THE EFFECTS OF AGE ON THE WORKER CAPACITY AND MECHANISATION ON THE TASK DEMANDS IN A SOUTH AFRICAN MANUFACTURING INDUSTRY

BY

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THESIS

Submitted in fulfilment of the requirements for the Degree

Master of Science

Department of Human Kinetics and Ergonomics

Rhodes University, 2014

Grahamstown, South Africa

ABSTRACT

The focus of the study was two-fold, firstly to determine the effect of age on the capacity of manual materials handling workers and secondly to determine the effect of increasing task mechanisation on the workers' responses to task demands.

The first component of this study, namely Part I, 101 male and 12 female 'unskilled' manual workers – of various ages – from a brick manufacturing industry were assessed. Anthropometric, health and strength factors were measured to improve the understanding of the South African manual worker capacity and more specifically, the effect of age on this capacity. Data collection was done between 7.30am and 9.30am in a laboratory-type setting on-site. Anthropometric characteristics (including body mass index, waist to hip ratio, waist circumference and body fat percentage) provided information on the state of obesity and the impact of age in the South African context. Linked to this, the health factors (including blood pressure, resting heart rate and a self-reported questionnaire) provide an extra snapshot of the disease profile in South Africa, and could potentially influence other capacity factors. Isometric strength capacities (of eight different areas, namely: back, leg, bicep, shoulder, pinch, pinch and pull) demonstrated whether South African manual workers show the same decline in strength with aging as seen in industrially advanced countries. The second component of the study, Part II, was performed *in situ* and measured the workers' responses to task demands of three brick palletising tasks, one manual (n=21) and two with increasing mechanisation (n=12 each). Spinal kinematics, joint forces and working heart rate were assessed on normal work days during a 30-lift duration and body discomfort measures were taken at the start, middle and end of the work-shift. Spinal kinematics were measured dynamically using a lumbar motion monitor, whereas the spinal forces were estimated using the three dimensional static strength prediction program.

The worker capacity results showed that waist to hip ratio, waist circumference and body fat percentage increased significantly with aging, whereas body mass index was not affected by age. All body morphology values were within 'normal' ranges. Although diastolic blood pressure increased significantly with age, systolic was not affected significantly by age. Both groups, however, showed an increasing prevalence of hypertension with aging. There were no significant changes in resting heart rate with aging, with a range of 66 bt.min^{-1} to 74.86 bt.min^{-1}, therefore within normal ranges. Of the strength factors, age only affected shoulder and push strength significantly: Showing a decrease in shoulder strength from 49.89 kgF to 39.91 kgF in the men aged 20-29 to the 50-59 respectively and an increase in push strength from men aged 30-39 and 40-49 to those aged 50-59. Part II results revealed highly frequent lift rates and large degrees of sagittal flexion and lateral bending in all three tasks. These postures adopted for long durations are likely to lead to the development of musculoskeletal disorders. Heart rates of workers from the three tasks were significantly different and heart rates for two tasks were above the recommended 110 bt.min^{-1}. Similarly the body discomfort ratings of the three tasks differed, although a common trend was seen in that lower back pain was the most commonly reported area of discomfort in all tasks.

South African manual materials handling males did not show the same responses to aging as men from industrially advanced countries, calling for further research into these differences. Due to the high risks of the three tasks assessed, future research and interventions are required to reduce the risk of injury in the assessed tasks.

ACKNOWLEDGEMENTS

This thesis would not have been possible without the contributions of many people throughout my research process. I would like to acknowledge and thank the following people for their encouragement and support in conducting this study:

Firstly I would like to thank my supervisor, Andrew Todd, for his tireless efforts in guiding me throughout the research process. Thank you for the many hours you sacrificed, to share your knowledge with me and for your continued encouragement.

To my mother, Peta Myers, thank you for the many hours you spent reviewing my thesis and for the love and encouragement you have given me throughout the last two years. Your input and unfailing support has been greatly appreciated. To my other family members, Adrian Bezuidenhout and Stephen Bezuidenhout, thank you for keeping my spirits up over the last two years. I love you all and am grateful to all of you for your impact on my life.

I would like to acknowledge my friend and colleague, David Goble, for his efforts in assisting me in the research design, data collection and reporting of my thesis. Thank you for your many hours of help and your academic and emotional support throughout my research process, I greatly appreciate your contribution. Thank you to the staff and students of the Human Kinetics and Ergonomics Department for their assistance over the last two years. In particular, thank you to the many research assistants who helped me at various stages of my data collection, namely; Simone Haywood, Andrea Elliott, Tegan Crymble, Sarah Kennedy, Kirsten Huysamen and Lee Pote. And to Rhiannon Parker and Elizabeth Bassey-Duke for their assistance throughout the entire data collection phase, your assistance was invaluable and I am so grateful to have had you as part of my team.

Thank you to the National Research Foundation for funding this research, your contribution made this project possible.

Finally I would like to acknowledge the management of Makana Brick in Grahamstown for their willing cooperation and for going the extra mile in ensuring my data collection was fast and efficient. In addition, thank you to the staff and participants for keeping my spirits up and a smile on my face throughout my data collection phase, without you this research would not have been possible.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

Despite increasing automation and widespread ergonomics research, manual materials handling (MMH) tasks, lifting tasks in particular, still represent a major health and safety risk in industry (Marras, 2000; Lin *et al*., 2006). During lifting, the lumbosacral joint (L_5/S_1), arguably the weakest joint in the spinal column, is placed under increased stress from compression and shear forces which increase the risk of lower back injuries and pain (Waters *et al*., 1993).

Rates of lower back pain are higher in countries with a lower income (e.g. industrially developing countries), due to the hard physical labour in these countries (Volinn, 1997). MMH factors are often exacerbated in industrially developing countries (IDCs), which have less industrial mechanisation than industrially advanced countries (IACs), and often consists of weaker workers due to the enhanced burden of disease (O'Neill, 2000). Therefore workers in South Africa, which is an IDC, may potentially have a reduced worker capacity due to the increasing average age of the workers and the unique burden of disease profile. In addition to this, as it is an IDC it would have a greater task demands in terms of MMH lifting requirements.

Manual brick manufacturing is a very common MMH industry IDCs, as it utilises unskilled labour and provides cheap building materials to be used in the areas. Tasks in brick kilns involve a variety of physical actions, including: pushing, pulling, bending, reaching, lifting and lowering, to name a few (Chung and Kee, 2000; Qutubuddin *et al*., 2013). The risks of performing these tasks are often exacerbated by unfavourable work environments, resulting in a higher risk of musculoskeletal disorders (Qutubuddin *et al*., 2013). There are many types of kilns used for baking bricks, from, manually stacked coal kilns, to automated tunnel kilns. Automated tunnel kilns can bake bricks in only a few days, whereas the process of preparing and baking bricks manually will take months. Manual brick manufacturing is a long process, starting with collecting clay from quarries and ending with palletising dry bricks to be transported. Palletising occurs at least twice for each set of bricks, once placing the wet bricks onto pallets to be dried, and again when the bricks are dry (i.e. have been baked and cooled) and are ready for sale. Palletising requires highly repetitive lifting and lowering, moving bricks from the origin to the pallets, and can therefore increase the risk of lower back injury or pain. In South Africa, there is an increase in the mechanisation of the brick kilns; where tasks were previously manual, conveyor belts have been introduced to speed up the production process. Although the loading and unloading of bricks from and to static fittings has been identified as a medium to high risk task (Qutubuddin *et al*., 2013), it is unknown whether the addition of conveyor belts is detrimental or beneficial to the palletising process. In order to fully understand the task demands of palletising in a brick manufacturing industry, the workers responses to the tasks need to be assessed. This forms the basis of the experimental design of the current research project and there are several approaches which can be adopted in order to do this.

Physiological assessments will show the energy exertion of the workers in order to complete the tasks. Biomechanical assessments will offer insights into the spinal movements and forces applied on the body, while perceptual assessments will provide an idea of the areas of discomfort felt by the workers. For palletising tasks, where the lower-back and upper-back have the highest number of discomfort reports (Qutubuddin *et al*., 2013), it is necessary to investigate the biomechanical spinal kinematics and joint forces associated with the tasks, with supplementary information from physiological and perceptual factors. Understanding these task demands within a South African industry context is essential to ensure the workers have the capacity to complete tasks with minimal risk of injury or pain.

Of the worker capacity factors, age is amongst the most researched as it is non-modifiable and impacts on numerous other worker capacity factors. Age is an important factor as it affects physiological, biomechanical and morphological capacities, which will in turn impact the physical work ability (Kenny *et al, 2008)*. Aging is linked to: the progressive decline of the cardiovascular system (Kenny *et al*., 2008), a reduction in muscle strength and mass (Metter *et* al., 1997; Metter *et al*., 1999; Doherty, 2001) and deteriorations in bone mineral density and bone microarchitecture (Mosekilde, 2000; Brooks *et al*., 2005) as well as, decreased testosterone and adrenal androgen (Snyder *et al*., 1999; Doherty, 2003). Declines in these factors will result in an overall lowering of the worker capacity and a subsequent decline in work performance ability. Increased non-communicable disease deaths and linked to this, increases in abdominal obesity and body mass index (Puoane *et al*., 2002; Bolton and Rajkumar, 2011), as well as, hypertension (Fach, 1967) are also associated with aging in males. This is important as increased non-communicable disease risk factors (such as obesity and hypertension) have been linked to a decrease in productivity in the work place (Rodbard *et al*., 2009).

These findings are noteworthy, as research in IACs shows that the workforce is aging. For example, in Canada the number of workers aged 55-64 is expected to double from 2005 to 2015, reaching an estimated 48% of the workforce in 2015 (Kenny *et al*., 2008). In spite of this increase, there has not been any subsequent decrease in task demands, despite the physical work capacity decline experienced with aging (Kenny *et al*., 2008). It is thought that the workforces in IDCs have not yet reached these levels, but due to the HIV/AIDS epidemic in South Africa there is an increased prevalence of disease in younger individuals (aged 30-34 for males and 25-29 for females), resulting in a decreased retention of younger employees, due to HIV/AIDS related morbidity and mortality (Harrison *et al*., 2010). Therefore, South Africa may also have an aging workforce but for different reasons to those seen in IACs.

In order to quantitatively characterise the brick palletising task demands, the current study investigated spinal kinematic variables, spinal joint forces, working heart rate and body discomfort associated with three palletising tasks of varying mechanisation within a South African brick manufacturing company. In addition to this, to further understand the workers abilities in this MMH industry, the effect of age on the capacity of workers in this industry was measured. In order to do this, several strength measures, diastolic and systolic blood pressure, resting heart rate, obesity (in the form of body mass index, waist to hip ratio, waist circumference and body fat composition), and health factors (from a self-reported questionnaire) were assessed and compared between different age groups.

STATEMENT OF THE PROBLEM

Recognising the importance of understanding both task demands and worker capacity in a unique South African industry is essential in order to design safe guidelines for MMH tasks. In order to achieve this; the biomechanical, physiological and perceptual task demands of three brick palletising tasks, varying in manual-mechanisation requirements, were assessed; and the effect of age on the biomechanical, physiological and personal worker capacity factors was determined. This research therefore aimed to: research the task demands of the manual to mechanisation transition in South African industries and to understand effect of age on the worker capacities of unskilled South African manufacturing workers; research which has previously not been conducted.

RESEARCH HYPOTHESES

PART 1: WORKER CAPACITY

It was postulated that there would be a meshing of the IAC aging trends (i.e. strength and health declines with aging in response to hormonal and structural changes) with a unique South African worker capacity decline in the age groups which are most affected by the HIV/AIDS epidemic. If this was the case, it can be predicted that males aged 25-45 will have; lower strength, body mass indexes, waist to hip ratios, waist circumferences and body fat percentages and a higher disease prevalence than normal, all affecting the general decline in strength and increase in body morphology factors seen with aging in IAC persons.

PART 2: TASK DEMANDS

As the three tasks assessed varied in level of mechanisation, the responses of workers to these tasks were expected to be different, despite the all tasks involving palletising. As the more manual task involved a larger sagittal range of lifting, it was expected that the sagittal flexion of this task would be the greatest. It was also thought that a large amount of sagittal movement would cause a greater increase in heart rate than is seen in the other tasks. In addition to this, the more variable manual task was expected to have reports of body discomfort in more body areas than the other tasks and due to the highly repetitive bending, all tasks were predicted to have reports of lower back discomfort. As the more mechanised tasks lifted bricks off conveyor belts, there were increasing time pressures to palletise the bricks. Due to these time pressures, it was expected that these tasks would have greater acceleration and velocities in all planes. The different weights of bricks, were thought to change the compression forces on the workers, whereas shear forces were predicted to be affected by the sagittal movements of the workers.

