcal.min^{-1}) in Task B were significantly less than the 194 kcal.kg^{-1}.day^{-1} (9 kcal.min^{-1}) obtained in Task A. According to the classification tables by Sanders and McCormick (1993), the former condition would therefore fall into the 'very heavy work' category, whereas the intervention strategy has resulted in only a 'heavy work' classification. In terms of multiples of resting metabolic rate, Task A increased from resting values of 1 MET to 7.9 METs, whereas Task B only increased to 7.1 METs; a significant difference between the two conditions.

As with oxygen consumption, the intensity of an activity depends on each individual's physiological capacity. Classification tables for individuals differing in maximum oxygen uptake capacity (VO_{2max}) by Howley (2001) indicate that an individual with a low VO_{2max} would, for example, not be able to work at intensities of 8 METs for extended durations, whereas for a person with a high VO_{2max} the experimental conditions could be classified as ‘hard’.

Although De Looze *et al*. (1994) found that repetitive lifting of loads was more expensive in terms of energy cost compared to lowering loads of the same mass at the same frequency (probably due to the mechanical disruption of the actin-myosin bonds of the cross-bridges, rather than through ATP-dependent actions (Enoka, 1996)), they also noted significantly lower energy costs during isometric muscular contractions compared to concentric contractions. Not only were the majority of muscle activations in Task A concentric and eccentric in nature, the muscular contractions were also forceful, particularly for the pushing motion to slide the crates the entire length of 5 m. In Task B however, the dominant action, namely carrying, required isometric contractions, which, in all likelihood, reduced the energy cost for the post-intervention condition. However, these statements are made tentatively, as each of the two experimental conditions involved a combination of varying manual handling components, which were analysed as a whole.

Respiratory Quotient (RQ)

The respiratory quotient can be defined as the ratio of carbon dioxide removed to the amount of oxygen taken up. Due to the different chemical compositions of food substances the oxygen requirements to metabolise these molecules differ. The RQ is therefore a useful indicator of the nutrient catabolism which occurs in the cells, a value of 0.70 signifying pure lipid utilization, whereas a value of 1.00 or greater being indicative of carbohydrate metabolism (McArdle *et al*., 1996). This is, however, only valid during rest and steady-state activities. Tasks that require anaerobic metabolism usually lead to an increase in breathing frequencies, which alter the oxygen–carbon dioxide relationship. In such cases the RQ is termed respiratory exchange ratio and is no longer a reflection of the substrates being oxidized.

In Table XII the measured ‘anticipatory’ respiratory quotients of 0.82 (Task A) and 0.80 (Task B) indicate a mixture of carbohydrate and lipid utilization. McArdle *et al*. (1996) explain that oxidation of purely lipids or purely carbohydrates seldom occurs and that substrate utilization usually is a mixture of nutrients, with fats and carbohydrates contributing at different ratios, even during resting states.

TABLE XII: Respiratory Quotient under Conditions A and B (means with standard deviations in brackets, % = coefficient of variation).

	Respiratory Quotient	
	Task A	***Task B***
‘Anticipatory’	0.82 (0.08) 10.4%	0.80 (0.08) 9.7%
‘Working’	0.89 (0.08) 8.6%	0.85 (0.05) 5.9% *****
Recovery Minute 3	0.97 (0.08) 8.5%	0.93 (0.09) 10.1%

* denotes significant difference ($p<0.05$) between Task A and Task B.

It was previously established that in both conditions subjects were working at steady-state, therefore substantiating the use of RQ as a reflection of nutrient break-down. RQ increased to 0.89 and 0.85 under Conditions A and B respectively, a significant difference that indicated a greater increase in carbon dioxide production in relation to oxygen uptake in the pre-intervention than the post-intervention task. Even though the “cross-over point”, the point where a shift occurs from one pre-dominant fuel source to another, is a complex interaction between the responses induced by the exercise intensity and the effects brought about by endurance training (Brooks and Mercier, 1994), a respiratory quotient of 0.85 roughly indicates the midpoint where the contribution of carbohydrates and lipids towards substrate utilization is equal (McArdle *et al*., 1996). During Task A the percent contribution from carbohydrates was 68%, but only 61% for Task B, as at high intensities there is a greater reliance of the body on energy sources that can yield energy quickly, hence the increased dependence on carbohydrates as the dominant fuel source. The experimental results displayed in Figure 21 therefore point towards a greater contribution of carbohydrates during the pre-intervention condition compared to the post-intervention scenario, which, according to Brooks and Mercier (1994), is indicative of hard work. The significant difference in the RQ between Task A and Task B, even through the recovery period, reiterates that the latter condition is a significantly less demanding than the former.

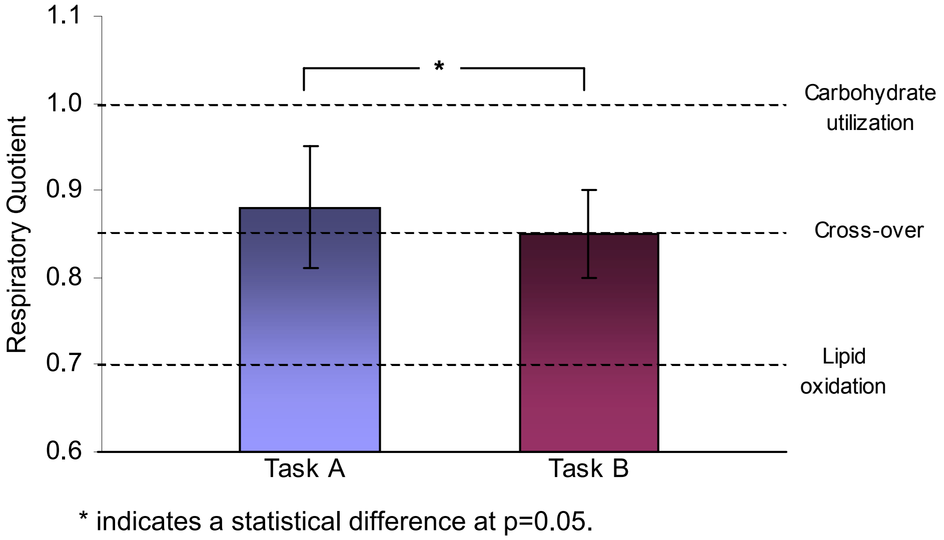


Figure 21: Respiratory Quotient pre- and post-intervention (means and SD).

PERCEPTUAL RESPONSES

The use of psychophysical rating scales served to quantify the subjects' perceptions and interpretations of the intervention strategy compared to the working method currently employed *in situ*. The assessment of personalized responses should be an integral part of any ergonomics intervention study, as emotions and motivation are just as strong determinants of an individual's end-point of performance as physiological and biomechanical factors.

Ratings of Perceived Exertion (RPE)

Borg's (1970) psychophysical scale Ratings of Perceived Exertion (RPE) is a useful tool that encompasses many interactive factors to provide a 'gestalt' response giving a concrete measure of the effort invested by an individual, as Robertson (1982) and Davis *et al*. (2000) argue that the underlying mechanisms of perceived strain are not only physiological in nature, but also depend on the person's current mood state, motivation, as well as past experiences. Initial and final measurements of Central and Local RPE are presented in Table XIII.

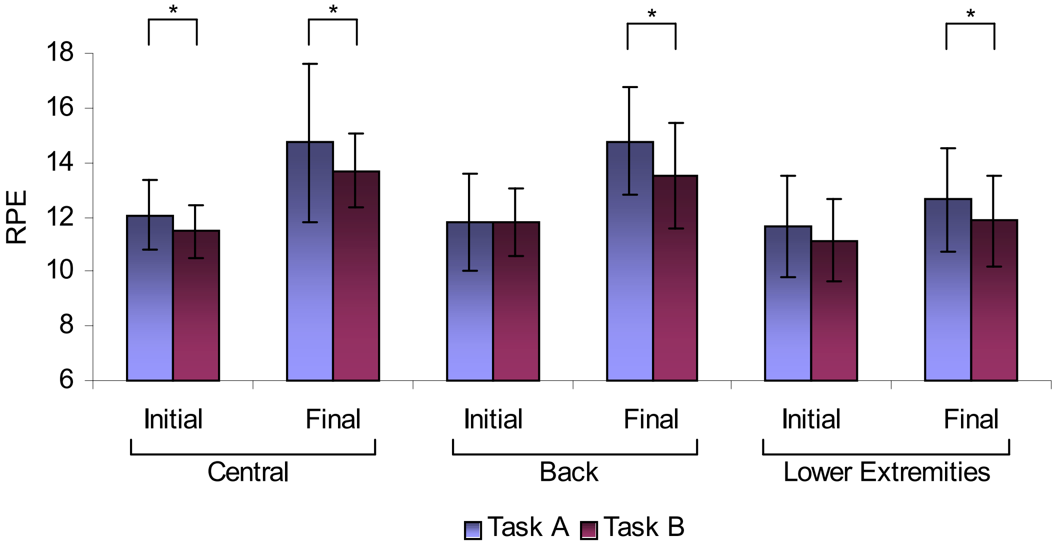
TABLE XIII: Central and Local RPE responses from the initial and final collection interval of both tasks (means with standard deviations in brackets; %=coefficient of variation).

	Interval	***Task A***	***Task B***
Central RPE	***Initial***	12.1 (1.3) 10.8%	11.5 (1.0) 8.4% *****
	Final	14.7 (1.7) 11.5%	13.7 (1.4) 10.0% *****
Local RPE: Back	***Initial***	11.8 (1.8) 15.2%	11.8 (1.2) 10.7%
	Final	14.8 (2.0) 13.2%	13.5 (2.0) 14.4% *****
Local RPE: Lower Extremities	***Initial***	11.7 (1.9) 16.0%	11.1 (1.5) 13.5%
	Final	12.6 (1.9) 15.1%	11.9 (1.6) 13.9% *****

* denotes significant difference ($p<0.05$) between Task A and Task B.

Central Ratings of Perceived Exertion are representative of the overall cardiovascular and respiratory strain that individuals perceive while executing a particular task. Figure 22 presents Central RPE recordings for both tasks during the initial and final testing intervals of the experimentation periods. Initial mean Central RPE of 12.1 and 11.5 were recorded for Conditions A and B respectively, a difference between the two experimental tasks that already showed statistical significance. Although still rated as 'fairly light' on average, maximum values of 15 were recorded for Task A, compared to maximum RPE of only 13 for Task B, reiterating the beneficial effects of the intervention strategy. The progression of the intensity of exertion is evident from the increases in Central RPE in the final collection interval. In the pre-intervention task the subjects' perceived exertion increased to 14.7, a classification of 'hard' on the Borg Scale, whereas an increase to a final average rating of 13.7 only placed Task B in the 'somewhat hard' category. Maximum Ratings of Perceived Exertion of 18 for Condition A and 17 for Condition B were recorded in the final interval. According to Borg (2001) 60-70%

of the variance can be attributed to physiological factors such as heart rate, respiratory frequency, minute ventilation and oxygen uptake. The remaining 30 to 40% reflects the psychological component of the gestalt response. As pronounced differences were observed in the physiological variables of the two experimental tasks in this study, this explains the greater rise in Ratings of Perceived Exertion of Task A compared to Task B.



* indicates a statistical difference at p=0.05.

Figure 22: Central and Local (Back; Lower Extremities) RPE for the initial and final collection interval (means and SD).

Local Ratings of Perceived Exertion were collected for the lower limbs and the back, as these were the body areas where subjects partaking in the pilot studies experienced the greatest strain. Due to the strenuous nature of the tasks Local RPE for the back were rated ‘somewhat hard’ (11.8) for both conditions in the first collection interval. However, the significantly reduced task demands of the post-test were evident from the subjects’ final ratings of 13.5 for Task B compared to 14.8 for Task A.

Drawing a comparison to the field, Central Ratings of Perceived Exertion of 17 were reported by the industrial workers *in situ*. Although these ratings are higher than the results of the laboratory experimentation, the recordings were consistent with the high heart rates measured and can be attributed to the high handling frequencies observed during the offloading process in the field. In respect of the back, the labourers reported RPE values ranging between 11 and 15, which correspond with the results obtained from subjects during the experimental sessions in the laboratory.