STATISTICAL HYPOTHESES

PART 1: WORKER CAPACITY

IMPACT OF AGE

Where: Age1 = 20-29 years
Age2 = 30-39 years
Age3 = 40-49 years
Age4 = 50-59 years or ≥50 years

HYPOTHESIS 1C:

No significant differences exist between biomechanical (strength) responses for each age group.

$$H_o: \mu_{STR\ Age1} = \mu_{STR\ Age2} = \mu_{STR\ Age3} = \mu_{STR\ Age4}$$

$$H_a: \mu_{STR\ Age1} \neq \mu_{STR\ Age2} \neq \mu_{STR\ Age3} \neq \mu_{STR\ Age4}$$

Where STR refers to: Strength (of the Legs, Back, Shoulder and Bicep areas, as well as, Pinch, Grip, Push and Pull Strength).

HYPOTHESIS 1A:

No significant differences exist between the anthropometric measurements of each age group.

$$H_o: \mu_{ANT\ Age1} = \mu_{ANT\ Age2} = \mu_{ANT\ Age3} = \mu_{ANT\ Age4}$$

$$H_a: \mu_{ANT\ Age1} \neq \mu_{ANT\ Age2} \neq \mu_{ANT\ Age3} \neq \mu_{ANT\ Age4}$$

Where ANT refers to: Body Mass Index, Waist to Hip Ratio, Waist Circumference and Body Composition.

HYPOTHESIS 1B:

No significant differences exist between the health reports of each age group.

$$H_o: \mu_{HEA\ Age1} = \mu_{HEA\ Age2} = \mu_{HEA\ Age3} = \mu_{HEA\ Age4}$$

$$H_a: \mu_{HEA\ Age1} \neq \mu_{HEA\ Age2} \neq \mu_{HEA\ Age3} \neq \mu_{HEA\ Age4}$$

Where HEA refers to: Blood Pressure (systolic and diastolic) and Resting Heart Rate.

PART 2: TASK DEMANDS

IMPACT OF TASK

Where: Task1 = Clay Dry Brick (completely manual)
Task2 = Clay Wet Brick (increased mechanisation- unpacking off one side of conveyor belt)
Task3 = Kiln Dry Brick (increased mechanisation- unpacking off both sides of conveyor belt)

HYPOTHESIS 2A:

No significant differences exist between the biomechanical responses of each task.

H_o: $\mu_{\text{BIO Task1}} = \mu_{\text{BIO Task2}} = \mu_{\text{BIO Task3}}$

H_a: $\mu_{\text{BIO Task1}} \neq \mu_{\text{BIO Task2}} \neq \mu_{\text{BIO Task3}}$

Where BIO refers to: Spinal Kinematics, Spinal Joint Forces

HYPOTHESIS 2B:

No significant differences exist between the physiological (working heart rate) responses of each task.

H_o: $\mu_{\text{HRW Task1}} = \mu_{\text{HRW Task2}} = \mu_{\text{HRW Task3}}$

H_a: $\mu_{\text{HRW Task1}} \neq \mu_{\text{HRW Task2}} \neq \mu_{\text{HRW Task3}}$

Where HRW refers to: Working Heart Rate at the; Start, Middle and End of the testing protocol.

HYPOTHESIS 2C:

No significant differences exist between the perceptual (body discomfort) responses of each task.

H_o: $\mu_{\text{BD Task1}} = \mu_{\text{BD Task2}} = \mu_{\text{BD Task3}}$

H_a: $\mu_{\text{BD Task1}} \neq \mu_{\text{BD Task2}} \neq \mu_{\text{BD Task3}}$

Where BD refers to: Perceived Body Discomfort at the; Start, Middle and End of the work shift.

DELIMITATIONS

The present study aimed to investigate the worker capacity and task demands of workers in a South African manual materials handling industry. Due to the testing being conducted *in situ*, many environmental factors could not be controlled, but certain factors were delimited in an attempt to increase the accuracy of the measurements. Participants were selected from volunteers with no recent injuries (within six months of testing), who were right-hand dominant and within the ages of 20 and 60 years.

PART 1: WORKER CAPACITY

A sample of 113 ‘unskilled’, Black African manual workers from a brick manufacturing industry in the Eastern Cape were measured in an onsite laboratory-type setting. This allowed the temperature, noise, light, dust and vibration conditions to be controlled in order to standardise the methodological factors. To further control temperature and circadian effects, testing only took place in the morning between 7.30am and 9.30am.

The testing procedure was controlled by ensuring anthropometric measures were taken before the strength tests, to negate any effects of sweat loss. For the strength tests, each dynamometer was adjusted for workers of different heights, to ensure the same body postures were adopted by all participants. Research assistants were assigned to a certain strength test which they controlled for the entirety of the testing period. Standardised instructions on how to complete each strength test were given to each of the research assistants, who were required to read the same explanation to the participants before participants asked questions and were habituated. Three repetitions of each strength test were performed and these were required to be within 5% of each other to ensure intra-subject consistency. If only two strength measures were within 5%, the third value was discarded, if none of the measures were consistent, the results from that particular test were discarded. Each participant had to complete all tests on the same day to ensure the same level of exertion for each subject. The order in which participants completed the strength tests were permutated to control for any fatigue effect experienced throughout the test battery.

PART 2: TASK DEMANDS

A sample of 45 Black African male volunteers were recruited from three brick palletising tasks, namely; the Clay Dry Brick (n = 21), Clay Wet Brick (n = 12) and Kiln Dry Brick (n = 12) tasks. In order to accurately measure the tasks demands, the testing needed to be done *in situ* to be representative of the actual tasks, despite this, efforts were made to control certain environmental factors. Testing was conducted in the mornings (between 7.30am and 12pm) of four consecutive work days with similar environmental conditions; minimal wind and temperatures between 23º C and 25º C.

When measuring the spinal kinematics, participants were required to remove bricks, one in each hand, from the origin - off the conveyor belt for clay wet brick (CWB) and kiln dry brick (KDB) tasks and off the stacked brick kiln for the clay dry brick (CB) task

- and place them directly onto the pallet, forming the first layer. This allowed a standardised measure of the most extreme posture for each task. Photographs for the joint force prediction were taken of this brick placement posture, to better understand the maximum risk of each task.

LIMITATIONS

The nature of *in situ* testing is highly volatile and despite every attempt to minimise the impact of confounding variables, some factors could not be controlled. Due to the time constraints of the industry, participants had to be tested as quickly as possible to ensure the work processes were not affected. Therefore, due to the standard overalls and work shoes provided to all workers, participants' stature and mass were recorded with these on and the weight of the overalls and height of the heel of the shoe were subtracted from the recorded values after testing. Due to differences in the duration in which participants wore the shoes, the wear on the shoes will differ, therefore affecting the recorded stature and mass of the participants. In addition to this, overalls of larger sizes will have a greater mass, which would also affect the recorded mass of participants.

Although the equipment and testing procedures were explained verbally and in writing with an interpreter present, it is unknown whether the participants fully understood the testing protocols or the explanation of the body discomfort chart (in Part II of the testing). It is therefore unknown whether the reported discomfort measures are accurate representations of how the workers were feeling. Similarly, despite the habituation of participants to the equipment, the strength exerted on the dynamometers may not have been maximal and the technique of brick palletising may have changed when wearing the lumbar motion monitor, due to the unfamiliarity of the equipment. The lumbar motion monitor is, however, considered to present minimal interference.

Additionally, for the worker capacity testing (Part II), anthropometric measurements (stature and mass) were taken in the field. Although every effort was made to ensure the scale was on a level section of concrete, there was often clay dust on the ground, which may have affected weight measurements. Stature was measured using a tape measure against a wall, although the placement of the tape measure was checked numerous times to ensure its accuracy, a stadiometer would have been more accurate.

Lastly, although participants were instructed (verbally and in writing) to not consume alcohol, to eat ‘normal’ meals and to not part-take in any strenuous exercise/activity the day before testing, adherence to this could not be controlled. Any deviation from these requirements could impact the results obtained.

CHAPTER II

REVIEW OF RELATED LITERATURE

INTRODUCTION

Manual materials handling tasks are dynamic in nature and can include the following movement patterns; lifting, lowering, pushing, pulling, carrying, loading and unloading of objects (Mital, *et al*., 1997; Bridger, 2003; Dempsey, 2003). Additionally, at any one time, a number of these movements can happen simultaneously. Dempsey (1998) states that MMH is present in many manufacturing industries, particularly in IDCs. Despite an increase in automation and ergonomic research, these tasks contribute substantially to injuries and compensation costs (Lin *et al*., 2006; Marras, 2000). Manual workers are regularly required to work in hazardous conditions with severe environmental conditions and often in restricting work postures, while being required to perform physically taxing tasks (Scott and Christie, 2004). These working conditions increase the task demands and the effort required of each individual. In Industrially Developing Countries (IDCs), increasing the effort required at work is often not possible, due to the sub-standard living conditions, poor nutritional status and the related health problems that lower the capacity of the worker (Scott and Christie, 2004). Despite this problem, little research focusing on the capacity of South African manual labourers and the task demands of South African manual industries has been conducted.

In order to ensure this understanding of the human-system interactions, characteristics of workers and their home and work environments, need to be understood. The worker and environment characteristics are dependent on the state of the country; the infrastructure, social circumstances and the level of manual and mechanised work (Scott 1993). Countries can be broadly divided into IDCs and Industrially Advanced Countries (IACs) according to the level of industrialisation. Ergonomic risk assessment tools which were developed in IACs and are based on individuals from their populations (NIOSH, 1981; McAtamney and Corlett, 1993; Hignett and McAtmney, 2000) are commonly used to assess workplaces in both IACs and IDCs. There are, however, many differences between these groups of countries which suggest that they should require separate individualised approaches and assessments (O’Neill, 2000).

When worker capacity can no longer meet the task demands that are required (a common occurrence in IDCs), fatigue, discomfort and injury are often the outcomes (Dempsey, 1998). As such it is important to further the understanding of the relationship between worker capacity and the task demands. Ergonomics is a discipline that strives for efficiency by matching task demands to worker capacity, with the intent of reducing risk of injury to workers while maintaining productivity. Despite the increase in ergonomic research into occupational musculoskeletal disorders and the implementation of interventions that have moved towards increased mechanisation in industries, work-related musculoskeletal disorders are still prevalent world-wide (Mital, 1989; Marras, 2000). Perhaps the reason for this is the implementation of laboratory-based interventions into field-based scenarios. Therefore, there is a growing need for field-based research that can aid in the generation of knowledge for these highly dynamic workplace tasks.

MANUAL MATERIALS HANDLING

Manual materials handling refers to any handling task involving the human body as the ‘power source’ and includes a wide range of dynamic movements (Mital, *et al*., 1997). Although there is a movement towards increasing the mechanisation in the clay brick industry, the majority of the work processes are still manual in nature, espcially in IDCs (Scott and Christie, 2004). Many jobs in the brick kiln operations in industry involve a wide range of the physical actions listed above as well as awkward working postures, asymmetrical postures, twisting and high acceleratory twisting and bending. As a result the work-related tasks involved in brick manufacturing are dynamic in nature and may comprise several of these movement patterns simultaneously; which, if not assessed and controlled properly could result in injury to the worker (Qutubuddin, et al., 2013).

The clay brick-making industry is important to South Africa because this industry utilises a naturally occurring resource (i.e. clay) and manual kiln methods. It therefore, a) provides job availability in the country (where 14.5% and 18% of Black African males and females are unemployed (Mwabu and Schultz, 2000) and b) allows for the manufacturing of cheap bricks (which are used to produce subsidised housing in the more rural areas in South Africa).

RISK FACTORS

Risk factors most commonly found in MMH tasks were; heavy physical work or work intensity, lifting, pushing or pulling, frequent bending and twisting, whole body vibration, static work postures and repetition (Bernard, et al., 1997; Fathllah et al., 1998). Heavy physical work is described as work that has high energy demands or requires "some measure of physical strength" or imposes large spinal compression forces (Bernard, et al., 1997). Lifting is described as moving an object from a lower level to a higher one, whereas forceful movements include movement of objects in other ways, such as pulling and pushing. Bending is defined as flexion of the trunk in the sagittal or lateral direction and twisting refers to trunk rotation and spinal torsion. Whole body vibration refers to the mechanical energy oscillations which are transferred through the entire body, usually through a seat or platform. Static work postures are defined as isometric positions where little movement occurs, as well as, cramped or inactive postures which cause static forces on the muscles. The presence of more than one risk factor in a task, which is common in dynamic MMH tasks, will cause the overall task risk to increase exponentially. For example, Magora (1970), found that twisting and lateral bending were determined to be significant when only occurring simultaneously in a dynamic environment and Punnet *et al*. (1991) showed that lifting with repetitive twisting or lateral bending are significant risk factors, even with light loads.

These risk factors are common in palletising in the brick manufacturing industry, where workers are often required to lift bricks, twist at the trunk, bend both laterally and sagittally and lower the bricks onto a pallet. Similarly, these movements are common in stacking - when bricks are packed for firing.

RISK ASSESSMENT TOOLS

Although there are many risk assessments tools (e.g. RULA, REBA, NIOSH, OCRA, OWRAS, Moore-Garg fine strain, Snook lifting tables) which have been developed to assess and quantify the risk of work tasks, most of these were developed for first world populations. Furthermore, these were developed in work-systems from IACs, thereby making the validity and transfer of these tools into an IDC setting questionable. In order to determine whether these tools are valid in a South African context, one first needs to understand the worker and task characteristics in South Africa, to determine if they differ to those of industrially advanced countries.

SYSTEMS APPROACH

The systems approach is a method of attempting to understand the entire work system by adopting a holistic approach by measuring various factors affecting the workplace (Dempsey, 1998). In manual materials handling tasks, the systems approach aims to understand the interaction between the worker capacity and the task demands of these systems (Dempsey, 1998). The approaches are based on criteria from epidemiological, biomechanical, physiological and psychophysical principles. These principles will be discussed further.

EPIDEMIOLOGICAL APPROACH

Dempsey (1998) noted that the role of epidemiology in the development of MMH criteria is threefold; First, to determine the aetiological significance of a variable. Second, to verify the validity of a criterion by establishing the relationship between a specific variable and the probability or severity of injury or disability. Lastly to provide guidance in the development of a criterion through the reflection of previously identified relationships between a set variable and selected outcomes measures.

BIOMECHANICAL APPROACH

Biomechanics is concerned with the strength and movement of bone, joint and muscular structures of the body. The biomechanical approach, therefore, ensures that work tasks do not exceed the capabilities of the musculoskeletal system (Dempsey, 1998). There have been advances in level of occupational exposure quantification, in terms of; improved exposure metrics, quantification of three-dimensional loads experienced on the spine, identification of tissue tolerance limits and tissue response to mechanical stresses (Marras et al., 2009). There is a need, however, to link epidemiological, biomechanical loading, soft tissue tolerance and psychosocial factors to increase overall understanding (Marras et al., 2009).

PHYSIOLOGICAL APPROACH

The physiological approach is concerned with the demands placed on the cardiovascular system, determining the energy requirements of the task (Dempsey, 2007). This approach is primarily concerned with gaining an indication of whole-body fatigue induced by work related tasks (Dempsey, 2007). If the task demands outweigh the energy resources, over time a depletion of the energy reserves occurs, reducing the ability of the individual to perform. Within the work environment this whole-body fatigue leads to gradual decreases in performance, in particular a reduction in worker output (Jorgensen *et al*., 1999). Therefore the goal of the physiological approach is to ensure that the energy requirements of a task do not exceed the energy resources an individual has available (Carayon and Smith, 2000). It is important to note that the goal of this approach is to ensure that workers are able to deliver quality performance for an eight hour work shift, five days a week, rather than to deliver a once off peak performance.

PSYCHOPHYSICAL

The psychophysical approach aims to design tasks which the majority of workers perceive to be ‘acceptable’ (Dempsey, 2007). Ayoub and Mital (1989) stated that physical, physiological, mental and emotional factors will determine the end-point of performance and pushing workers to the extremes of any of these factors will have negative implications. Psychophysical responses can be measured with perceptual scales such as the Borg’s (1978) Rating of Perceived Exertion scale and the Body Discomfort scale developed by Corlett and Bishop (1976).

Aiming to optimise all of these characteristics is impossible, as by nature these criteria are conflicting. Therefore one area should be used as a focal point for the research. In a MMH work place, where work-related musculoskeletal disorders are of major concern, ensuring the tasks do not exceed the capacity of the musculoskeletal system is essential. Therefore the biomechanical approach was selected as the main focus for this research.

SPINAL KINEMATICS

Lower back disorders (LBDs) have commonly been found to negatively affect the human population, without reference to a specific cause (Snook, 1978). The risk factors for LBDs can be grouped into personal: anthropometric and demographic information of the individual (Marras, 2006) as well as occupational: attributes of the job, i.e. biomechanical and psychosocial factors (Pheasant and Haslegrace, 2006). These risk factors do not happen in isolation but rather are interactive, making them difficult to understand (Pheasant and Haslegrave, 2006).

Pope (1989) suggested that the nature of work may be an indication in the level of risk of suffering a LBD. Manual materials handling tasks, involving lifting in particular, are linked to lower back injury (Marras *et al*., 1995). In addition to the effects of the job, some people are more genetically predisposed to LBD and will develop lower back pain despite a low risk job, whereas others will not develop lower back pain regardless of working in a high risk job (Snook, 1978). In the workplace, LBDs make up approximately 20% of reported injury (Marras, 1995), but account for 33-41% of the total compensation costs (Spengler *et al*., 1986; Marras, 2003), adding up to approximately U.S.$100 billion each year (Marras, 2000).

BIOMECHANICAL LOGIC

The two areas most commonly assessed for this approach are; the compression limits for the lower spine (L_4/L_5 or L_5/S_1 joints) and maximum joint torques (Dempsey, 1998). During any lifting task, the weight of the head, arms and trunk (HAT), in addition to the external load lifted, are transmitted through the body to the base of support. In this process the lower back; in particular the L5/S1 joint, is the weakest in the body and the most likely point of injury (Ayoub and Mital, 1989), which is due to the interaction of internal and external forces acting on the spine. Internal forces are due to muscles contractions in attempt to counteract the external forces of the HAT and external load, in order to maintain balance.

A large amount of biomechanical research is aimed at defining limits for compression forces of the L5/S1 joint (NIOSH, 1981; NIOSH, 1991; Jager and Luttmann, 1999). The guidelines of the National Institute of Occupational Health and Safety (NIOSH), which have been used in policy making internationally, state that these forces should not be greater than 3400N to ensure the majority of the workforce will be able to perform the task. However, due to the dynamic effects and the interaction of numerous factors (Karwowski, *et al*., 1992) an exact magnitude of spinal loading that can be sustained without injury is uncertain (NIOSH, 1981). The two main personal factors which influence spinal loading strength are: age and the degree of degeneration of the intervertebral disc (Karwowski, *et al*., 1992). Karwowski *et al*. (1992) for example showed a compressive load failure range of between 5000N and 8000N, whereas Hutton and Adams (1982) showed compression values below 500N and above 1000N. This change in failure cut-offs could be linked to biomechanical logic, based on a load-tolerance relationship (Marras, 2000) as shown in Figure 1. The load-tolerance relationship assumes that during a work task, a load is imposed upon the structures of the spine. While the load is below the tolerance level no injury should occur because of a safety margin, however, if the spinal load is greater than the tolerance level, injury is likely to occur. This can happen when the repetitive lifting of a load is variable, when the tolerance decreases with time (Figure 1), or as a combination of both.

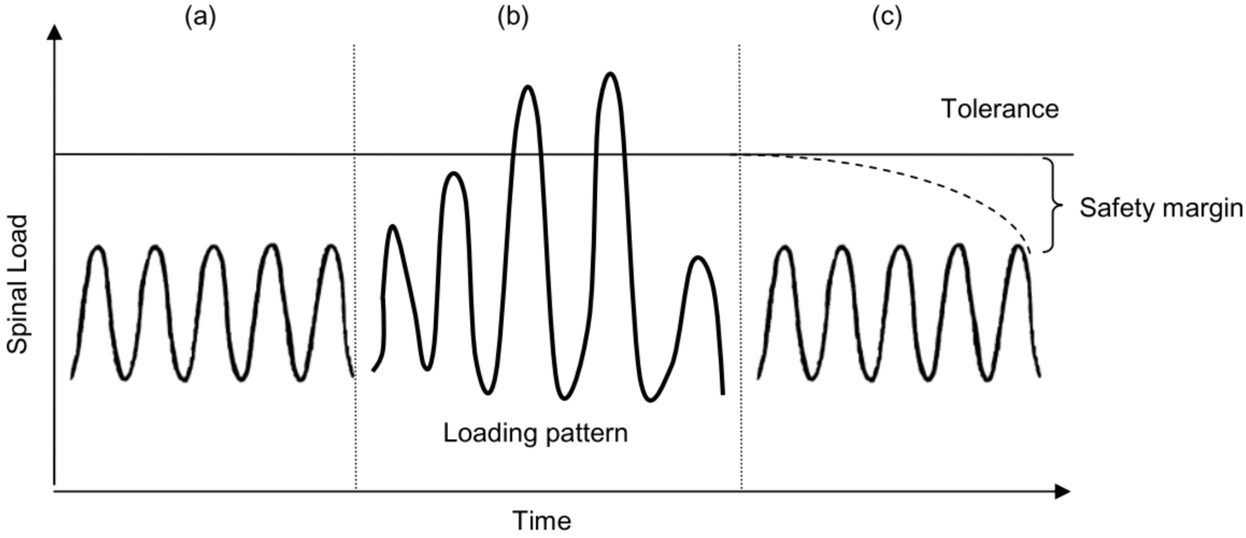


Figure 1: The load-tolerance relationship showing, a) the load below the tolerance level, b) increased loading variability resulting in trauma, and c) a reduced tolerance over time, resulting in trauma (adapted from McGill, 1997 and Marras, 2000 as seen in Desai, unpublished research).

In realistic working conditions, loading of the spine occurs dynamically in a three-dimensional (3D) space made up of three types of spinal forces; compression, torsion and shear (made up of lateral and anterior-posterior) as seen in Figure 2 (Mital, et al., 1997; Dempsey, 1998; Marras, 2000).

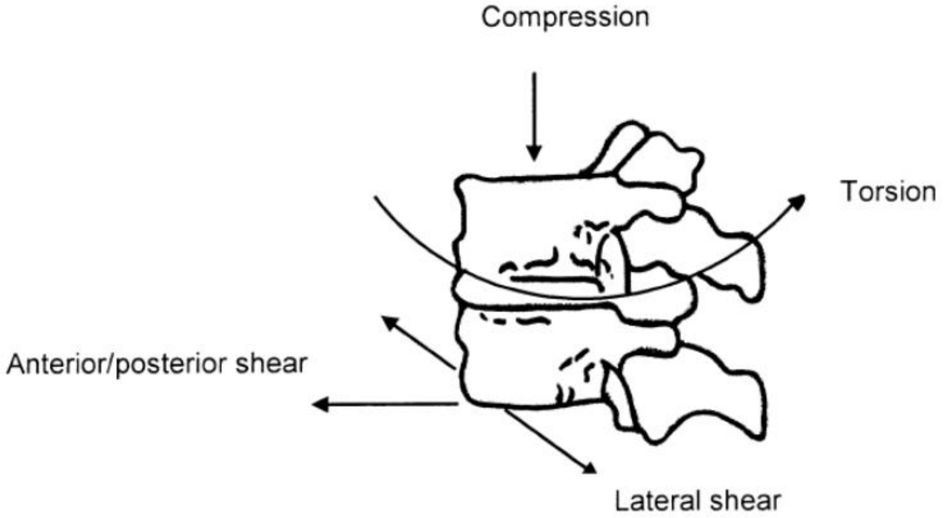


Figure 2: The three main loading components of the spine (Marras, 2000).

In order to realistically evaluate the spinal loading of all of these forces expected in the workplace, the internal forces (from muscles and connective tissues) and external forces (from the effects of gravity on the weight of the workers' HAT and the mass of any object lifted) would need to be assessed (Marras, 2000). Several approaches have been used to calculate the contributions of the loads.