Interestingly, Central and Local (Back) RPE recordings were similar in the final collection interval of both tasks. Further analysis revealed that although Central RPE in Task A was higher in the first collection interval; by the final interval Local RPE for the back had increased to a greater extent than Central RPE. This suggests that initially exertion was mainly cardiovascular in nature, but that the excessive postural demands over the duration of the experiment contributed to muscular fatigue of the trunk. Local exertion of the back became an increasingly important factor, which could play a significant role in determining a subject's end-point of performance and even the predisposition to musculoskeletal disorders. In Task B, on the other hand, Central RPE increased to a greater extent than Local RPE for the back. By altering the work method and reducing the physical strain of stooping, but maintaining the same handling frequency, cardiovascular exertion could become the limiting factor. Similar results were obtained by Jiang *et al.* (1986) and Davis *et al.* (2000) who found frequency to be the main contributor to fatigue, particularly with combined manual materials handling tasks, as was the case in the tasks under investigation.

Local RPE (Lower Extremities) followed the same trends as the other responses. During the first collection interval RPE for the two tasks were similar, with ratings of 11.7 and 11.1 for Conditions A and B respectively. By the final interval however, the fatiguing effects of lunging while pushing the crates had increased Local RPE in the lower extremities to 12.6 in Task A. Although some subjects commented on the greater fatigue in the legs during the carrying component of Task B, RPE values for the lower extremities in this condition only increased to 11.9, significantly lower than for the pre-intervention condition.

Body Discomfort

The importance of assessing body discomfort is that in many cases it is an indicator of a mismatch between the worker and the task performed (Corlett and Bishop, 1976). Axelsson and Eklund (2001) pointed out that once discomfort rises beyond a certain ‘comfort threshold’ productivity is compromised and the risk of accidents and injuries is increased. Even though some tasks might only elicit minor feelings of localized fatigue or discomfort during a once-off performance, repetitively executing these tasks over long periods can intensify the discomfort and amount to intolerable pain. Kroemer and Grandjean (1997) emphasized that the origin of musculoskeletal disorders lies with body discomfort, as long-term damage not only occurs to the muscles, but also to associated joints, ligaments, tendons and nerves, ultimately rendering the worker unable to complete the required tasks. The Body Discomfort results obtained on completion of each of the two experimental conditions indicate the most severely affected body areas reported by the subjects in each of the experimental tasks, as well as the extent of the discomfort.

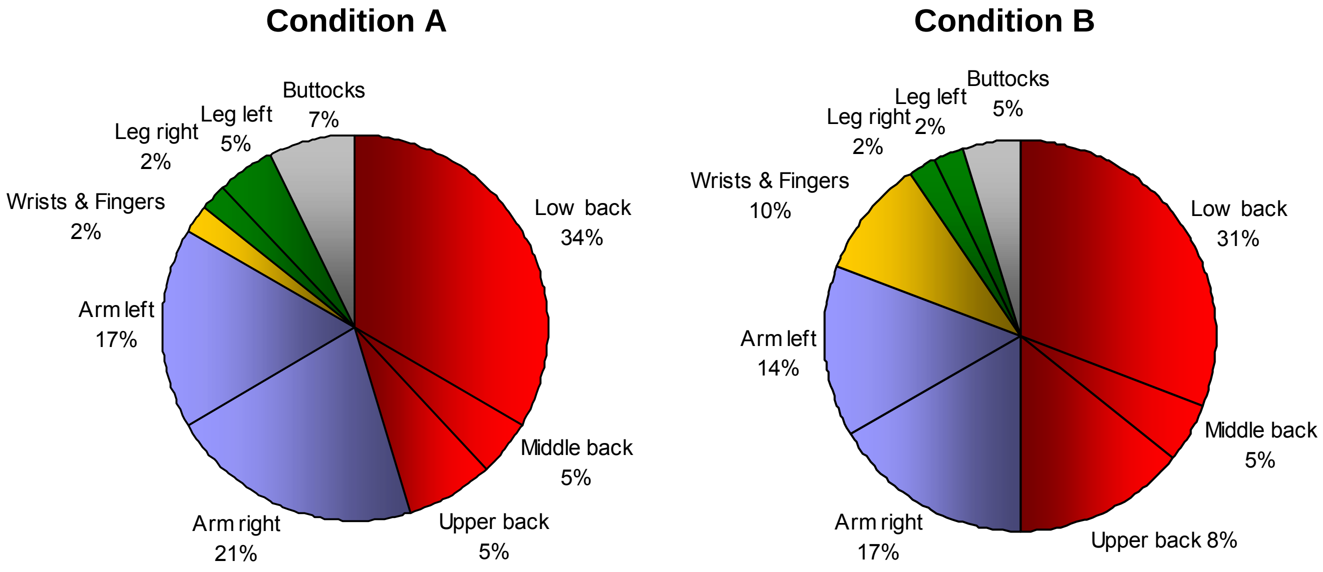


Figure 23: Percent total incidence of the most dominant Body Discomfort ratings.

As is evident from Figure 23 discomfort was predominantly experienced in the back, which accounted for 44% of responses under both experimental conditions.

The similar recordings for the back in both tasks are the result of the back muscles acting as the main stabilizers during both tasks. Oborne (1995) pointed out that irrespective of the task performed maintaining postural control involves continuous static contractions from the back musculature. Particularly static contractions compress the blood vessels, prohibiting the removal of waste products and the supply of oxygen and nutrients, therefore giving rise to fatigue, discomfort and ultimately pain (Kroemer and Grandjean, 1997). In Task A the muscular effort while lowering each crate to the floor plus the subjects' upper body weight required almost constant tension by the low back musculature, contributing to the perceived exertion and ultimately discomfort in the lower back over the duration of the activity. In addition, the asymmetric component of the pushing / sliding action in Task A required significant muscular control to maintain balance, thus contributing to the local discomfort. In Task B the action of holding while carrying the crates resulted in a high occurrence of discomfort in the upper and lower back.

TABLE XIV: Mean intensities of the most dominant Body Discomfort Ratings (range in brackets).

Area	***Task A***	***Task B***
Lower Back	6.7 (4-9)	5.9 (3-8)
Middle Back	7.5 (7-8)	7.0 (0)
Upper Back	5.7 (2-7)	5.5 (3-8)
Right Arm	5.2 (3-7)	4.6 (3-6)
Left Arm	5.1 (3-7)	4.7 (3-6)
Wrists & Hands	6.0 (0)	5.0 (4-7)
Right Leg	6.0 (0)	4.0 (0)
Left Leg	6.5 (6-7)	4.0 (0)
Buttocks	6.0 (4-8)	5.5 (5-6)

Although the number of discomfort reports in the back are similar for the two experimental conditions, the discomfort intensity ratings in Table XIV reveal nominal reductions, ranging between 0.2 and 2.5, for all responses to the modified task. From these trends one could conclude that the intervention was effective. In the most extreme cases, the stretching action when reaching for the top crates under the pre-intervention condition forced particularly the shorter subjects into hyperextension. By decreasing the stacking height the resulting discomfort experienced in the lower back during Task A was reduced by 12%. Marginal improvements were also seen in the middle and upper back under the post-intervention condition.

Manual handling technique plays a great role in the onset of fatigue and discomfort of specific body parts. During the habituation period a ‘free-style’ manual handling technique was encouraged, but it was stipulated that once subjects felt comfortable with a specific style they were required to use that same method throughout the duration of the experimental condition. During both conditions the back-lift dominated the lifting actions, although several subjects adopted the leg-lift technique in Condition B. Even though many subjects commented that the discomfort in the back could be the result of the lifting technique, there seems to be no relationship between the manual handling style and the intensity of discomfort perceived.

Another general body area where the greater strain of the manual handling activities of Task A was evident, was in the upper extremities, encompassing the shoulders, upper arms and forearms. Under this condition the left and right sides contributed 17% and 21% of responses respectively, whereas under Condition B, these values were reduced to 14% for the right and 17% for the left side. Intensity of discomfort was also lower for the post-intervention condition, with the average rating of Task A being 5.2, compared to 4.7 in Task B. With the elimination of the top two crates and the pushing action required to slide the crates, which placed significant strain on the upper extremities, the carrying activity under the post-intervention condition resulted in marginally lower discomfort ratings.

In situ recordings demonstrated that the industrial workers also perceived discomfort to be greatest in the lower back and shoulder regions. Ratings of the intensity of discomfort ranged from 5 to 6 for both areas and were consistent with those recorded during the experimental sessions in Table XIV.

It should also be noted that there was an unequal distribution of discomfort occurrences for the left and the right sides. The 4% greater occurrence of discomfort in the right arm is attributed to the asymmetrical nature of Task A; for all subjects it was the right arm that led the pushing action. Due to this use of the dominant leading arm, discomfort featured more often and more prominently on the right side than on the left. Similarly, the 3% greater occurrence of discomfort, as well as the nominally higher discomfort rating in the left leg is attributed to the lunging action to the left side when sliding the crates, which would also explain frequent reports and a high average discomfort rating in the buttocks.

The only areas experiencing discomfort ratings more frequently and more intensely during Condition B were the hands and the wrists, receiving 10% of responses in Task B, compared to only 2% in Task A. The high occurrence and nominally elevated intensity of discomfort in Task B could be explained by the longer contact periods of the hands with each crate, due to the carrying component of the post-intervention task.

INTEGRATED DISCUSSION

Most manual materials handling tasks display a combination of potential problem factors, which need to be considered in conjunction with their environmental and organizational context. As this is not always practical or viable, interventions have to be restricted to combating the most severe factors. The re-design strategy of the current study focussed on two task characteristics considered to be in need of ergonomics intervention: working height and working method. Although the effects of these factors on the musculoskeletal and cardiovascular systems are relatively easily assessed in isolation, Ayoub and Mital (1989) pointed out that the net effect of all system components together could be fairly complex. This is probably the greatest hurdle to be overcome in ergonomics intervention research, as interventions could be beneficial in one area, but ineffective or even harmful in another. It is therefore only by using an “interdisciplinary holistic approach”, as described by Charteris *et al*. (1976) plus a “macro”-approach proposed by Hendrick (1991), that the *overall* compatibility of the proposed intervention strategy with all other system components can be evaluated.