SPINAL LOADING ASSESSMENT

As lower back injury and compensation are still so prevalent, a large amount of research has looked into assessing the loading of the spine (Mirka and Shin, 2006). These assessments aim to predict stresses imposed on the spine, in particular the lumbosacral joint in order to minimise the risk of lower back injury.

STATIC ASSESSMENTS

Originally, spinal loading was assessed using static assessment tools which predicted the loading on L_5/S_1. Some of the static assessments were; the Multiple Muscle System Models (Schultz and Andersson, 1981), NIOSH Lifting Guide (Waters *et al*., 1993) and the Static Strength Prediction Models. These assessments, however, do not take into consideration the dynamic nature of tasks, which has been shown as a factor for lower back injury risk (Marras *et al*., 2003) and the majority were therefore shown to under-predict the compression and shear forces (Granata and Marras, 1999). In many of the earlier static assessments, the co-contraction of muscles (which has been linked to an increased spinal loading) was not considered (Marras, 2005).

The NIOSH Lifting Guide, developed by the National Institute for Occupational Safety and Health (1981) is one of the most widely used assessment tools. Although first developed as an entire body assessment tool, it is commonly used to assess lower back risk (Marras *et al*., 1999). As the first model only took sagittal movements into account, a revised NIOSH equation was developed in 1991, which considered asymmetrical lifting in all three planes (Waters *et al*., 1993). This tool, however, has been largely criticised by Jager and Luttman (1999), who state that the threshold limits of 3400N and 6400N proposed by NIOSH are not biomechanically or epidemiologically validated.

Static Strength Prediction Programmes or Biomechanical models can be used to predict compression and shear forces on various joints in the spine (Mirka and Shin, 2006). As this model is performed using static imagery, it should be limited for assessment on heavy manual work involving slow movements, as it cannot reliably be used to assess highly repetitive tasks or extremely dynamic motions (Rodrick and Karwowski, 2006).

DYNAMIC ASSESSMENTS

Due to the limitations of the static models, Marras *et al*. (1993) developed a model based on trunk motion and Marras and Granata (1997) developed biologically assisted models. Biologically assisted models aim to include assessments which measure the co-contractions of muscles related to the dynamic nature of many MMH tasks, the most common of which use electromyography to directly measure muscle activity (Marras, 2000). Through this direct measurement, internal torques can be measured and therefore directly linked to spinal loading (Marras, 2006). The biologically assisted models, which used electromyography (EMG) to measure the muscle activity during a work bout, are deemed to be the most accurate assessment method (Marras and Granata, 1997). This is because these models predict the three-dimensional loading of the spine, as well as the spinal loading characteristics unique to each worker (Marras, 2006). Despite the highly accurate nature of these tools, a large amount of equipment and time is required in order to perform this assessment method.

The Low Back Disorder Risk Model designed by Marras *et al*. (1993), proposed that a combination of three spinal motion factors (measured with a Lumbar Motion Monitor) and two task characteristics may, more accurately, identify the potential risk exposure of repetitive MMH tasks. These factors are; maximum sagittal flexion, average twisting velocity, maximum lateral velocity, maximum moment and lift rate, and together they aid in differentiating between low and high risk tasks (Allread *et al*., 2000). Although the five factors individually cannot accurately determine tasks of high and low risk, an increase in one factor will increase the overall risk of lower back injury risk (Marras *et al*., 1993; Marras *et al*., 1995). Conversely then, it is important to note that a decrease in any single factor will reduce the overall risk of lower back morbidity (Marras *et al*., 1995). This Low Back Disorder Risk Model or Multivariate Model can be used in industry to assess individual tasks and identify tasks with high and low risks of lower back injury (Marras *et al*., 2003). Since its inception, this model has been validated by Marras *et al*., 2000) by comparing predictions of lower back disorder injury rates to actual lower back injury occurrences. Note must be made, however, that because this model was developed using data from repetitive jobs, its use is limited within these types of tasks and the validity of its use on non-repetitive tasks is therefore questionable (Mirka and Shin, 2006).

TASK DEMANDS

Task demands are defined in terms of material characteristics, environmental characteristics, task/workplace characteristics and organisational characteristics (Dempsey, 1998), see Figure 3. The workers' (biomechanical, physiological and psychophysical) responses to these demands in a work place will show the demands of the task on the worker.

MATERIAL CHARACTERISTICS

Material characteristics define the tools or work objects that workers manipulate, or use to manipulate the product in the workplace. Important factors to consider for these objects are; a) the *dimensions* (Dempsey, 1998), as larger objects will force the workers hands further away from the body, increasing the external moment and hence compression forces on the spine; b) *coupling* (Ayoub and Mital, 1989; Dempsey, 1998), as an object with poor coupling will require a greater amount of grip strength from the worker; c) *symmetry* (Dempsey, 1998), as asymmetrically shaped or weighted objects could cause an imbalance in muscle recruitment, increasing risk of injury and d) *mass*, as heavier objects would require a greater amount of strength and would increase forces on the spine, resulting in an increased chance of injury (Mital, 1997). The most important of these is said to be load/ mass (Mital, 1997) and this is the most researched due to the negative impacts of heavy loads on the musculoskeletal system. As the weight of the load increases, the stresses on the musculoskeletal and cardiovascular systems are increased, resulting in an earlier onset of fatigue and an increased perception of exertion.

In relation to palletising in the brick-manufacturing industry, brick dimensions are small and will not cause the hands to be far away from the body, however, coupling is not ideal, especially with the addition of safety gloves, therefore sufficient grip strength would be required to efficiently complete the task. The bricks are symmetrical and workers most often lift one brick in each hand, therefore the brick itself will not cause muscle imbalances. Finally the mass of bricks is between 2.4kg and 4.4kg and therefore should not add a significant load to the musculoskeletal system.

TASK/WORKPLACE CHARACTERISTICS

Task/workplace characteristics to consider include; height, displacement, frequency and duration, task asymmetry and working postures.

A very high or low *height* of either the starting point or end point of any lifting, lowering or moving task can result in an increased risk of injury. Greater heights will increase the risk of upper body areas (i.e. shoulders and arms) and lifting above shoulder level can result in circulatory inefficiencies (Hoozemans *et al*., 1998). Low heights will require greater sagittal flexion angles, increasing the injury risk of the lower back due to the high shear forces, caused by higher torque produced by the erector spinae muscles which are innervated to maintain balance. In IDCs, working conditions often require objects to be moved to or from pallets on the ground, which is why the stoop range according to Charteris and Scott, (1990) is 15cm-72cm; the average knuckle height of the South African worker. As the anthropometric characteristics are different in all areas and places of work, the heights would need to be assessed in conjunction with the stature of the sample population.

A large d*isplacement* of an object from the starting point to end point increases risk of injury if it requires the worker to stretch or reach while carrying a load. A small displacement area may lead to increased sagittal bending depending on the height of the areas. The horizontal distance of a load from the worker has been stated to be the most significant factor affecting lumbosacral compressive and shear forces (Sanders and McCormick, 1993). A greater displacement distance will increase the sagittal flexion of the worker causing an anterior shift in the centre of gravity which will offset the workers' balance. The resultant increased torque of the erector spinae muscles to maintain balance, will cause amplified shear forces on the spine (Knapik *et al*., 1996). The presence of obstructions in the workplace can increase this risk as it will require workers to stretch/ reach with a load to complete a task, therefore putting extra stress on their spine.

A highly repetitive f*requency* of movements and a longer *duration* of task performance will also increase the risk of injury to workers (which is exacerbated if there is a load). Frequency or lift rate has been described by Marras *et al*. (1995) as the most important factor to consider for physiological cost of activity. Heart rate and metabolic cost increases with a higher frequency, therefore decreasing time to onset of fatigue (Mital *et al*., 1994). Although Waters *et al*. (1993) stated that light loads should not be lifted more than 15 times per minute, this limit is impractical for South African tasks, as the lift rate is often above this due to the manual nature of tasks.

Task *asymmetry*, linked to lateral bending, handling an unevenly weighted object or handling an object in one hand (Drury *et al*., 1989), will move the centre of mass of an individual towards the perimeters or outside of the base of support. This will result in adopting awkward working postures, straining the musculoskeletal system, increasing injury risk (Drury *et al*., 1989) and increasing the energy expenditure needed to complete the task (Gallagher, 1991).

While executing a task, *working postures* that cause increased deviation of the body from the natural anatomical position will result in an increased risk of injury due to cardiovascular and musculoskeletal stresses (Ayoub and Mital *et al*., 1989). Awkward working postures are commonly seen in IDCs, due to badly designed, cramped work areas, often a result of limited finances, and these postures are often adopted for long durations in order to complete tasks. These types of postures will often increase the muscular effort required (in order to sustain them), which will increase the energy expenditure of the workers, resulting in a premature onset of fatigue (Gallagher, 1991).

In addition to measuring these demands externally, they can also be measured as the effect which they have on the worker, through spinal kinematics and physiological assessments. This will show the spinal movement adopted by workers and the physiological measures required in order to complete the tasks.

ORGANISATIONAL CHARACTERISTICS

According to Dempsey (1998) organisational characteristics consider; a) work-pace, a fast work pace can increase the chance of injury, whereas a slow workplace may cause workers to be less alert; b) autonomy will allow workers to rest when they need and will therefore reduce injury, it may also, however, reduce productivity if there is a poor work ethic; c) medical services onsite will allow workers to get frequent check-ups to avoid certain injuries and will provide quick treatment in the event of an injury to minimise the injury. Hendrick (1991) highlighted that an effective workplace design could have benefits, such as; improved productivity, safety, comfort, employee motivation and quality of work life. Therefore, assessing the needs of employees in addition to empirically assessing work place characteristics could result in a more productive workplace.

ENVIRONMENTAL CHARACTERISTICS

Environmental characteristics, such as; very high or very low temperatures, constant or sudden loud noises, dust, poor lighting and the presence of vibration will cause physical and psychological strain which can lead to a decline in productivity and performance (Parsons, 2000).

Heat stress is a particularly common factor to consider in IDCs, especially in conjunction with manual material handling tasks (O’Neill, 2000). A combination of heat stress and high humidity reduces the efficiency of sweat evaporation- the body’s most important thermoregulatory mechanism (Sanders and McCormick, 1993). Similarly it can be deduced that heat stress in addition to safety ‘overalls’ worn in many MMH industries will have the same cooling difficulties and will put workers at comparable risk. This thermoregulatory inefficiency will cause dehydration which can result in an increased physiological exertion and hence performance decrements (Sanders and McCormick, 1993). A 1% loss in body weight due to sweat responses can, decrease the physical capacity of the worker, increase the body discomfort and perceived exertion, leading to performance decreases. It is therefore imperative to have water sources near all work sites to ensure workers remain optimally hydrated. In a South African study by Strydom *et al*. (1965), it was shown that increasing external temperature did not influence oral/rectal temperature, but rather work rate was the determining factor for increases in internal temperature.

In order to define acceptable task demands relative to the worker capacity, an understanding of the workers' responses to the demands needs to be acquired. This can be done by assessing workers' biomechanics, physiology and psychophysical/ perceptual responses, as used in the systems approach. To fully understand the work systems, ergonomics aims to 'match' the worker to the task by ensuring the worker capabilities are suitable to fulfil the task that needs to be performed. A work task where the task demands exceed the capabilities of the worker will result in a mismatch, leading to fatigue or injury, whereas a task where the worker capacity can cope with the task demands will result in a match, allowing high quality, efficient performance (Dempsey, 1998), shown in Figure 3.

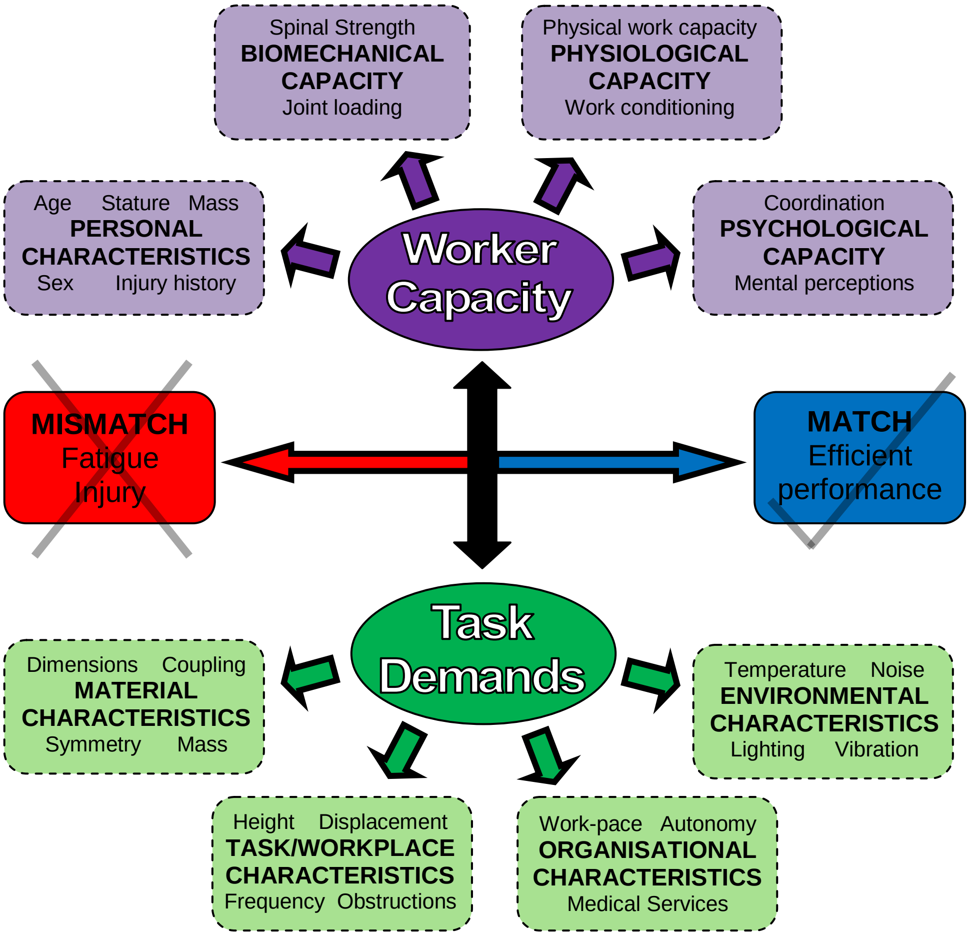


Figure 3: Graphical summary of the factors influencing the match or mismatch between the worker capacity and task demands (adapted from Dempsey, 1998).

WORKER CAPACITY

Worker capacity is defined by personal characteristics and biomechanical, physiological and psychological capacities (Dempsey, 1998) as seen in Figure 3. Personal characteristics include factors such as, sex, age, anthropometric and morphological characteristics, as well as, current and past health (Dempsey, 1998). According to Dempsey (1998), biomechanical characteristics refer to spinal strength and joint loading; physiological characteristics include physical work capacity and work conditioning while psychological characteristics encompass mental toughness and psychological perceptions.

Of the personal characteristics highlighted by Dempsey (1998), age and sex are important areas to consider, as these factors are non-modifiable and will have an impact on the other worker capacity factors. This can close individuals off to some work opportunities (International Labour Organization, 2009) as many jobs are only offered to certain workers based on their sex and/or age (with a preference for younger males)- this to ensure the safety of the workforce (Barnett *et al*., 2008). With laws of equality, however, all workers should have equal access to jobs based on merit or performance rather than characteristics which, alone, do not inform of the abilities of the workers (Ashworth *et al*., 2004). Sex differences in the workplace are a commonly researched area, largely due to the differences in capacity between males and females. Age is of particular importance in recent literature due to the current 'Aging workforce' trends in IACs. The impact of sex and age on worker capacity factors will be discussed further, in order to understand this bias toward certain worker profiles. In addition, comparisons between South African data (where available) and data from IACs will be presented.

SEX

Females tend to run a higher risk of work-related musculoskeletal disorders than males (Rollman and Lautenbacher, 2001). This could be due to a lowered worker capacity of females compared to males, resulting in an increased risk of injury. More specifically, females have been shown to have an increased prevalence for obesity (Goedecke *et al*., 2005) and hypertension, reduced strength and force producing capability (Nolte and Bredenkamp, 2008), lower physiological capacity (Lewis *et al*., 1986) and lower musculoskeletal pain tolerance (Rollman and Lautenbacher, 2001) than their male counterparts. Taking cognizance of the aforementioned and the high burden of disease in South Africa, health and anthropometric factors are important to consider. In addition to this, strength is a particularly relevant factor to consider in a MMH setting. These factors will therefore be discussed further.

HEALTH AND ANTHROPOMETRICS

Despite being the most easily avoidable of the quadruple burden of disease, non-communicable diseases are the greatest cause of deaths in both males and females in South Africa (Bradshaw *et al*., 2003). Cardiovascular disease alone is the second highest cause of disease in South Africa (Bradshaw *et al*., 2003). Risk factors of important consideration with regard to cardiovascular disease include; hypertension, smoking, diabetes, family history, obesity, hypercholesterolemia, physical activity and age (Centre for Health Services, 2004). As a result these must be important factors to consider when determining worker capacity.

OBESITY

Obesity occurs when there is inequity between energy intake and energy expenditure- in that extra energy is stored as fat in the body (Goedecke *et al*., 2005). Obesity has been described as a body mass index (BMI) > 30kg/m^2 (National Institutes of Health), a body fat percentage (BF%) of >25% for males and >30% for females while abdominal obesity is described as a waist to hip ratio (WHR) ≥ 1.00 for males and ≥ 0.85 for females (Dalton *et al*., 2003; SANHANES, 2013) or a waist circumference (WC) ≥ 102cm and ≥ 88cm for males and females respectively.

In South Africa, females were found to have greater mean BMI's and higher percentages of obesity as well as increased percentages of abdominal obesity (Puoane *et al*., 2002; Goedecke *et al*., 2005). In IACs, males have been found to have a lower body fat percentage (Sandberg and Ji, 2012) than premenopausal, age-matched females, but a higher percentage of the male population were found to be overweight or obese (Table I). Additionally, the mean values and prevalence toward obesity in males was higher in IACs compared to South African data. In contrast the mean BMI and percentage of the population with abdominal obesity of South African women were greater than females from the United States and Australia respectively,

Table I: Summary of sex comparisons of demographic findings in South Africa (South African National Health and Nutrition Examination Survey, 2013 and Puoane *et al*., 2002*), Australia (Dalton, *et al*., 2003) and the United States (NHANES 1999-2004*, 2003-2006** and 2007-2008).

	SOUTH AFRICA		AUSTRALIA		UNITED STATES	
	Male	Female	Males	Females	Males	Females
Mean BMI (kg.m^{-2})	23.5	28.9	-	-	28.4	28.4
%Population Overweight/ Obese (BMI ≥ 25)	31.2%	65.1%	67.5%	52.1%	72.3	64.1
Mean Waist Circumference (cm)	*81.8	*85.5	-	-	**100.8	**94.1
%Population with Abdominal Obesity	7.0%	47.4%	9.5%	21.8%	-	-
Mean % Body Fat	-	-	-	-	*28.1%	*39.8%

Abdominal Obesity is defined as a WHR ≥ 1.00 for males and ≥ 0.85 for females

HYPERTENSION

Hypertension, the most common factor for congestive heart failure (Haider *et al*., 2003), is classified as a systolic pressure of >140mmHg and a diastolic pressure of >90mmHg (Chobanian *et al*., 2003). Hypertension is also a risk factor for strokes and coronary heart disease, making it an important factor to consider for risk of overall cardiovascular diseases (Shisana *et al*., 2013).

STRENGTH

Muscular strength is arguably the single most important biomechanical factor in determining the ability of a worker to perform any manual materials handling task.

Strength is the maximum ability of the muscles to overcome an external force; therefore, the capabilities of a combination of various muscles will predict the ability of the worker to perform common manual materials handling tasks.

In South Africa, a study performed on military personnel showed that overall, females were capable of 60% of the force production of men (Nolte and Bredenkamp, 2008). In upper body strength percentages: handgrip of females strength was 50% of males, whereas the trolley push and pull (whole body movements) were higher at 70-80% (Notle and Bredenkamp, 2008). Nolte and Bredenkamp (2008) also state that these strength values differ to available international strength data.

The greater strength of males could be a result of larger muscle fibres (Miller *et al*., 2002) or due to bone changes associated with gender differences (Mosekilde, 2000). The link between muscular strength and bone mass have been clearly established (Hughes *et al*., 1999); an increase or decrease in one will result in the same change in the other. Mosekilde (2000) looked into the impact of ‘gender’ in the aging process and found three main differences. First, men between the ages of 20 and 30 have a 20-30% higher peak bone mass and strength than women. Second, men show an age-related compensatory increase in bone size (cross-sectional area of vertebral bodies) that cannot be found in women and in addition to this, women with osteoporosis have small vertebral bodies and low load-bearing capacity. Lastly, after the age of 50, women show higher tendency for disconnection of trabecular struts than men, which would lead to more pronounced deterioration of the network and therefore increased loss of strength. Osteophytes are found in 60% of women and 80% of men older than 50, which could cause greater risk of injury at this age (Mosekilde, 2000). This shows that men of all ages are stronger than females and would have a distinct advantage when performing physical work tasks.

AGE

Worker capacity factors have been shown to decline with aging (Doherty, 2001; Kenny *et al*., 2008; Metter *et al*., 2008). This is important to consider as IACs have recently shown a trend toward a rapidly aging workforce (Kenny *et al*., 2008). Despite the decline in worker capacity with age, the task demands have not decreased, therefore increasing the workers’ risk of injury.

Research has shown that aging has a negative impact on several worker capacity factors, including decreasing strength capabilities and increasing prevalence of obesity (Ogden *et al*., 2006; Wang and Beydoun, 2007), hypertension (Joffres *et al*., 2013; Nwankwob *et al*., 2013) and disease.

HEALTH AND ANTHROPOMETRICS

Age is a risk factor for cardiovascular disease, as there is an increased prevalence for cardiovascular disease in the aging process (Centre for Health Services, 2004). Due to this, the presence of any additional risk factors will greatly increase the probability of cardiovascular disease development. Therefore, increasing the understanding of cardiovascular factors which are seen with aging is important in any worker capacity research.

OBESITY

Obesity has been found to have a link to many other clinical problems, such as osteoarthritis and coronary heart disease (Goedecke *et al*., 2005; Ryan, 2011). The problems associated with obesity have been characterised according to those which are linked to excess fat mass (adipose tissue) and those which are linked to the metabolic effects of this increased adipose tissue (Goedecke *et al*., 2005). Osteoarthritis, sleep apnoea and psychological problems are examples of diseases associated with excess adiposity, whereas coronary heart disease (CHD), hypertension, type 2 diabetes mellitus and some types of cancer are examples of diseases linked to the metabolic effects associated with excess adipose tissue (Goedecke *et al*., 2005). These diseases can affect the workers mental and physical strength and may therefore have an impact on their abilities to efficiently perform the tasks required of them.

Goedecke *et al*. (2005) show that in South African males, BMI increases from age groups 15-29 (BMI = 21.5 $kg.m^{-2}$) to 30-44 (BMI = 24.2 $kg.m^{-2}$) and is the greatest between the ages 45-59 (BMI= 25.3 $kg.m^{-2}$), thereafter decreasing from 60 years of age (BMI = 24.8 $kg.m^{-2}$). Puoane *et al*. (2002) also studied South African males, showing similar increases in BMI from 20.7 between ages of 15-24, to 24.6 between the ages of 45-54, and demonstrating a slight decrease to 24.4 when over 55 years of age. In addition to BMI, Puoane *et al*. (2002) examined WHR in South African males, showing an increase with age, 0.82 at ages 15-24, 0.91 at 45-54 and 55-64 and peaking at 0.93 at 65-95. Data from Flegal, *et al*. (2001) showed that in the United States 27.5% of men aged 20-39 were obese. This increased to 34.3% in men aged 40-59 and 37.1% in men 60 and older (Flegal, *et al.*, 2001).

HYPERTENSION

In older males, systolic blood pressure has been more strongly associated with coronary heart disease than diastolic blood pressure, but all blood pressure readings in ‘high’ and ‘high-normal’ categories are signs of risk.

Data from Statistics South Africa (2013) shows that the prevalence of hypertension increases with age, demonstrating an increased prevalence of 1.5% in people aged 25-34 to 32.2% in people aged 55-64. This general trend of increasing hypertension was also seen in England, Canada and the USA (Joffres *et al*., 2013).