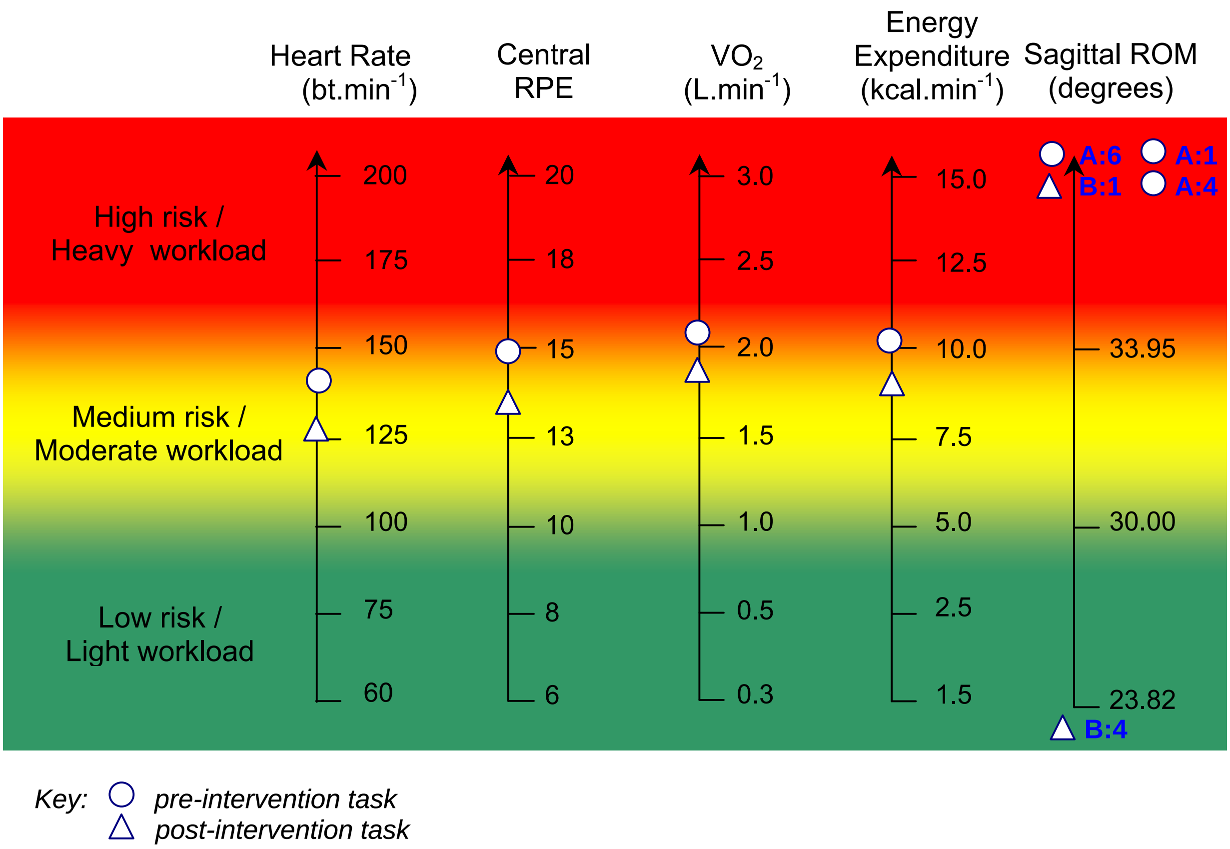


Figure 24: Categorization of measured biomechanical, physiological and perceptual risk ratings pre- and post-intervention (biomechanical, physiological and perceptual risk classifications taken from Marras et al. (1995), Sanders and McCormick (1993) and Borg (1970) respectively).

Laboratory assessments of the intervention strategy revealed significant reductions in the overall stresses that were imposed on the body compared to the pre-intervention condition. Figure 24 illustrates that the spinal ranges of motion, velocities and accelerations measured during Task A continuously posed very high biomechanical risks to the back due to the high stacking height of the crates, as well as the extreme stoop required when pushing the crates along the floor. Spinal motions such as hyperextension and excessive stooping augment the harmful shearing forces on the lower back, which are at their greatest during maximum trunk flexion. These, together with the high velocities and accelerations, exacerbate the risk of injury to the lower back, as muscular contractions during fast movements are weakened, with the result that the erector spinae are less effective in stabilizing and supporting the trunk during these extreme motions.

The basic ergonomics intervention of the task itself was to eliminate the excessive overhead reach and the extreme bend associated with pushing the crates along the truck's loading surface. Decreases in the stacking height eliminated the extreme stretching motion and resultant hyperextension. Adjustments in the working method of transferring the crates from one point to another by means of carrying, rather than sliding, reduced the excessive stooping motions by at least 50% and eliminated the force required to push / slide the crates over 5 m. It also became apparent from observations that several subjects employed the squat lifting technique during Condition B, whereas under the pre-intervention condition the working method forced all subjects to assume a stooping posture in order to slide the crates along the floor. As a result sagittal velocities and accelerations were reduced significantly, mostly falling into the category of 'low risk' biomechanical hazards established by Marras *et al*. (1995).

As was the case with the biomechanical results, analyses of physiological variables indicated excessive strain on the cardiovascular system for the pre-intervention task, due to the great demands placed on the working muscles by the sub-optimal working postures. Within three minutes of having started the activity all measured physiological variables, particularly heart rate, oxygen uptake and energy expenditure had increased to such an extent that they were classified as 'heavy' and 'very heavy work' (Figure 24). Large increases in breathing frequency and tidal volume resulted in a 317% increase in minute ventilation above anticipatory values, and the respiratory quotient indicated that carbohydrates had become the dominant fuel source. The improvements brought about by the intervention are evident from the statistical reductions in all physiological variables.

The excessive demands of the simulated industrial task were also reflected in the perceptual responses, with mean Central Ratings of Perceived Exertion being classified as 'hard' towards the end of the activity, and several subjects even perceiving the pre-intervention task as 'very hard'. The intervention strategy significantly reduced Central RPE, as can be seen in Figure 24, as well as Local

Ratings of Perceived Exertion in the Back and the Lower Extremities. However, the moderate increases of most physiological and perceptual variables over time pointed towards the likelihood of the onset of cardiovascular and muscular fatigue, even though the ventilatory equivalent showed that subjects had achieved steady-state. It is argued that due to the high intensity of the task a physiological drift would occur over the extended time period within industry which would prevent labourers from working at such a pace for longer durations.

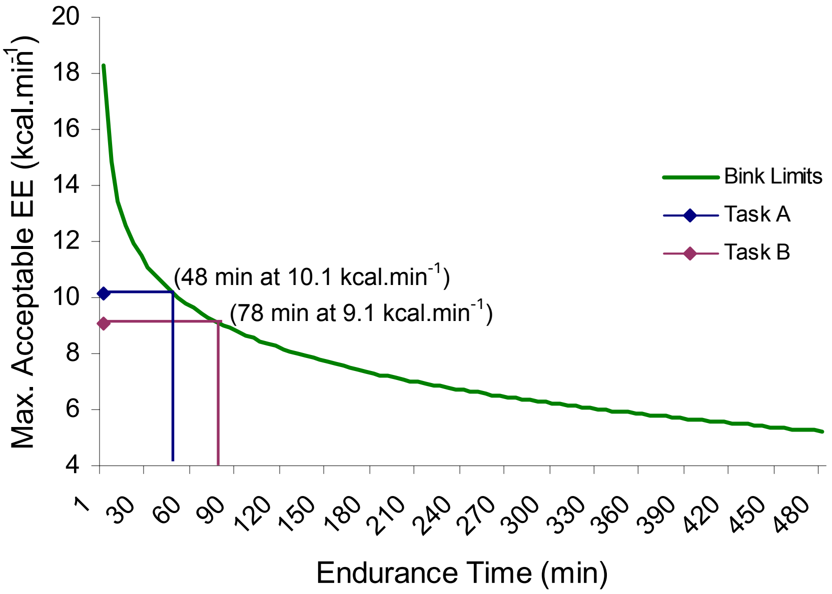


Figure 25: The effect of endurance time on energy cost (based on Bink, 1962).

Figure 25 illustrates Bink's (1962) logarithmic relationship between working time and energy required to perform a certain task (see Appendix C for formula). According to this graph people of average aerobic capacity would only be able to perform Task A for a duration of 48 minutes as a physiological drift would set in after some time, taking individuals to the limit of their aerobic capacity. In the industrial setting of the present project the offloading process usually lasts for one hour, which, according to the limits illustrated above, would be too long for individuals with an average aerobic capacity. Considering the generally poor physical work capacities of workers in IDCs, due to ill health and malnourishment (Bourne *et al*., 1993), the metabolic demands of Task A for the entire offloading period are considered excessive. The predicted maximum duration of Task B is 78 minutes, which reiterates the beneficial effects of the intervention strategy. At the same time, work-to-rest ratios need to be considered, as adequate rest periods are required to compensate for the excessive task demands and to prevent fatigue from accumulating to such an extent that workers reach their maximum work capacity. Murrell (1965) put forward a simple equation to calculate the amount of rest required for a given activity (Appendix C). According to this formula a 60-minute working duration, as is the present case, would require a resting time of 37.2 and 32.4 minutes at the measured intensities under Conditions A and B respectively.

Despite the statistically significant reductions the physiological and perceptual responses were still classified as ‘moderate’ to ‘heavy’, probably due to the excessive handling frequency of 12 crates per minute. Findings by researchers such as Mital and Manivasagan (1983a), Jiang *et al*. (1986) and Waters *et al.* (1993) illustrate that frequencies of more than six handlings per minute had a significant fatiguing effect, particularly with combined MMH tasks. Having demonstrated the significant improvement in the subjects’ responses when working height was reduced and the work pattern of one worker was modified, the application of the modifications were expanded / developed within the industrial setting where six workers were responsible for the completion of the overall job of offloading the truck.

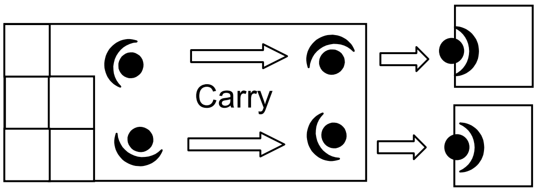


Figure 26: Alternative workflow enabling a handling frequency of six crates per minute.

Although much of ergonomics in IDCs tends to be of a reactive nature with problems only being addressed at a ‘micro’-level, there is clear evidence that it is also necessary to take a more global ‘macro’ view of the situation (Scott and Zink, 2003). In the present research study the initial problem identified was at the basic “man-task” interface and the intervention strategy devised thus addressed the mechanical stresses imposed on experimental subjects and workers *in situ* by adjusting the stacking height and working method. However, in the business interest of maintaining current levels of productivity other modifications of job requirements, such as reducing the handling frequency, would require a re-organization of the labourers and a change in the workflow. Creating two offloading lines, as depicted in Figure 26, would allow the frequency to be halved to the universally accepted six handlings per minute and still result in 12 crates being offloaded every minute. For the workers, however, handling one crate every ten seconds as opposed to every five seconds would relieve them of a considerable amount of physical stress, particularly in the physiological parameters.

TABLE XV: Theoretical risk ratings pre- and post-intervention.

		Condition A	**Condition B**	**Condition C ***
NIOSH	**Action Limit (kg)**	1.4	2.3	7.0
	Max. Permissible Limit (kg)	4.1	7.0	21.1
LIFTRISK	**Task Inherent Risk Rating (Highest crate)**	5.2 (High)	3.9 (Mod)	3.1 (Low - Mod)
	Task Inherent Risk Rating (Lowest crate)	4.0 (Mod)	3.8 (Mod)	3.1 (Low - Mod)

* Note: Task demands in Condition C are the same as in Condition B, except for frequency, which was reduced to 6 handlings per minute.

Calculations using theoretical models such as the revised NIOSH lifting equation and LIFTRISK, developed by Charteris and Scott in 1990, indicate that halving the working pace would dramatically reduce the physical and physiological hazards imposed on the body (Table XV). The mass of the crates handled under the task demands of Condition A were 2.4 times greater than the maximum acceptable weight (MAW) stipulated by NIOSH, and 1.4 times greater in Condition B, indicating that less than 25% of male workers would be able to perform these tasks without risk of physical injury. However, a reduction in the handling frequency to 6 crates per minute, in addition to the proposed modifications to working height and method, would significantly increase the NIOSH MAW and reduce the LIFTRISK task-inherent risk from ‘high’ in Condition A (pre-intervention) to ‘low-moderate’ in Condition C (post-intervention with reduced frequency). A further organizational change such as introducing a system of worker rotation would distribute the workload evenly over the six workers, resulting in further reductions of the physical stresses.

As the basic “man-task” interaction is subject to a variety of human, task and environmental factors, transferring an intervention from one context to another could yield completely different results. It is therefore important to acknowledge differences such as morphology, physical condition and experience. LIFTRISK calculations presented in Table XVI illustrate the effects of a poor versus a good physical condition on the overall situational risk rating. For both experimental conditions the situational risks for persons with a ‘below average‘ physical condition were rated at ‘very high’ and ‘high’, as opposed to ‘above average’ individuals who would only be at ‘moderate’ or even ’low’ risk. Manual labourers thus ideally need to be young, healthy and robust individuals as they are less likely to suffer from an early onset of fatigue, as well as work-related musculoskeletal disorders.

TABLE XVI: LIFTRISK situational risk ratings for individuals with poor and good physical conditions.