STRENGTH

Age-related strength declines have been linked to sarcopenia - a decline in skeletal muscle mass with aging - which is accompanied by a reduction in bone mineral density and a deterioration of bone architecture (Kenny *et al*., 2008). Additional factors which may contribute to dynapenia (decline in strength with aging) are; muscle composition changes, a decrease in the efficiency of neurogenic motor control, a decline in the number of active motor units making up the skeletal muscle, changes in the metabolic activity of the muscles, increases in amounts of connective tissue and intramuscular fat as well as changes in the contractile abilities of the muscle (Knapik *et al*., 1996; Doherty, 2001; Kenny *et al*., 2008).

Most research looking at strength changes with aging, shows a steady decline in strength with age between 20 and 35 (Shock and Norris, 1970; Kallman *et al*., 1990; Metter *et al*., 1997; Voorbil and Steenbekkers, 2001; Yian *et al*., 2005; Kenny *et al*., 2008), some research however, only shows declines after a certain age, for example 40 (Teimoori *et al*., 2009; Werle *et al*., 2009) and 50 (Voorbil and Steenbekkers, 2001; Marcell *et al*., 2003). Kenny *et al*. (2008) reported an average strength decline of 12-15% per decade after the age of 50, with a more rapid decline after 60-65 years of age.

Research has shown, however, that the strength declines with aging may be delayed if strength training is maintained (Laforest *et al*., 1990; Ivey *et al*., 2000a; Ivey *et al*., 2000b; Kenny *et al*., 2008). Therefore if workers are performing manual materials handling tasks that require muscle loading on a daily basis, then the same declines in strength may not be present.

In addition to these factors, worker characteristics can be affected by weight loss or gain in stressed or low income individuals (Ayoub and Mital, 1989), or individuals who start smoking due to stress or anxiety. Physiological capacity can be impacted by reduced conditioning, and decreased ability to perform physical work, from injury or disease (Bernard *et al*., 1997). Biomechanically, joint and spinal strength can be reduced from malnutrition for example. A reduction in any of these will reduce the overall worker capabilities, which will then cause an imbalance with the task demands potentially being too great for the worker capability, resulting in either less efficient work or injury to the worker (Kenny *et al*., 2008).

STRENGTH

As MMH tasks often involve manipulation of heavy objects, muscular strength is arguably the most important worker capacity factor determining the ability to perform manual tasks. Strength is the maximum ability of muscles to overcome external forces. Therefore, the ability of workers to cope with MMH tasks (e.g. lifting, lowering and carrying) is determined by muscle strength from the hands, arms, shoulders, back and legs.

Strength is multifaceted, with physiological determinants, including; the cross-sectional size of the muscle area, the location of the muscle in relation to the skeletal levers, the ratio of fast-twitch to slow-twitch muscle fibres, innervation of muscles and the overall aerobic capacity of the body (Kenny *et al*., 2008). Strength is also affected by factors such as race; for example, Wagner and Heyward (2000) found that Black individuals in IACs have an increased inclination to mesomorphy and a related increase in strength production. This may not be the case in IDCs, however. This is likely to be due to the high prevalence of malnutrition which has been linked to inhibited muscle development, resulting in potentially weaker individuals than their first world country counterparts. An additional contradicting factor to be taken into account with IDC manual workers is that most manual workers in IDCs are from rural areas; these workers tend to be more physically active and have increased work conditioning compared to workers from urban areas. As no studies have recently been done to determine the strength profile of South African workers, it is unknown whether the muscle loss from malnutrition or strength gains from work conditioning will have a greater impact.

Muscular work can be both static (muscles contracting at a constant force over an extended period of time, resulting in the length of the muscle remaining constant) and dynamic - muscles contacting concentrically and/or eccentrically, hence changing the muscle length (Knapik *et al*., 1983). Static muscular work can be high risk due to the compression of blood vessels, decreased oxygen delivery, reduced strength abilities and increased strain and discomfort (Mital *et al*., 1997). Optimal work performance depends not only on muscular strength, but also the hardiness of surrounding tissue structures to withstand forces imposed on the body. When blood supply to the ligaments, tendons and surrounding areas of articular cartilage is limited, these structures weaken, resulting in a decreased ability to safely perform manual work. Due to the dynamic nature of concentric and eccentric strength forces in the work place, these actions are favourable when compared to isotonic contractions. One of the downsides to dynamic MMH tasks is the restricted working space, causing workers to adopt awkward working postures. In addition to this, a lower strength capability could also force workers to assume alternate working postures in order to handle the task demands.

Static strength is often criticised as a method of strength measurement in industry, because the majority of tasks in MMH industries in South Africa are dynamic, and should require a dynamic strength assessment methods (Dempsey, 1998; O'Neill, 2000). Ayoub (1992) and Dempsey (1998), stated that static assessment models underestimate stresses associated with dynamic tasks. Equipment measuring dynamic strength is often large and impractical to use in a study in the field, in addition to this, there is a lack of systematic dynamic strength data with which to compare task acceptablility (Dempsey, 2007). Both static and dynamic methods, however, can be used to assess the functional capacity of a muscle group (Knapik, *et al*., 1983). Muscular fatigue is likely during an eight-hour MMH work shift, as a constant stimulation will result in weakened muscle contractions. Added to this, the removal of waste products from, and supply of oxygen to muscles by the cardiovascular system becomes less efficient.

INDUSTRIALLY ADVANCED AND DEVELOPING COUNTRIES

'Industrially Developing Countries' is a blanket term which describes many different countries with wide arrays of cultures, various levels of infrastructure and differing availability of resources (O'Neill, 2000). For example, an IDC may have a high availability of resources, but lack the industry needed to make full use of them, or conversely may have very limited resources available which are needed for the populations' own use (Scott, 2008). A common thread which can be used to characterise IDCs is the high population growth of the country, which in the majority of circumstances is too great to be supported by the infrastructure, thereby aggravating the already high unemployment rates (O'Neill, 2000).

In comparison, IACs have advanced industry and service sectors as they have access to many resources and the sectors have technology which is far superior to those of IDCs (Scott, 2008). In addition to this, people in IACs work in order to obtain social identification rather than for subsistence (O'Neill, 2000). Ergonomics in IDCs was implemented much later than in IACs, therefore, ergonomics is still relatively new and is found in formative stages or not at all in many IDCs (Shahnavaz, 1996). This is problematic as workers from IDCs make up 75% of the World's working population (O'Neill, 2000) and the work in these countries is often degrading and inhumane and would benefit the most from ergonomic interventions (Shahnavaz, 1996).

South Africa is classified as an IDC due to the inadequacy of the infrastructure and job availability to support the rapidly growing population, but is a relatively advanced IDC due to the presence of organised industry (O'Neill, 2005). Some of the more advanced IDCs (such as South Africa) have started implementing ergonomics into their workplaces (O'Neill, 2005), but due to the lack of finances of the country, the equipment purchased is often second-hand and therefore, outdated and not designed for the worker populations. Although the ergonomic principles required for IDCs and IACs are essentially the same, the interventions needed for IDCs would need extra work and a different starting point to those of IACs (Scott, 2008). This is due to: the lack of a stable infrastructure in IDCs within which the ergonomists can work, the different cultural dimensions which need to be dealt with and finally to determine inexpensive improvements which can be made for those people who can afford it (O'Neill, 2000).

In order to reduce poverty and increase quality of life, people need to draw upon their 'livelihood assets' as described by O'Neill (2000). These assets are described in Table II.

Table II: The elements making up the 'Livelihood Assets'.

HUMAN	NATURAL	PHYSICAL	SOCIAL	FINANCIAL
Skills	Land	Buildings	Networks	Savings
Knowledge	Water	Machinery	Relationships	Credit
Strength/ Health	Biodiversity	Infrastructure	Affiliations	Remittances

In order for an intervention to be successful in reducing poverty, it needs to take all of these assets into account and increase the overall sum total of the assets (O'Neill, 2000). This is a big challenge for the South African ergonomist, as they would need to understand not only the workplace, but also the background to the workers and their lifestyles.

SOUTH AFRICAN CONTEXT

South Africa falls on the higher end of the IDC scale (O'Neill, 2005). There are sufficient resources to allow sustainability within the country as well as having additional resources which can be used for export- indicating a need for industry in the country in order to improve economic development.

WHY SOUTH AFRICA IS UNIQUE

ECONOMIC CYCLE OF DISEASE

In South Africa, the economic development is hindered by a group of factors, which fit together to make up the 'economic cycle of diseases' (O'Neill, 2000). The factors which make up the cycle, as described in O'Neill (2000), are; a) poor food, housing and education, b) poor health, c) a low working capacity d) low productivity at work and e) a low income, which link together as seen in Figure 4. Therefore, if workers earn a low income, they will have less money to spend on food, housing (resulting in poor health) and education (resulting in a decreased likelihood of a good job). Poor health, exacerbated by the burden of disease in South Africa will lower the worker capacity, which means a lower productivity at work, resulting in a low income.

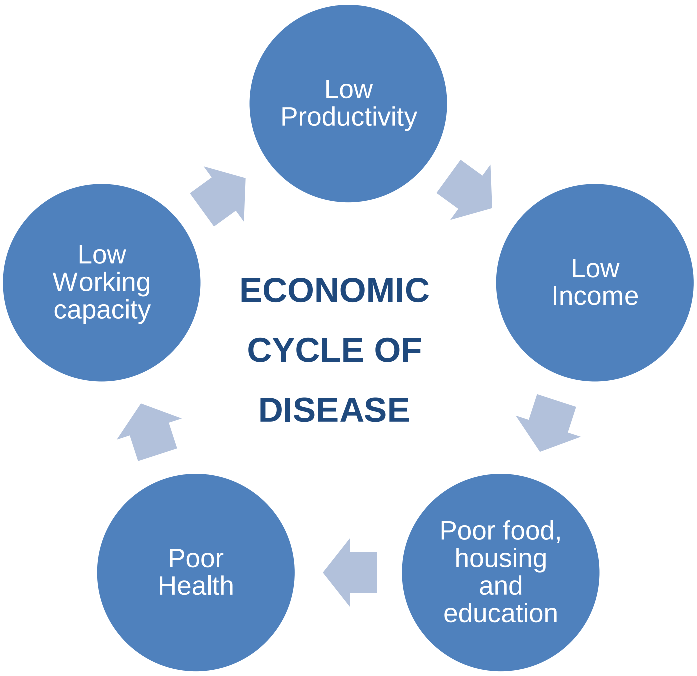


Figure 4: The economic cycle of disease (adapted from O'Neill, 2000)

In order to break this cycle (Figure 4), at least one of the factors needs to be changed. This may be achieved by an ergonomic intervention. For example, if an ergonomist can implement a change in the workstation that lowers the energy required to complete the job, then the worker could increase the productivity (even with a lower working capacity), thus facilitating the potential enablement of higher income, which in turn could increase the quality of food, housing and education for the worker, as well as the health of the worker. All of which is likely to result in an increased and improved worker capacity - i.e. effecting a positive spin of the cycle. Therefore if a company was willing to invest in proper ergonomic assessments and interventions, then the company should be able to increase not only the productivity of the workplace, but also improve the health, safety and lifestyle of the workers.

QUADRUPLE BURDEN OF DISEASE

Globally, both IACs and IDCs are affected by the double burden of disease, namely, communicable and non-communicable disease (Boutayeb, 2006). The burden of disease is considerably higher in South Africa due to the quadruple burden of disease, which involves; communicable diseases (including maternal and perinatal conditions and nutritional deficiencies), non-communicable diseases, human immunodeficiency virus (HIV) and Injury (Econex, 2009). Although HIV/AIDS is a communicable disease, its impact is so profound that it has been considered by the South African National Burden of Disease (SA NBD) as a separate group (Econex, 2009).

Non-communicable disease accounts for the majority of the deaths (40.8%) (Econex, 2009) (Figure 5) and were responsible for the deaths of 92 418 males and 98 100 females in South Africa in 2008 (WHO, 2013). Obesity has originally been thought to be a disease more often associated with developed countries (such as United States), with 26.6% and 32.2% of males and females over 20 years, respectively, being overweight or obese (Goedecke, et al, 2005). In developing countries (such as South Africa), however, it is becoming an increasingly concerning issue. A study done in South Africa in 2002 showed that 29% of males and 56% of females had a BMI of greater than 25kg/m^2 (Puoane *et al*., 2002).

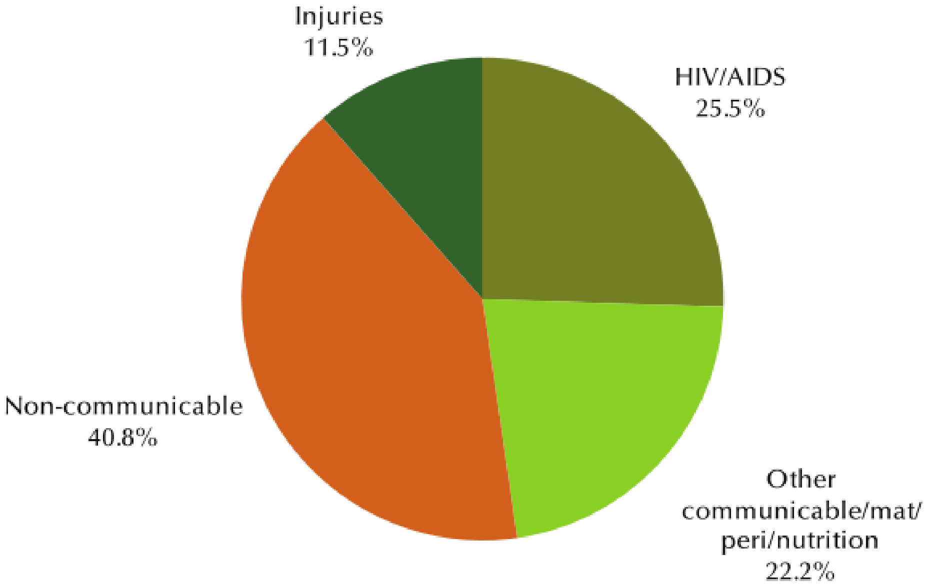


Figure 5: The estimated deaths of the four groups making up the Quadruple burden of disease (Bradshaw *et al.*, 2006, as cited in NHI Note 2, 2009).

In 2000, communicable disease accounted for 22.2% of the overall deaths in South Africa (Econex, 2009) (Figure 5). One of these diseases, Tuberculosis, was the number one cause of death in 2010 (Statistics South Africa, 2012) (Figure 6), with 323 664 deaths recorded in 2012 (WHO, 2013).

Injuries accounted for 11.5% of the premature deaths in South Africa (Econex, 2009). Non-natural deaths, from accidents and injuries, are the highest in individuals between the ages of 20 and 40 years (Statistics South Africa, 2013) (Figure 6). In South Africa, between 2000 and 2004, 43% of non-natural deaths were violence-related (National Injury and Mortality Surveillance System, 2001-2005). These are more common in Males, with 6.5 violence related male deaths to every 1 violence related female death (NIMSS, 2007).

HIV and AIDS accounted for 25.5% of premature deaths in South Africa in 2000 (Econex, 2009) (Figure 5). South Africa has been said to be the most affected country by the HIV/ AIDS epidemic, with an estimated total of 4.2 million people in the country living with HIV or AIDS (Dorrington *et al*., 2001; UNAIDS, 2008).

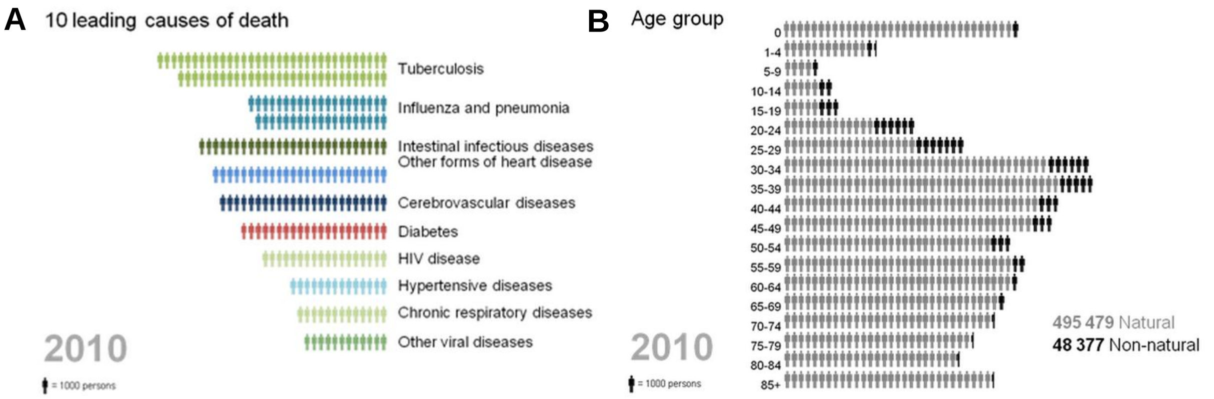


Figure 6: A) The 10 leading causes of death in South Africa in 2010, B) The proportional natural and non-natural deaths per age group in South Africa in 2010 (Statistics South Africa, 2013).

HIV is a virus that leads to acquired immunodeficiency syndrome (AIDS) which weakens the immune system. This allows infections and cancers to more easily affect the individuals, resulting in weakness which if not treated can very quickly lead to death (UNAIDS, 2008). This disease was the seventh highest cause of disease in 2010 (Statistics SA, 2012) (Figure 6), with 270 000 deaths in 2011 and an additional 5.1 million Adults and 460 thousand children infected with the disease (WHO, 2013). A study performed in 1996, showed that HIV infected patients had significantly lowered physical health, general health, vitality, social functioning and mental health, as well as lessened physical and mental roles in their lives (O’Keefe and Wood, 1996). This, in addition to AIDs wasting syndrome and muscle deconditioning, therefore suggests that

HIV and AIDS-affected workers will have a largely affected worker capacity, with a lowered psychological and biomechanical capacity, and would not be as efficient as a healthy worker (Mars, 2000). This study also showed that there is little effect of race in these results (O'Keefe and Wood, 1996). With the only differences being shown, that HIV infected Black women scored significantly lower on all scales except physical function, and HIV infected males and females of mixed races reported to have a decreased physical function (O'Keefe and Wood, 1996). Therefore, regardless of race, HIV will cause lower physical function, resulting in a decrease in the capacity of the worker, leading to a decreased productivity, as shown by Mars (2000). Workers with HIV will therefore not be able to perform tasks to the same degree as healthy individuals and could cost the company in terms of reduced productivity and absenteeism.

The majority of AIDS-related deaths occur in individuals between the ages of 25 and 40 years, therefore AIDS reduces the life expectancy and the rate of population growth, and will also increase the stress on the working population, who need to care for those who cannot care for themselves (Arndt and Lewis, 2000). AIDS is an epidemic in South Africa which affects many aspects of the country, for example, the epidemic has shown to slow population growth, causing a disparity in the growth of the supply of individuals fit to perform labour (Arndt and Lewis, 2000). The high incidence of HIV/AIDS in the manual working population could result in lower productivity ratesin labour intensive tasks (due to the lower immune systems of individuals resulting in a decreased performance and energy level) (Arndt and Lewis, 2000). Ergonomists would therefore need to assess what can be done to ensure that people with this virus are able to still work (in order to earn money for living costs), without negatively impacting on the productivity of the company (Arndt and Lewis, 2000). Employers are often hesitant to employ people affected by this disease as they are concerned about the impact which the disease may have on the operation of their companies (Colvin *et al*., 2007). This is due to decreased productivity, increased production costs and higher employee turnover related to HIV mortality and morbidity (Colvin *et al*., 2007). With antiretrovirals (ARVs), however, the absenteeism of affected workers can be reduced and general health of these workers can increase, resulting in a healthy and productive workforce (Habyarimana *et al*., 2010). Although ARVs are free in South Africa, people in rural areas still struggle to access the medication or people are not seeking treatment as they do not feel ill, resulting in either not starting treatment or not consistently taking the medication. This means that the CD4 count of these people will lower more quickly

One of the biggest challenges in South Africa is the high percentage of people who are affected by the quadruple burden of disease (Bradshaw *et al*., 2003; Dorrington *et al.*, 2001). This is problematic as the number of able-bodied individuals is diminishing, while the population continues to increase (Dorrington *et al.*, 2001). This therefore leaves fewer individuals to fulfil the increasing demand for resources for the steadily growing population (Van der Berg *et al*., 2007). A new measure of burden of disease, disability-adjusted life-years (DALYs), is an incident-based representation of the health status of the population in comparison to a pre-determined norm (Econex, 2009). Considering the DALYs in South Africa, the burden of disease is approximately 4 times greater (46.2%) when compared to developed countries (between 10.1% and 12.8%). This burden of disease will in turn create a greater burden on the finances, facilities and human resources in the country, compared to that of other countries (Econex, 2009).

CULTURAL DIVERSITY

South Africa has been described as having four main racial categories; White, Black/African, Coloured and Indian/Asian (Henrard, 2002). The following descriptions are offered for the various racial groups; the black group is categorised by individuals descending from Africa, whose skin is of a darker complexion. The white group contains individuals with a pale complexion who are descendants of European countries. The coloured group is one of mixed race, with a combination of ethnic backgrounds and the Asian/ Indian group are descendants from Asia and India (Henrard, 2002).

In addition to the many racial groups, South Africa has a plethora of cultures (Goedecke *et al*., 2005), which provides a challenge for ergonomists. ‘Fitting the job to the culture’ was described by Kaplan (1995) to be more important that fitting ‘the job to the man’ and he states that technology can only be usefully transferred if it fits the culture which it is moving to. The ergonomics intervention implemented in South Africa would need to be ‘participatory ergonomics’ as contended by Zalk (2001). This entails allowing employees, who generally know the workplace better than the management, to design the workplace and plan their own activities (Zalk, 2001). This will also lead to an increase in worker empowerment, allowing workers to feel more pride in their work, resulting in better performance (Zalk, 2001). Gurr *et al*. (1998) states that ergonomists' recommendations could be detrimental to both the health and the performance of individuals if the recommendations do not consider specific cultures. Therefore, in areas of South Africa which can afford ergonomic implementations, any machinery or tools that are bought would need to be tested to determine if they suit the culture of people who will be working with them (which would result in a greater cost of ergonomic implementation) (O'Neill, 2000). Often in IDCs, when machinery is bought to improve working efficiency, it is bought second-hand from IACs which have managed to implement more ergonomically designed machinery (James, 1975). This machinery would need more labour to function, and would generally produce a lower quality product than new machinery (James, 1975). New machinery will also be more efficient in covering its own costs than second-hand machinery, as transport costs would be the same, but the years of use that a company can get from a second hand machine are fewer, the machine is slower (therefore not optimizing productivity) and often produces a product of a lower quality (James, 1975). Therefore, even when South Africa is able to afford certain ergonomic interventions, it is generally already outdated, and would not be designed specifically for the country (compared to its purpose in an IAC which could afford to buy new ergonomically designed machinery).

Furthermore due to the apartheid period in South Africa, the majority of the workforce today consists of uneducated and unskilled workers (Van der Berg *et al*., 2007). This means that these workers are often limited to jobs that require minimal skill and are generally very labour-intensive and not well paid (Carter and May, 1999). This means that workers have very little money to support their families and to provide enough nutritional food to sustain themselves in their energy intensive jobs. As Carter and May (1999) state; as a result of apartheid, significant numbers of poor individuals in South Africa are stuck in 'chronic, structural poverty' and they lack the resources which are necessary in order to break away from this poverty.

These factors add a complex spin to the already suffering infrastructure and economy in South Africa, making South Africa a unique IDC, which cannot be likened to any other country. This provides more reason why there is a need for a specific understanding of the South African worker capacity.

SOUTH AFRICAN LABOUR FORCE

When considering the South African labour force, the jobs performed can be separated into 3 broad categories, namely; agriculture (including hunting and forestry), industry (mining and quarrying, as well as manufacturing), and finally services (electricity, construction, trade, transport, finance, and community and social services) (Bollinger and Stover, 1999). Industry had the second highest percentage of workers in the South African labour force in 1995 with 19.7%. In 2010, the manufacturing industry in South Africa contributed the second highest annual GDP, with 15.4% (Figure 7). Despite the movement towards a more mechanised/automated industry in South Africa, manual work is still common, especially in the more rural areas).