		Condition A	**Condition B**
Below Average Condition	**Highest Crate**	7.0 (Very high)	5.0 (Moderate-High)
	Lowest Crate	6.2 (High)	5.2 (High)
Above Average Condition	**Highest Crate**	4.3 (Moderate)	2.4 (Low)
	Lowest Crate	3.8 (Moderate)	2.6 (Low)

One month after introducing the intervention strategy to the bottle sorting business a re-assessment of heart rates and perceptual responses was conducted on the selected labourers to determine whether the intervention strategy was successful in the field, as it had been in the laboratory. The firm did not accept the suggestion to reduce the stacking height due to the varying quantities of bottles picked up with every truck delivery and the limitation of the truck size; hence the only variable changed was that of eliminating the deep stoop and pushing the crates along the truck's loading surface. Despite this, the measured data revealed a significant reduction in the effort invested by the workers during the offloading process. Mean and maximum heart rates during the post-intervention assessment were measured at 96 bt.min^{-1} and 112 bt.min^{-1} respectively, as opposed to the 116 bt.min^{-1} and 167 bt.min^{-1} before the introduction of the intervention. Observations also revealed a calmer ambience and more consistent working pace during this task, compared to the high variations in the offloading speed during the initial *in situ* assessment, where handling frequencies varied from 0 to 26 crates per minute. From a perceptual point of view, Central RPE were reduced from a classification of 'very hard' to 'hard', and although Body Discomfort ratings in the shoulders and arms dropped substantially, Local RPE for the Back remained unchanged due to the extreme stretching and stooping motions when picking up the highest and lowest crates.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Despite times of technological developments manual materials handling remains very much a part of many industries within industrially developing countries (IDCs) such as South Africa. Small local enterprises in particular rely heavily on human power due to limited financial and technical resources. At the same time, socio-economic circumstances experienced by manual labourers result in a negative spiral of poverty, ill health and low work capacity. It is therefore evident that sooner or later the combination of poor physical condition, excessive task demands and extreme environmental conditions will result in accidents and injuries to the workers, and decreases in the quality and quantity of productivity in industry. It is the ergonomist's responsibility to identify incompatibilities between the task demands and worker capabilities and to provide realistic interventions, which are not only practical but also financially viable.

In the past most ergonomics research has been confined to the laboratory setting and has been criticized for not being aware of many industrial issues and problems faced on a daily basis. On the other hand, conducting extensive *in situ* experimentation is not always feasible, and often rejected by management due to its disruptive effect on the production processes, and by researchers due to the inability to control the many impinging variables. Combinations of field and laboratory research are therefore the best option, particularly with regards to ergonomics intervention research, as transferring research results from the laboratory into industry cannot always guarantee the same success, due to numerous extraneous variables *in situ* that did not exist or were controlled for in the laboratory (Oborne, 1995; Westgaard and Winkel, 1997; Allread *et al.*, 2000). Acknowledging these influencing factors and re-assessing intervention solutions in the field, albeit with modifications, increases the likelihood of a successful transfer.

In the current study a physically demanding manual handling task was selected from a small local bottle-sorting enterprise. Using a combination of field and laboratory investigations workers' and subjects' responses to the original task were compared to their responses to the execution of the task once it had been modified. It was hypothesized that the intervention strategy would result in significant reductions in spinal stresses, metabolic cost, perceived exertion and body discomfort compared to the current working set-up and work methods employed in the industry. The objective was to provide the original business with a suitable solution to relieve the labourers of physical and physiological stresses.

SUMMARY OF PROCEDURES

The research commenced with an *in situ* assessment of the various activities at the bottle-sorting business. The worst-case scenario, namely the offloading process of crates filled with empty bottles off a truck was chosen for further analysis. Worker and task characteristics were measured *in situ* and heart rate responses, Ratings of Perceived Exertion and Body Discomfort were recorded during the offloading process on a normal working day. These evaluations served to establish worker responses, workspace dimensions, job requirements and procedures to be used in the laboratory set-up. A final re-evaluation of the effects of the intervention strategy in the industry took place after the experimentation in the laboratory had been completed.

The rigorous experimental phase of the current study took place in the Ergonomics laboratory of the Department of Human Kinetics and Ergonomics at Rhodes University, where two experimental conditions were assessed and compared. Condition A, the pre-intervention condition, was a simulation of the task requirements and working methods observed *in situ*. Subjects had to transfer crates stacked one on top of another in columns up to 6 crates high (1970 mm) from one end of a 5 m long hardboard, representing the length of the truck's base, to the other end, by means of sliding them along the floor. Condition B, the post-intervention task, was devised according to basic ergonomics principles and business interests. In recognition of the extensive literature reporting on the effect of lowering frequency, the handling frequency of unloading remained unaltered, as did the mass of the object. The thrust of the intervention was therefore on the reduction of the stacking height and the modification of the work method; stacking height was reduced to 1300 mm (4 crates high) and subjects were required to carry the crates for 2.5 m at which point they handed them over to an assistant who represented another worker in industry.

Twenty-eight male students between the ages of 18 and 26 years, with a mean stature of 1781 mm and body mass of 75.8 kg were required to partake in two separate sessions. Session 1 served as a familiarization period, where basic demographic and anthropometric data were collected and the subjects familiarized themselves with the tasks they would have to perform during the following session. Session 2 involved experimentation of both pre- and post-intervention conditions, each condition lasting for 16 minutes. Subjects were fitted with a Polar heart rate monitor, the Cosmed® K4b^2 on-line metabolic system and the Chattecx™ Lumbar Motion Monitor. This ensured a multi-disciplinary assessment of the subjects' responses to the stresses placed upon them.

Spinal kinematics were measured at four regular intervals relating to the subjects' working patterns. The mean data obtained for each of the experimental conditions were compared at different levels, namely, the lowest crate of each column, the fourth crate from the floor and the top-most crate (6 high). Physiological data were measured at rest and at work, and recovery responses were obtained during the third minute after termination of the activity. Working cardiovascular, respiratory and metabolic responses for both tasks were analysed using the average obtained over the 16-minute activity. Central Ratings of Perceived Exertion and Local RPE, alternating between the back and the lower extremities, were also collected at four intervals during the execution of each condition. Upon completion of each task subjects had to provide final Central and Local ratings before identifying areas of body discomfort and rate the intensity of discomfort experienced. The order in which the two tasks were executed was randomly assigned and a rest period of at least 30 minutes was required between conditions.

Due to the extensive amounts of data obtained from each of the assessment methods, the following specific variables were selected for analysis:

- Physical variables : Sagittal range of motion
  Sagittal velocity
  Sagittal acceleration
  Rotational range of motion
  Rotational velocity
  Rotational acceleration

- Physiological variables : Heart rate
  Breathing frequency
  Tidal volume
  Minute ventilation
  Oxygen consumption
  Energy expenditure
  Respiratory quotient

- Perceptual variables : Central RPE
  Local RPE - Back
  Local RPE - Lower Extremities
  Body Discomfort

These variables were analysed using basic descriptive statistics and related t-tests ($p<0.05$) to determine whether Condition B was a significant improvement from Condition A.

SUMMARY OF RESULTS

Comparisons of responses under pre- and post-intervention conditions revealed significant differences in spinal kinematics when the stacking height was reduced from 1970 mm to 1300 mm, eliminating the hyperextension of the spine when lifting the highest crates. Modifications in the working method from sliding the crates along the floor to carrying them also resulted in a significant decrease in trunk flexion from 82^{o} to 12^{o}, as well as concomitant reductions in the flexion and extension velocities in the sagittal plane. The reduced stresses placed on the musculoskeletal system were reflected in the lower Ratings of Perceived Exertion in the Back and the Lower Extremities in the final collection interval, as well as from Body Discomfort ratings. The only exception where Condition B was not statistically reduced was during the handling of the crates at the lowest level. The ranges of motion through which subjects had to move when picking up the lowest crates under the post-intervention condition (77^{o}) were the same as during the original industrial task. High velocities and accelerations were also associated with these large ranges of motion due to the subjects needing to lift the crates (as opposed to sliding them while in a stooped position) before stepping forward and handing them over to the assistant worker. The data therefore indicate that crates stacked beyond shoulder height and lower than knuckle height resulted in significantly higher spinal kinematics. Working at levels between shoulder and knuckle height, however, decreased the biomechanical forces on the lower back.

Cardiovascular, respiratory and metabolic responses also revealed the extent of the strain imposed on the subjects in the laboratory with Condition A. Mean working heart rates of 138 bt.min^{-1} were obtained for the pre-intervention task, 10 bt.min^{-1} higher than in Condition B (128 bt.min^{-1}). Based on the suggestion by Åstrand and Rodahl (1986) that the upper limit for heart rate responses during continuous work should be 130 bt.min^{-1}, it is evident that the simulated task elicited responses, which were above this guideline limit, while the post-intervention results were just below it. Central RPE reflected the beneficial effect of the intervention strategy by decreasing from 15 in Task A to 14 in Task B. Similarly, oxygen consumption for the pre- and post-intervention conditions were measured at 28 ml.kg^{-1}.min^{-1} and 25 ml.kg^{-1}.min^{-1} respectively. As a result the risk classifications of oxygen consumption and energy cost were reduced from a ‘high’ risk to a ‘medium’ risk. Despite indications that subjects were working at steady-state during the simulated industrial task, Bink’s (1962) logarithmic relationship between working time and energy required suggests that this steady-state was only temporary. According to this prediction equation (Appendix C) an individual with an average aerobic capacity would only be able to maintain an activity requiring 10.1 kcal.min^{-1} (194 kcal.kg^{-1}.day^{-1}), such as in Task A, for 48 minutes, whereas an energy cost of 9.1 kcal.min^{-1} (174 kcal.kg^{-1}.day^{-1}), as in Task B, could be maintained for 78 minutes.

Although the intervention clearly did have a beneficial effect on energy metabolism, it is well known that high handling frequencies result in a large metabolic cost (Ciriello and Snook, 1983; Jiang *et al*., 1986; Ayoub and Mital, 1989; Ciriello *et al.*, 1990; Mital *et al.*, 1994; Dempsey, 1998), and because of this universal acceptance of the benefits of a reduction in high frequencies, the handling pace of 12 crates per minute in the current study was kept constant in order to identify and quantify the effects of the modifications in working height and method on the subjects' responses. However, the practical application of an effective intervention strategy in the bottle sorting business necessitates a reduction in the working pace, which could be achieved by re-organizing the workers into two offloading lines, thereby halving the handling frequency while maintaining overall productivity. Theoretical evidence from models such as LIFTRISK (Charteris and Scott, 1990) and the 1991 NIOSH equation (Waters *et al*., 1993) indicated that decreasing the handling frequency to six crates per minute would result in substantial additional reductions in the task inherent hazards to acceptable limits proposed by LIFTRISK and NIOSH.

A re-assessment of heart rate responses, RPE and Body Discomfort in the industry after introduction of the intervention strategy revealed results, which reflect the trends of the measurements obtained in the laboratory. Mean and maximum heart rate responses were reduced by 20 bt.min^{-1} and 55 bt.min^{-1} respectively, due to a more consistent workflow as a result of the intervention. Central RPE decreased from 17 to 15, and although Local RPE in the back remained the same, Body Discomfort ratings in the shoulders had decreased.

HYPOTHESES

The significant reduction in virtually all variables selected for analysis of the effects of the intervention strategy lead to a general rejection of the null hypotheses, which are discussed in more detail.

Hypothesis 1:

Due to the different stacking heights of the two experimental conditions, analyses of spinal kinematics in the sagittal and transverse planes of movement focussed on three key levels, namely the lowest level, four crates up from the floor and the highest level in each column.

(a) Comparisons of the highest crates (A:6 vs. B:4) yielded statistical differences for all spinal variables in the sagittal plane. However, in the transverse plane, only three of the six variables analysed indicated a significant change between the experimental conditions. The null hypothesis is therefore rejected for all responses in the sagittal plane and tentatively accepted based on the results of the responses in the transverse plane.

(b) At level A:4 vs. B:4, the null hypothesis is also rejected due to significantly lower responses in the sagittal plane under Condition B. However, as only 50% of variables in the transverse plane showed significant differences between the two experimental conditions, the null hypothesis is tentatively accepted in that movement plane.

(c) For the lowest level of analysis (A:1 vs. B:1) the null hypothesis is rejected due to a significant difference in five of the six variables in the sagittal plane. Spinal motions in the transverse plane however elicited significant differences for 50% of variables, resulting in a tentative acceptance of the null hypothesis.

Hypothesis 2:

The second hypothesis focussed on the physiological responses and was sub-divided into cardiovascular, respiratory and metabolic cost variables to identify specific changes that occurred with implementation of the intervention.

(a) The null hypothesis tested was that there would be no change in the cardiovascular variables between the two experimental conditions. This hypothesis is rejected, as significant differences were found between overall responses in working heart rates and oxygen consumption.

(b) Similarly, as breathing frequency, tidal volume and minute ventilation were found to be significantly lower for the post-intervention scenario, the null hypothesis addressing the respiratory responses is rejected.

(c) The null hypothesis for metabolic cost is rejected due to statistically higher values for energy expenditure and respiratory quotient in the pre-intervention condition.

Hypothesis 3:

The final hypothesis dealt with the perceptual responses.

(a) The initial collection interval only elicited statistically significant differences between pre- and post-intervention tasks for Central Exertion, whereas Local RPE for the Back and the Lower Extremities showed no significant difference between the two experimental conditions. The null hypothesis is thus tentatively retained.

(b) Central and Local Ratings of Perceived Exertion collected during the final interval showed significant differences between the two experimental condition, hence resulting in a rejection of the null hypothesis.

CONCLUSIONS

Comparisons of the pre- and post-intervention conditions revealed that the modifications to the original industrial task had an overall beneficial effect on the subjects' responses. Decreasing the stacking height of the crates and changing the working method significantly reduced the biomechanical stresses imposed on the spine, particularly in the sagittal plane of movement, which was the plane associated with the highest risk factors. In terms of physiological responses, all of the selected variables yielded significantly lower results under the post-intervention condition, and Central and Local Ratings of Perceived Exertion of the Back and the Lower Extremities, as well as Body Discomfort also elicited decreases in the intensity of exertion and discomfort experienced. As a result the task was reduced from a ‘high risk’ category to one of ‘moderate risk’.

Although frequency was held constant during the experimental procedures in order to observe the effects of the modifications in working height and working method, the use of theoretical models confirmed that a reduction in the handling frequency as part of the intervention strategy would lessen primarily the physiological, but also the cumulative physical and perceptual stresses imposed on an individual to an even greater extent. The outcome of a reduced intensity in the pace of work would decrease in the overall energy expenditure which is deemed necessary when performing these tasks for durations exceeding one hour, particularly when dealing with manual labourers in IDCs who generally have a poor physical work capacity.

The transfer of the intervention strategy into the field and the subsequent re-assessment of the workers’ responses to the new working method illustrated that some solutions are not always entirely feasible in the industrial context. However, although the original working height was retained, the working method of carrying the crates, as opposed to sliding them, was adopted. Recording the workers’ heart rate and RPE responses to this new task ascertained that physically, physiologically and perceptually the task demands of the offloading process had been reduced. It was further suggested to the company that two offloading lines, as well as task rotation should be introduced, as this would change the excessively demanding activity to an acceptable and low risk manual task.

RECOMMENDATIONS

In order for the ergonomics discipline to contribute meaningfully to industries in IDCs, further combinations of field and laboratory studies ought to be conducted. The following recommendations could assist in such research projects in the future.

Aerobic capacity is accepted as being a good indicator of how individuals will react physiologically to specific task demands imposed on them. In the current study large discrepancies existed in the physical capacities between the industrial workers and the laboratory subjects due to differences in health and training status of the two groups. In the interest of a successful intervention transfer from the laboratory into an industrial setting, determining the aerobic capacities of both labourers and subjects would have enabled more accurate comparisons and better extrapolations with regards to extended working durations and work-to-rest ratios.

Due to the existing differences between worker and student populations, and the many impinging variables in the field, that were controlled in the laboratory, a rigorous and holistic post-intervention assessment *in situ* is recommended to ascertain the overall effect of the intervention strategy in its industrial context.

From the results obtained from the pilot studies it was decided that the working duration for each experimental session be set at 16 minutes, as no significant differences were found in the pilot subjects' physiological responses between minutes 15 and 20. However, the data suggest that, due to a build-up of fatigue, the onset of the physiological drift was imminent. As a result extrapolations of optimal working durations and work-to-rest ratios were difficult. Setting experimental time periods as close as possible to the actual durations in industry would provide more accurate data on the effects of an intervention on the workers over the entire duration of a working cycle or shift.

The final recommendation is a six-month follow-up evaluation in the bottle sorting business to assess the long-term effects of the modifications to the working method and, although initially rejected by management, a possible reduction in the stacking height by at least one crate. Additionally, the follow-up assessment could quantify the effects of re-organizing the workers into two offloading lines, thereby reducing the handling frequency, and introducing job rotation, which would share the heavy workload amongst all six workers.

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APPENDIX A: GENERAL INFORMATION

Equipment Checklist

Subject Information Sheet

Subject Consent Form

EQUIPMENT CHECKLIST

General

- Basic stationary (clipboard, paper, pens, eraser, ruler, disks)
- Data Collection Sheets
- Subject Information Sheets
- Subject Consent Form
- Clock / Timing device
- Other (water, disinfectant, cotton wool)

Demographic data

- Scale
- Stadiometer
- Grip strength dynamometer
- Back strength dynamometer

Physical Measurements

- Lumbar Motion Monitor (including laptop, harnesses and LMM)

Physiological Measurements

- Polar heart rate monitor
- K4b^2 (including syringe, gas cylinder, laptop and equipment case)

Psychophysical Measurements

- RPE Scale
- Body Discomfort Map and Scale

SUBJECT INFORMATION SHEET

Dear ___________________________

Thank you for participating as a subject in my Masters thesis entitled:

LABORATORY INVESTIGATION OF A SIMULATED INDUSTRIAL TASK PRE- AND POST-ERGONOMICS INTERVENTION

Please read this document and ensure that you understand its contents before signing the Consent Form.

Manual materials handling (MMH) tasks, such as lifting and lowering, are the most frequently performed activities in South African industries. Often there are problems associated with excessive MMH demands, such as back problems, fatigue and low productivity. The present study is an ergonomics research project that aims at analysing the MMH activities of a small local bottle sorting business and to provide suitable intervention strategies to help the workers as well as the employer to work more efficiently and with less effort.

Your participation will involve **two** sessions at the Department of Human Kinetics and Ergonomics. The first session will start with a verbal briefing of the procedures and measurements of basic data, such as age, stature, body mass and strength measurements. You will also be given a chance to familiarize yourself with the equipment and the tasks you will be required to perform.

The second session will involve simulations of a task observed and measured in the industry, namely the offloading process of crates off a truck. During the session you will be required to perform two randomly assigned sub-tasks, one being a simulation of the current state in the industry and the second task being the proposed intervention strategy.

The following procedures will also be explained to you verbally, and once you have understood what is required and are comfortable with the procedures, you will be asked to sign a consent form acknowledging your willingness to participate in the study. The evenings before both experimental sessions you will be asked to avoid *excessive* intake of alcohol and heavy meals. On the mornings of the testing sessions, please refrain from drinks containing caffeine, smoking, or vigorous activity, as this may influence the research results!

For each of the following two sessions you will first be prepared for wearing the equipment, which will monitor your responses to the conditions. This involves wearing a heart rate monitor, a facemask, which is attached to a machine called the $K4b^2$, and an apparatus on your back called the Lumbar Motion Monitor. By using these technologies, we can determine your energy expenditure and what movements are occurring in your spine during the activities you will be performing. You will be required to wear this equipment throughout the entire duration of both sub-tasks, which will last 16 minutes each with an adequate rest period in-between. At various intervals you will be presented a scale for Ratings of Perceived Exertion to point out how easy or difficult you perceive the work to be, and after completion of each sub-task a Body Discomfort Map to indicate areas of discomfort or pain.

If you have any questions, feel free to approach me at any stage or to contact me at the Department of Human Kinetics and Ergonomics at Rhodes University. I will also gladly discuss your results with you once the test period for all subjects has been completed. Although you will derive no direct benefits from this project, you will get some insight into the world of Human Kinetics research and your involvement in this project will hopefully contribute towards developing successful MMH solutions to reduce the physical stresses experienced by workers in this and many other South African industries.

Yours Sincerely

Miriam Renz

(MSc student – Department of Human Kinetics and Ergonomics)

SUBJECT CONSENT FORM

I, ________________________________ having been fully informed of the research entitled:

LABORATORY INVESTIGATION OF A SIMULATED INDUSTRIAL
TASK PRE- AND POST-ERGONOMICS INTERVENTION

do give my consent to act as a subject in the above named research.

I am fully aware of the procedures involved, as well as the potential risks and benefits attendant to my participation as explained to me verbally and in writing. In agreeing to participate in this research, I waive any legal recourse against the researchers or Rhodes University, from any and all claims resulting from personal injuries sustained. This waiver shall be binding upon my heirs and personal representatives. I realise that it is necessary for me to promptly report to the researcher any signs or symptoms indicating any abnormality or distress.

I am aware that I may withdraw my consent and withdraw my participation in the research at any times. I am aware that my anonymity will be protected at all times, and agree that the information collected may be used and published for statistical or scientific purposes.

I have read the accompanying information sheet and understood it. Any questions, which may have occurred to me, have been answered to my satisfaction.

SUBJECT (OR LEGAL REPRESENTATIVE)

________________________	________________________	____________
(Print name)	(Signed)	(Date)

PERSON ADMINISTERING INFORMED CONSENT

________________________	________________________	____________
(Print name)	(Signed)	(Date)

WITNESS

________________________	________________________	____________
(Print name)	(Signed)	(Date)

APPENDIX B: DATA COLLECTION

Sequence of Procedures

Ratings of Perceived Exertion

Body Discomfort Map and Scale

Data Collection Sheet

SEQUENCE OF PROCEDURES

SESSION 1

1. Explanation of requirements and tasks involved, including RPE scale and Body Discomfort Map and Scale
2. Present ‘Subject Information Sheet’
3. Administer ‘Subject Consent Form’
4. Collect basic demographic and anthropometric data:
   - Stature
   - Mass
   - Grip strength
   - Back strength
   - Resting heart rate
5. Habituation of both experimental tasks

SESSION 2

1. Set-up K4b^2 and LMM one hour before testing
2. Calibrate LMM and K4b^2
3. Repeat procedures to subjects
4. Subject preparation
   - Fit heart rate transmitter
   - Fit K4b^2 harness
   - Fit LMM harness
   - Secure K4b^2 to harness
   - Secure LMM to harness
   - Fit mask
5. Basic data entry into LMM and K4b^2 computers

6. Final explanation of first condition to be performed including RPE and Body Discomfort Scales

7. Final calibration of LMM

8. Collect ‘anticipatory’ physiological responses for two minutes

9. Experimentation of first randomly assigned condition
   - Collect LMM and K4b^2 at minutes 3:30, 7, 11 and 15:30
   - Collect Central RPE at minutes 2, 5, 9, 13 and 16. At the same intervals collect Local RPE alternating between back and lower extremities.
   - Collect Body Discomfort on completion of condition.
   - Collect recovery data for three minutes
   - Remove equipment from subject and ensure that subject is well

10. Repeat procedures described in steps 4-9 on second subject.

11. Once second subject has completed the first condition, prepare first subject again for the second condition.

12. Final explanation of second condition to be performed

13. Experimentation of second randomly assigned condition as described above

14. Prepare second subject for his second condition and proceed as explained above.

RATINGS OF PERCEIVED EXERTION

Borg’s Scale for Ratings of Perceived Exertion

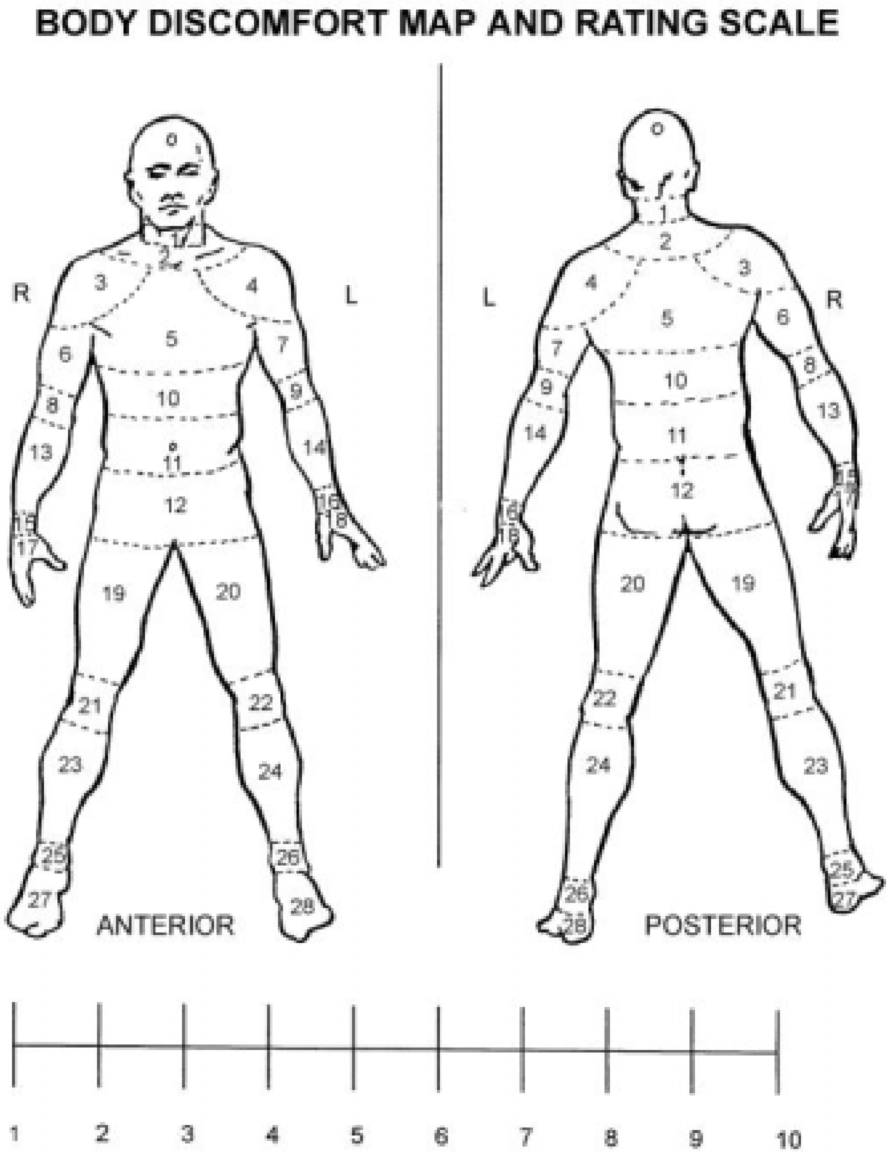
RATINGS OF PERCEIVED EXERTION

6	
7	VERY, VERY LIGHT
8	
9	VERY LIGHT
10	
11	FAIRLY LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD
16	
17	VERY HARD
18	
19	VERY, VERY HARD
20	

Borg G (1982). Psychophysical bases of perceived exertion. **Medicine and Science in Sports and Exercise**, 14(5): 377-381.

BODY DISCOMFORT MAP AND SCALE

Corlett and Bishop's (1976) Body Discomfort Scale



Adapted from: Corlett EN and Bishop RP (1976). A technique for assessing postural discomfort. **Ergonomics**, 19(2): 175-182.

DATA COLLECTION SHEET

Name: ____________________ Project Code: ____________________

Date of Birth: ____________________ Pred. HR max.: ____________________
Age (yrs): ____________________ Grip Strength: ____________________
Mass (kg): ____________________ Back Strength: ____________________
Stature (mm): ____________________ LMM Harness Size: ____________________
Resting HR (bt.min^{-1}): ____________________ K4b^2 Code: ____________________
Hand Dominance: ____________________ Other: ____________________

CONDITION A

		Min. 2	**Min. 5**	**Min. 9**	**Min. 13**	**Min. 16**
RPE	**Central**					
	Back		■		■	
	Legs	■		■		
Comment						

CONDITION B

		Min. 2	**Min. 5**	**Min. 9**	**Min. 13**	**Min. 16**
RPE	**Central**					
	Back		■		■	
	Legs	■		■		
Comment						

DATA COLLECTION SHEET

Name: ______________________ Project Code: ______________________

CONDITION A

		Resting	**Min. 3:30**	**Min. 7**	**Min.11**	**Min. 15:30**	**Recovery**
K4b^2 Markers	**Begin**						
	End						
	Comment						
Body Discomfort	**Area**	**1**		**2**		**3**	
	Rating						
	Comment						

CONDITION B

		Resting	**Min. 3:30**	**Min. 7**	**Min.11**	**Min. 15:30**	**Recovery**
K4b^2 Markers	**Begin**						
	End						
	Comment						
Body Discomfort	**Area**	**1**		**2**		**3**	
	Rating						
	Comment						

APPENDIX C: SUMMARY REPORTS

Physiological Formulae and Variables

Polar Heart Rate Monitor Print-out

$K4b^2$ Print-out

Lumbar Motion Monitor Print-out

Statsgraphics Print-out

Statistical Table

PHYSIOLOGICAL FORMULAE AND VARIABLES

Heart Rate (HR) in bt.min^{-1}

The number of cardiac contractions per minute

Age Predicted Maximum Heart Rate (HR_{max}) in bt.min^{-1}

HR_{max} = 220 – age (years)

Breathing Frequency (R_F) in br.min^{-1}

Number of breaths per minute

Tidal Volume (V_T) in L.br^{-1}

The volume of air inspired and expired with every breath

Minute Ventilation (VE) in L.min^{-1}

The total volume of air inspired every minute

VE = Breathing Frequency x Tidal Volume

Oxygen Consumption (VO_2) in ml.kg^{-1}.min^{-1}

The amount of oxygen consumed by the body each minute during a particular activity.

$$\frac{\text{ml.kg}^{-1}\text{.min}^{-1} \times \text{body mass}}{1000} = \text{L.min}^{-1}$$

Ventilatory Equivalent

Ratio of minute ventilation to oxygen uptake

$$\text{Ventilatory Equivalent} = \frac{VE}{VO_2}$$

Under steady-state conditions this value is usually 25 : 1

Metabolic Equivalent (MET)

Multiples of resting metabolic rate.

1 MET = 3.5 ml.kg^{-1}.min^{-1}

Energy Expenditure (EE)

VO_2 ($L.min^{-1}$) x 20.1 = EE ($kJ.min^{-1}$)

$kJ.min^{-1}$ / 4.186 = EE ($kcal.min^{-1}$)

Respiratory Quotient (RQ)

The ratio of CO_2 volume produced to O_2 volume utilized.

$$RQ = \frac{VCO_2}{VO_2}$$

Standard Deviation (SD)

68% of scores in a normal distribution fall within 1 SD of the mean

Coefficient of Variation (CV) in %

Measures the relative variability of scores, allowing for comparisons of different data.

$$CV = \frac{SD}{Mean} \times 100$$

Bink's Logarithmic Formula

Indicates the amount of working time relative to the energy required, based on an average aerobic capacity of 15.1 $kcal.min^{-1}$.

Energy Expenditure = (log 5700 – log time) x aerobic capacity / 3.1

Murrell's Work-to-Rest Formula

Calculates the amount of rest required for a given activity

$$R = \frac{T\,(M - 4)}{(M - 1.5)}$$

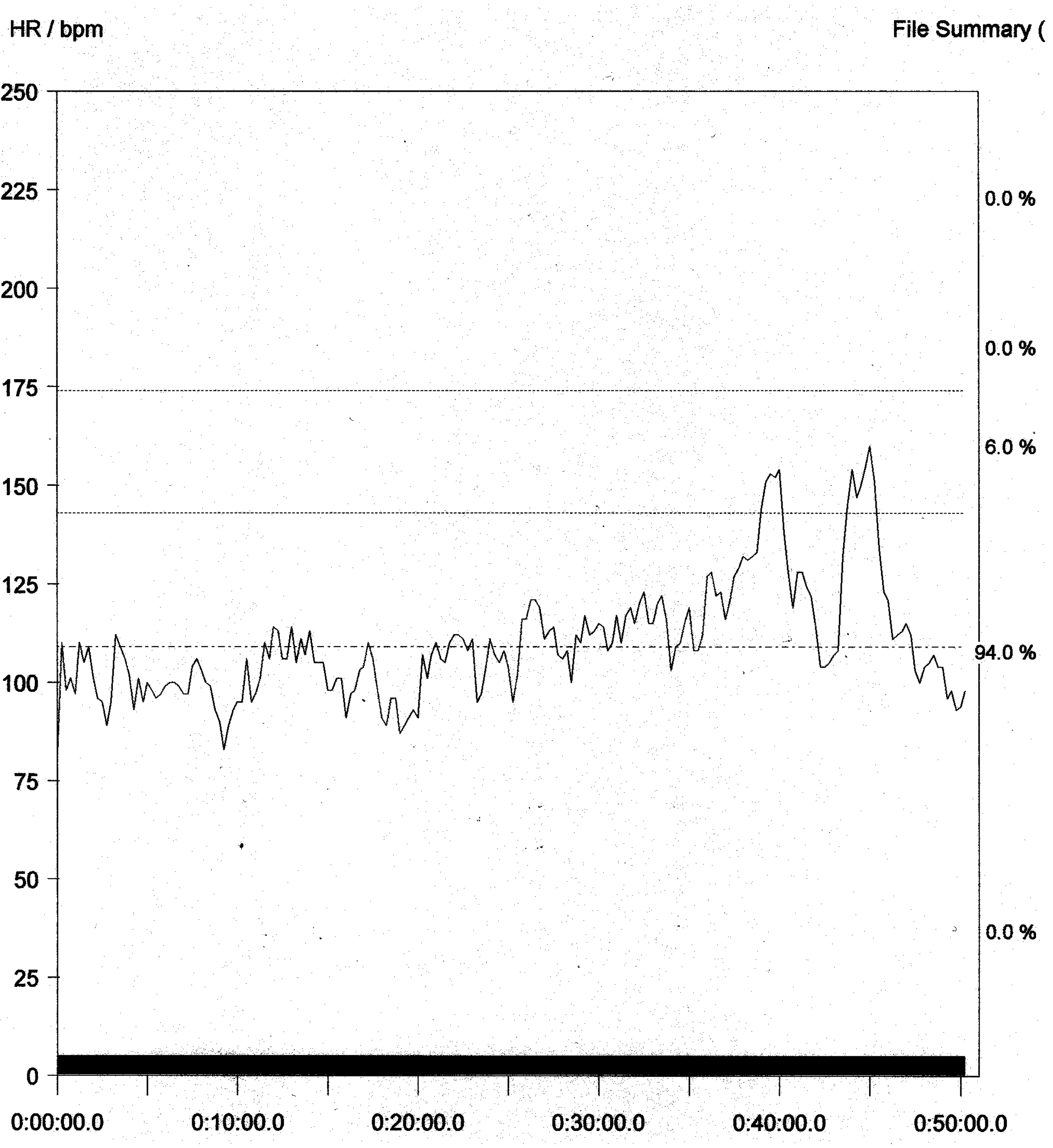
Where: R = rest required (minutes)

T = total working time (minutes)

M = net energy expenditure ($kcal.min^{-1}$) = total EE – resting EE

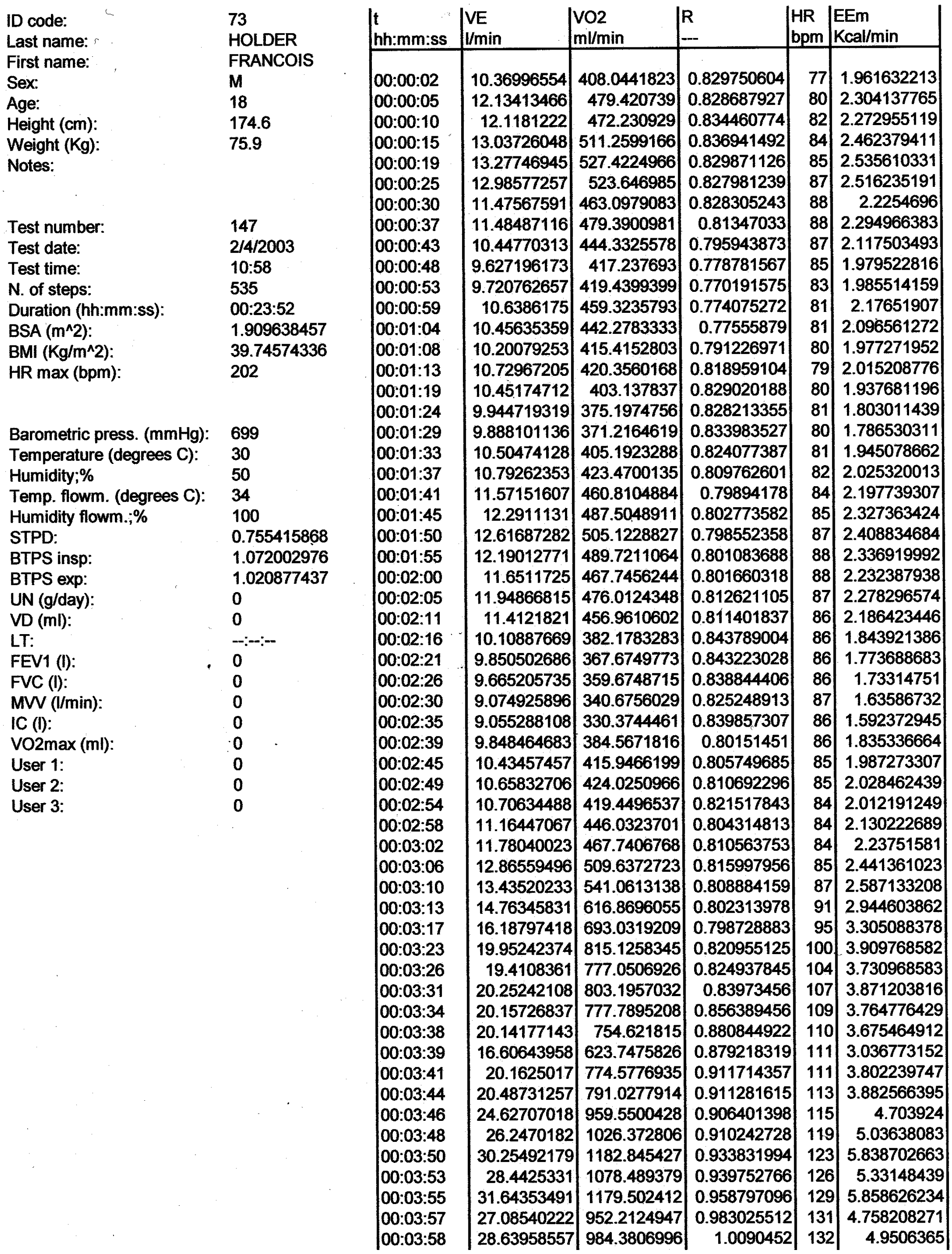
POLAR HEART RATE MONITOR PRINT-OUT

Sample Polar heart rate monitor print-out for an industrial worker during the pre-intervention offloading process.



K4b^2 PRINT-OUT

Sample print-out of raw data obtained from the K4b^2 online metabolic system.



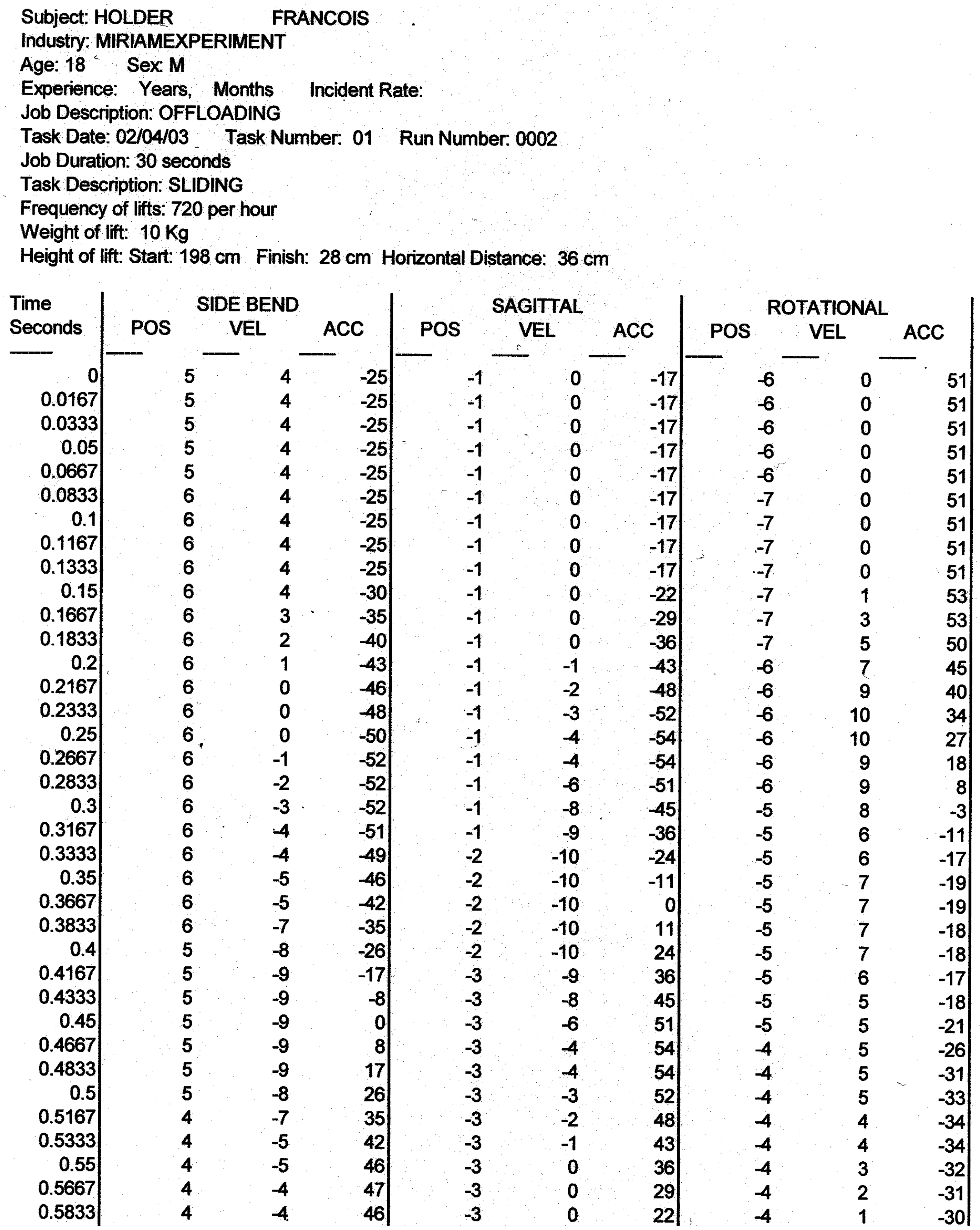
ID code:	73
Last name:	HOLDER
First name:	FRANCOIS
Sex:	M
Age:	18
Height (cm):	174.6
Weight (Kg):	75.9
Notes:	
Test number:	147
Test date:	2/4/2003
Test time:	10:58
N. of steps:	535
Duration (hh:mm:ss):	00:23:52
BSA (m^2):	1.909638457
BMI (Kg/m^2):	39.74574336
HR max (bpm):	202
Barometric press. (mmHg):	699
Temperature (degrees C):	30
Humidity;%	50
Temp. flowm. (degrees C):	34
Humidity flowm.;%	100
STPD:	0.755415868
BTPS insp:	1.072002976
BTPS exp:	1.020877437
UN (g/day):	0
VD (ml):	0
LT:	--:--:--
FEV1 (l):	0
FVC (l):	0
MVV (l/min):	0
IC (l):	0
VO2max (ml):	0
User 1:	0
User 2:	0
User 3:	0

t hh:mm:ss	VE l/min	VO2 ml/min	R ---	HR bpm	EEm Kcal/min
00:00:02	10.36996554	408.0441823	0.829750604	77	1.961632213
00:00:05	12.13413466	479.420739	0.828687927	80	2.304137765
00:00:10	12.1181222	472.230929	0.834460774	82	2.272955119
00:00:15	13.03726048	511.2599166	0.836941492	84	2.462379411
00:00:19	13.27746945	527.4224966	0.829871126	85	2.535610331
00:00:25	12.98577257	523.646985	0.827981239	87	2.516235191
00:00:30	11.47567591	463.0979083	0.828305243	88	2.2254696
00:00:37	11.48487116	479.3900981	0.81347033	88	2.294966383
00:00:43	10.44770313	444.3325578	0.795943873	87	2.117503493
00:00:48	9.627196173	417.237693	0.778781567	85	1.979522816
00:00:53	9.720762657	419.4399399	0.770191575	83	1.985514159
00:00:59	10.6386175	459.3235793	0.774075272	81	2.17651907
00:01:04	10.45635359	442.2783333	0.77555879	81	2.096561272
00:01:08	10.20079253	415.4152803	0.791226971	80	1.977271952
00:01:13	10.72967205	420.3560168	0.818959104	79	2.015208776
00:01:19	10.45174712	403.137837	0.829020188	80	1.937681196
00:01:24	9.944719319	375.1974756	0.828213355	81	1.803011439
00:01:29	9.888101136	371.2164619	0.833983527	80	1.786530311
00:01:33	10.50474128	405.1923288	0.824077387	81	1.945078662
00:01:37	10.79262353	423.4700135	0.809762601	82	2.025320013
00:01:41	11.57151607	460.8104884	0.79894178	84	2.197739307
00:01:45	12.2911131	487.5048911	0.802773582	85	2.327363424
00:01:50	12.61687282	505.1228827	0.798552358	87	2.408834684
00:01:55	12.19012771	489.7211064	0.801083688	88	2.336919992
00:02:00	11.6511725	467.7456244	0.801660318	88	2.232387938
00:02:05	11.94866815	476.0124348	0.812621105	87	2.278296574
00:02:11	11.4121821	456.9610602	0.811401837	86	2.186423446
00:02:16	10.10887669	382.1783283	0.843789004	86	1.843921386
00:02:21	9.850502686	367.6749773	0.843223028	86	1.773688683
00:02:26	9.665205735	359.6748715	0.838844406	86	1.73314751
00:02:30	9.074925896	340.6756029	0.825248913	87	1.63586732
00:02:35	9.055288108	330.3744461	0.839857307	86	1.592372945
00:02:39	9.848464683	384.5671816	0.80151451	86	1.835336664
00:02:45	10.43457457	415.9466199	0.805749685	85	1.987273307
00:02:49	10.65832706	424.0250966	0.810692296	85	2.028462439
00:02:54	10.70634488	419.4496537	0.821517843	84	2.012191249
00:02:58	11.16447067	446.0323701	0.804314813	84	2.130222689
00:03:02	11.78040023	467.7406768	0.810563753	84	2.23751581
00:03:06	12.86559496	509.6372723	0.815997956	85	2.441361023
00:03:10	13.43520233	541.0613138	0.808884159	87	2.587133208
00:03:13	14.76345831	616.8696055	0.802313978	91	2.944603862
00:03:17	16.18797418	693.0319209	0.798728883	95	3.305088378
00:03:23	19.95242374	815.1258345	0.820955125	100	3.909768582
00:03:26	19.4108361	777.0506926	0.824937845	104	3.730968583
00:03:31	20.25242108	803.1957032	0.83973456	107	3.871203816
00:03:34	20.15726837	777.7895208	0.856389456	109	3.764776429
00:03:38	20.14177143	754.621815	0.880844922	110	3.675464912
00:03:39	16.60643958	623.7475826	0.879218319	111	3.036773152
00:03:41	20.1625017	774.5776935	0.911714357	111	3.802239747
00:03:44	20.48731257	791.0277914	0.911281615	113	3.882566395
00:03:46	24.62707018	959.5500428	0.906401398	115	4.703924
00:03:48	26.2470182	1026.372806	0.910242728	119	5.03638083
00:03:50	30.25492179	1182.845427	0.933831994	123	5.838702663
00:03:53	28.4425331	1078.489379	0.939752766	126	5.33148439
00:03:55	31.64353491	1179.502412	0.958797096	129	5.858626234
00:03:57	27.08540222	952.2124947	0.983025512	131	4.758208271
00:03:58	28.63958557	984.3806996	1.0090452	132	4.9506365

Event markers were used to indicate the start and end of the ‘anticipatory’, ‘working’ and recovery periods. Other physiological variables analysed included R_F, V_T and MET.

LUMBAR MOTION MONITOR PRINT-OUT

Sample print-out of raw data obtained from the Lumbar Motion Monitor under Condition A.



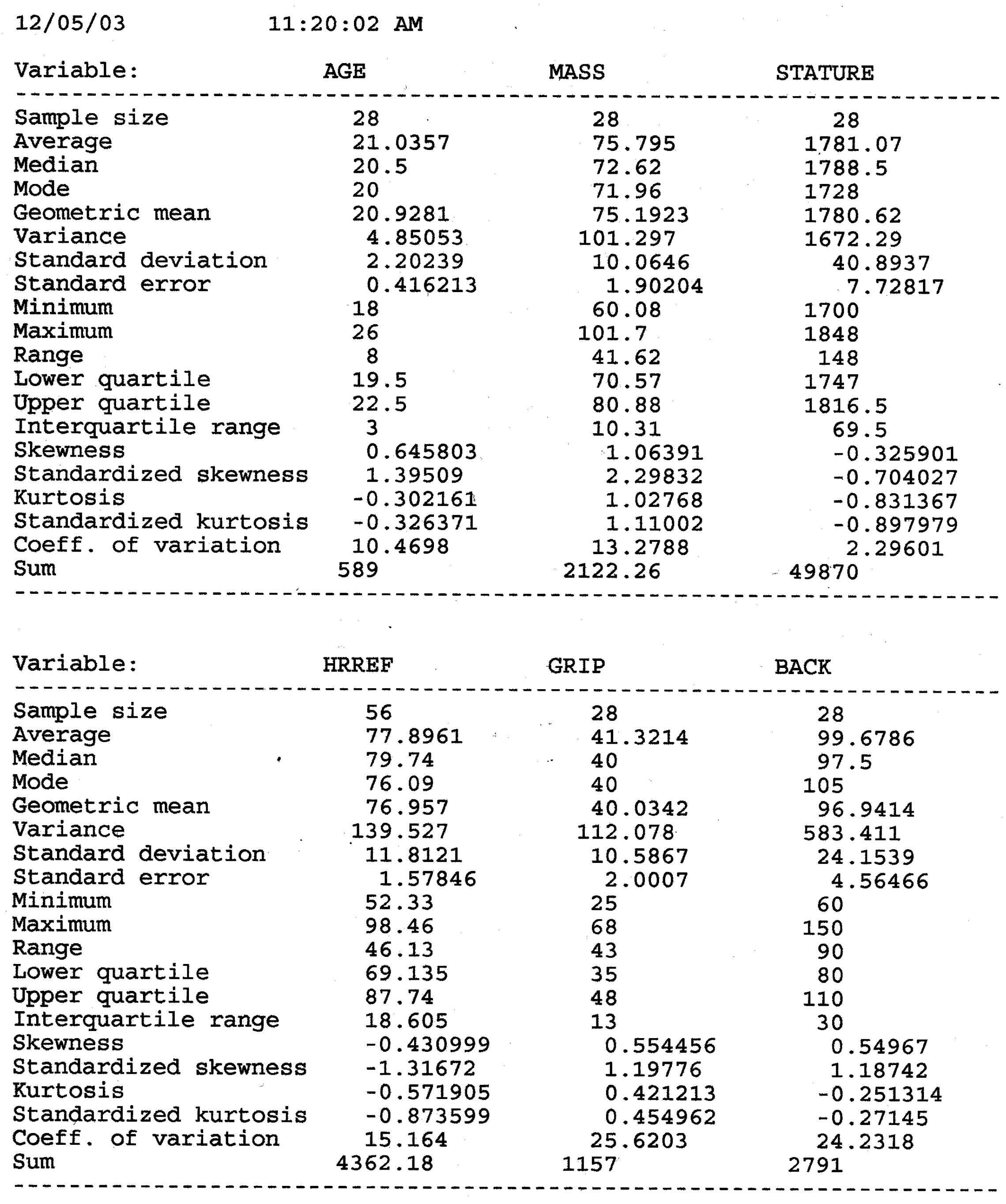
Subject: HOLDER FRANCOIS
Industry: MIRIAMEXPERIMENT
Age: 18 Sex: M
Experience: Years, Months Incident Rate:
Job Description: OFFLOADING
Task Date: 02/04/03 Task Number: 01 Run Number: 0002
Job Duration: 30 seconds
Task Description: SLIDING
Frequency of lifts: 720 per hour
Weight of lift: 10 Kg
Height of lift: Start: 198 cm Finish: 28 cm Horizontal Distance: 36 cm

Time	SIDE BEND			SAGITTAL			ROTATIONAL		
Seconds	POS	VEL	ACC	POS	VEL	ACC	POS	VEL	ACC
0	5	4	-25	-1	0	-17	-6	0	51
0.0167	5	4	-25	-1	0	-17	-6	0	51
0.0333	5	4	-25	-1	0	-17	-6	0	51
0.05	5	4	-25	-1	0	-17	-6	0	51
0.0667	5	4	-25	-1	0	-17	-6	0	51
0.0833	6	4	-25	-1	0	-17	-7	0	51
0.1	6	4	-25	-1	0	-17	-7	0	51
0.1167	6	4	-25	-1	0	-17	-7	0	51
0.1333	6	4	-25	-1	0	-17	-7	0	51
0.15	6	4	-30	-1	0	-22	-7	1	53
0.1667	6	3	-35	-1	0	-29	-7	3	53
0.1833	6	2	-40	-1	0	-36	-7	5	50
0.2	6	1	-43	-1	-1	-43	-6	7	45
0.2167	6	0	-46	-1	-2	-48	-6	9	40
0.2333	6	0	-48	-1	-3	-52	-6	10	34
0.25	6	0	-50	-1	-4	-54	-6	10	27
0.2667	6	-1	-52	-1	-4	-54	-6	9	18
0.2833	6	-2	-52	-1	-6	-51	-6	9	8
0.3	6	-3	-52	-1	-8	-45	-5	8	-3
0.3167	6	-4	-51	-1	-9	-36	-5	6	-11
0.3333	6	-4	-49	-2	-10	-24	-5	6	-17
0.35	6	-5	-46	-2	-10	-11	-5	7	-19
0.3667	6	-5	-42	-2	-10	0	-5	7	-19
0.3833	6	-7	-35	-2	-10	11	-5	7	-18
0.4	5	-8	-26	-2	-10	24	-5	7	-18
0.4167	5	-9	-17	-3	-9	36	-5	6	-17
0.4333	5	-9	-8	-3	-8	45	-5	5	-18
0.45	5	-9	0	-3	-6	51	-5	5	-21
0.4667	5	-9	8	-3	-4	54	-4	5	-26
0.4833	5	-9	17	-3	-4	54	-4	5	-31
0.5	5	-8	26	-3	-3	52	-4	5	-33
0.5167	4	-7	35	-3	-2	48	-4	4	-34
0.5333	4	-5	42	-3	-1	43	-4	4	-34
0.55	4	-5	46	-3	0	36	-4	3	-32
0.5667	4	-4	47	-3	0	29	-4	2	-31
0.5833	4	-4	46	-3	0	22	-4	1	-30

LMM data were collected at four intervals, each lasting 30 seconds. The raw data were analysed by highlighting each lifting level and then calculating the mean of all four intervals.

STATSGRAPHICS PRINT-OUT

Statsgraphics print-out of descriptive statistics.



```
12/05/03          11:20:02 AM

Variable:                  AGE              MASS              STATURE
----------------------------------------------------------------------
Sample size                28               28                 28
Average                    21.0357          75.795            1781.07
Median                     20.5             72.62             1788.5
Mode                       20               71.96             1728
Geometric mean             20.9281          75.1923           1780.62
Variance                    4.85053        101.297            1672.29
Standard deviation          2.20239         10.0646             40.8937
Standard error              0.416213         1.90204             7.72817
Minimum                    18               60.08             1700
Maximum                    26              101.7              1848
Range                       8               41.62              148
Lower quartile             19.5             70.57             1747
Upper quartile             22.5             80.88             1816.5
Interquartile range         3               10.31               69.5
Skewness                    0.645803         1.06391            -0.325901
Standardized skewness       1.39509          2.29832            -0.704027
Kurtosis                   -0.302161         1.02768            -0.831367
Standardized kurtosis      -0.326371         1.11002            -0.897979
Coeff. of variation        10.4698          13.2788              2.29601
Sum                       589             2122.26             49870
----------------------------------------------------------------------

Variable:                  HRREF            GRIP              BACK
----------------------------------------------------------------------
Sample size                 56              28                 28
Average                     77.8961         41.3214            99.6786
Median                      79.74           40                 97.5
Mode                        76.09           40                105
Geometric mean              76.957          40.0342            96.9414
Variance                   139.527         112.078            583.411
Standard deviation          11.8121         10.5867            24.1539
Standard error               1.57846         2.0007             4.56466
Minimum                     52.33           25                 60
Maximum                     98.46           68                150
Range                       46.13           43                 90
Lower quartile              69.135          35                 80
Upper quartile              87.74           48                110
Interquartile range         18.605          13                 30
Skewness                    -0.430999        0.554456           0.54967
Standardized skewness       -1.31672         1.19776            1.18742
Kurtosis                    -0.571905        0.421213          -0.251314
Standardized kurtosis       -0.873599        0.454962          -0.27145
Coeff. of variation         15.164          25.6203            24.2318
Sum                       4362.18         1157               2791
----------------------------------------------------------------------
```

STATISTICAL TABLE

Related t-tests of selected biomechanical, physiological and perceptual responses.

Variable	df	t-statistic	p
Sagittal ROM – A:6 vs. B:4	27	47.076	0.0000 *
Sagittal ROM – A:4 vs. B:4	27	44.35	0.0000 *
Sagittal ROM – A:1 vs. B:1	27	1.863	0.0733
‘Working’ HR (bt.min^{-1})	27	5.818	0.0000 *
VE (L.min^{-1})	27	7.193	0.0000 *
VO_2 (ml.kg^{-1}.min^{-1})	27	5.068	0.0000 *
EE (kcal.kg^{-1}.day^{-1})	27	6.027	0.0000 *
RQ	26	2.156	0.0404 *
Central RPE (final interval)	27	3.647	0.0001 *
Local RPE - Back (final interval)	27	3.147	0.0039 *
Local RPE - Lower Extremities (final interval)	27	2.268	0.0315 *

*** Note:** Significant differences are discussed within Chapter IV, and in Chapter V with the rejection or acceptance of the hypotheses.

Other variables included sagittal flexion and extension velocities and accelerations, as well as ROM, velocities to the right and left sides and positive and negative accelerations at the selected levels in the transverse plane. Central and Local RPE for the initial collection interval were also analysed.