The small percentage of people in the agricultural sector is unique to South Africa as an African country. However, in the formal sector approximately 52% of people aged between 16 and 30 were employed, and approximately half of these are classified as having minimal chance of becoming employed due to lack of education (Bollinger and Stover, 1999). Thirteen percent of the South African population is said to be financially stable, whereas 53% are said to be very poor. Of this ‘very poor’ group, only 50% have a basic primary school education, more than 33% of the children in this group are malnourished, and only 20% of the people in this group have running water and electricity (Bollinger and Stover, 1999).

CASE STUDIES

A few examples of ergonomics interventions that have been successfully implemented in South Africa or industries which are in desperate need of an ergonomic intervention include;

The forestry industry; Ergotech (an ergonomics company in South Africa) improved the safety and productivity in the South African forestry industry by improving the leg protectors used for tree debranching (which reduced the number of injuries by 100%, as well as achieving an annual saving of $250 000 US dollars) (Scott *et al.*, 1998). The seating and visibility of the tractor-trailers were also improved, saving $2000 per unit (with each unit costing $300) in accidents, and increasing the extraction of the load of each unit to save $6 900 US dollars annually (Scott *et al.*, 1998). Other cost-saving interventions included: redesigning the three-wheeled hydrostatic loaders, classifying different terrain levels and analysing which tree harvesting system would be the most efficient for each terrain and finally, designing check lists and surveys designed to improve the ergonomics of the forestry industry in South Africa (Scott *et al.*, 1998).

Mining is one of the biggest industries in South Africa, and this type of work often does not adhere to ergonomic guidelines (especially in IDCs), resulting in many injuries and a low performance level (Donoghue, 2004). Work in mines involves a high amount of thermal stress on the workers from the high temperatures of rocks, often causing heat stroke which is difficult to deal with in the mines, (Wyndham *et al*., 1967), as well as, very little ventilation, due to work underground (O’Neill, 2000; Donoghue, 2004). The most common causes of fatal injuries in mines are; rock falls, fires, explosions, mobile equipment accidents, falls from a height, entrapment and electrocution (Donoghue, 2004). So these are obviously the aspects that need the most attention when it comes to ergonomic interventions. There are, however, many other factors which contribute to harm and injury of workers, such as 1) noise (from drilling, ventilation, crushing etc.) which makes noise induced hearing loss common amongst miners, 2) drilling, may result in hand-arm vibration syndrome, 3) overhead work (during setting up of ground support for example) (McPhee, 2004). Workers are often required to lift heavy loads (lifting buckets of rocks/ stones when clearing out the mines for example), this added to a bent-over posture (which is required in the smaller areas of the mines) will result in a work-related musculoskeletal disorder (WMSD) if continued for an extended period of time (McPhee, 2004). Therefore an ergonomic intervention is necessary to reduce the load lifted, or the posture, without decreasing the performance of the workers. These are only the tip of the iceberg of problems related to mining; there is an endless list of hazards and areas in dire need of ergonomic interventions. Mines are operational for 24 hours per day, 7 days a week, and therefore workers are often exposed to shift work, requiring 12 hour shifts, often leaving workers sleep deprived and unable to work to their full potential (Donoghue, 2000).

Another large industry which is important in South Africa, and where there is a great need for ergonomic interventions, is agriculture/ farming (especially sugar cane in Kwa-Zulu Natal), where workers are employed to harvest crops, and generally need to carry heavy buckets or crates of the product to loading vehicles (Robins *et al*., 1998). Sugar cane harvesting is a significant problem due to the steep gradients of the farmland making it inaccessible to machines to harvest. Therefore workers are required to cut the sugar cane down (mainly done by men), collect it and carry it to loading vehicles (mainly done by women) (Robins *et al*., 1998). This repetition of high load or force exposure can be very damaging, creating a huge gap for ergonomists to intervene.

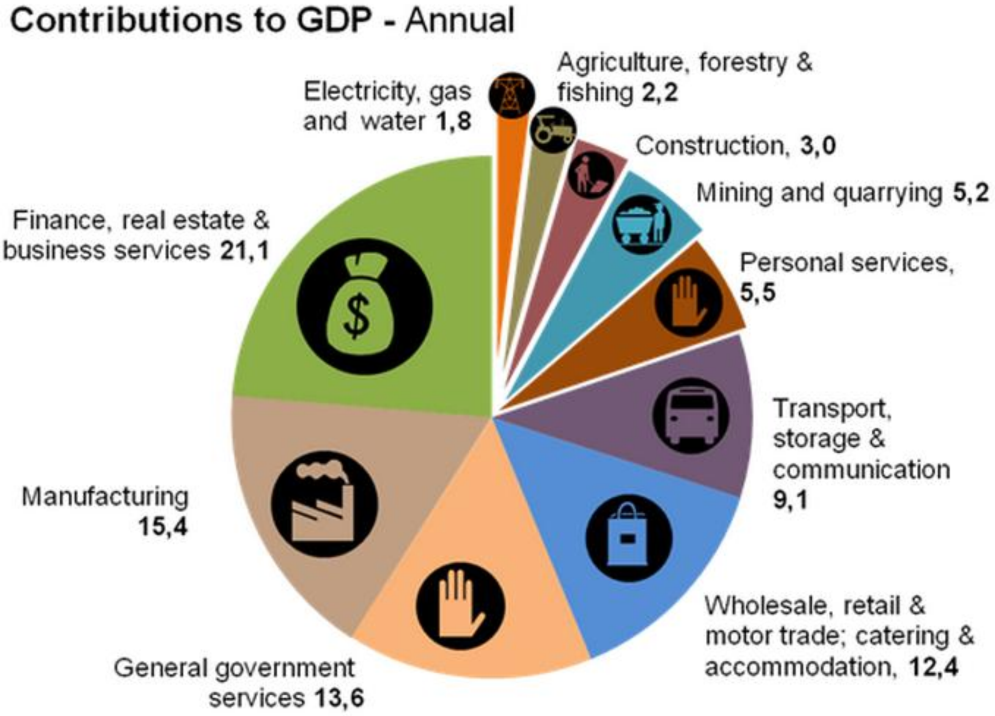


Figure 7: The annual gross domestic profit (GDP) contributions of various South African sectors in 2010 (Statistica South Africa, 2010).

In 2011, the Eastern Cape had the third highest population sample in South Africa, with approximately 6.657 million (13.22% of the total population) (StatsSA, 2011). Despite this, there were only 1.82 million housholds in this province in the same year showing the high level of poverty in this area.

CHAPTER III

METHODOLOGY

INTRODUCTION

A common debate amongst ergonomists around the world is that of the advantages and disadvantages of performing laboratory and field based investigations (Scott and Christie, 2004). Although the controlled laboratory environment allows for more accurate data collection in terms of the worker-to-task compatibility (Renz and Scott, 2004; Scott and Christie, 2004; James and Scott, 2006), the applicability of the results in this controlled environment to real work situations is questionable. This is often due to the considerable impact which the extraneous variables found in the workplace will have on results (Renz and Scott, 2004). Field investigations on the other hand are criticized, as the *in situ* environment is volatile and results obtained in this environment are often more variable as there are a multitude of factors which could be of influence (James and Scott, 2006). Studies assessing the match-up between worker capacity and task demands should preferably be done in the field, as the extraneous variables have a substantial impact on the task demands. If this is not taken into account, the task demands could be underestimated, thereby bringing the reliability of the research into question. In addition to this, in order to assess the worker characteristics, the workers performing the tasks also need to be assessed. Furthermore a consideration for this particular study was the fact that it is difficult to realistically simulate the various conveyor systems used for palletising the bricks in the laboratory. Field-based research would achieve the most applicable data from the task and together with a laboratory-type set up on site, would allow for accurate worker capacity assessment.

FIELD OBSERVATIONS AND PILOT STUDIES

In order to complete this research, field observations were done at a brick manufacturer in the Eastern Cape Province, South Africa. Black African male and female workers above the age of 20 with no recent injuries (not within 6 months) were approached to participate. From observations and reviewed literature, a two-Part research design was developed. This allowed for worker capacity factors, the effect of sex and age on this capacity (Part I), as well as, task demands, of three tasks (both manual and more mechanised) (Part II) to be assessed. These results were then assessed statistically.

Field observations and pilot studies were performed in order to determine whether the experimental procedures were appropriate, as well as to perform data collection test-runs. This aided in understanding the logistics of the methodological procedures and the functioning of equipment and ensured the smooth running of the testing protocol. Field observations were performed on site at the brick manufacturing industry in the Eastern Cape, South Africa. These observations facilitated the understanding of various muscles used in the field, so the strength of these could be measured in Part I. After tasks were observed and literature and workers had been consulted, a list of muscle groups that were affected in the tasks was compiled. A portable strength test battery was then developed with the aid of pilot studies, to ensure the validity of the tests in measuring the desired muscle forces. The observations and pilot studies will be discussed in more detail.

INDUSTRY OBSERVATIONS

Observations were done prior to testing in order to formulate the best possible methodology for this study. Within the manufacturing sector, which has the highest number of MMH employees in South Africa (Statistics South Africa, 2011b), a brick making operation in the Eastern Cape was selected to be tested. This particular operation has two main sections; 1) an older manual clay operation and 2) a more mechanised tunnel kiln operation. The manual operation involves mechanised mixing of clay and cutting of wet bricks, but is completely manual after this. The wet bricks are manually moved, by 12 workers, off a conveyor belt onto pallets (palletisation of the Clay Wet Brick task) which are placed outside until they contain a minimal amount of moisture (the brick moisture is measured on-site daily as drying time will vary according to the climatic conditions). These bricks are then manually stacked (by a group of ‘baser and caser’ workers) into a man-made kiln and baked in a carbon fire for approximately 18 days. Once cooled, these bricks are manually sorted back into pallets (palletisation of the Clay Dry Brick task) by a team of 24 male and female workers. There has been an increase in plant automation in this industry and there is now an automated tunnel kiln, where wet bricks are stacked mechanically and manually moved to the kiln. After approximately 83 hours in the kiln the dry bricks are manually pushed to the sorting area, where a group of 12 workers manually palletise the bricks (palletisation of the Kiln Dry Brick task) according to the degree of bake from the kiln. Despite this move towards automation, manual labour is still prevalent within all palletisation tasks in this industry. Several authors (Mital *et al*., 1997; Scott, 2006) have suggested that similar tasks have been shown to have task demands that often excessive and at levels that could be harmful to the workers.

SELECTION OF STRENGTH TESTS

From observing the workers perform the palletisation, which is a repetitive lifting and lowering task, and consulting literature, it was determined that the following muscles were used in these tasks. The legs, back, shoulders and arms for movement of the bricks from the origin to the pallet (Waters *et al*., 1993), and the forearm muscles, as the hands were required to hold onto the bricks during this process (Radwin *et al*. 1992). This is supported by Waters *et* al. (1993) who states that the muscles of the back and upper body are most commonly used for MMH and Kumar (2001), who shows that these areas are the most common areas for injury and discomfort. In addition to this, the two tasks required pushing and pulling of pallets to get them into place for collection by a forklift and for offloading onto the conveyor belt. In addition to the muscle observations, the various characteristics of the three tasks were recorded by weighing objects, observing processes and timing durations.

For Part I of testing, all workers performing unskilled tasks were informed about the study. Field observations and previous literature on manual lifting tasks showed which muscles were most commonly used to perform lifting and lowering tasks. From this, the muscles of the shoulders, biceps and back were measured, as well as the push and pull strength, which are required in some tasks to move pallets. Grip and pinch strength were also recorded, as the workers are required to pick up, hold and place bricks on-and-off for 8 hours of the day and these actions are therefore used. According to Bush-Joseph *et al*. (1988), in order to reduce compression forces on the spine, lifting loads with bent knees rather than a rounded back are promoted, therefore, leg strength was also measured. For the worker strength capacity factors assessed, pilot strength tests were performed on the bicep and shoulder musculature to ensure the selected strength measure was assessing the correct muscle groups. The bicep strength test showed that biceps brachii was the primary muscle used, with other muscle contributions being negligible. The shoulder strength test showed that the trapezius II was the primary muscle recruited, followed closely by the anterior and lateral deltoids, with minimal action by anterior deltoids.

TASK SELECTION

Part II of testing assessed task demands in order to characterise tasks according to potential risk profiles. Tasks which were identified as having the highest risk, according to reports from workers, were the palletisation tasks and the stacking-unstacking task. More specifically, the clay operation wet brick (CWB) palletising and clay dry brick palletising (CDB), basing and casing and the Kiln operation dry brick (KDB) palletising tasks.

Figure 8: Images of the three MMH palletising tasks; A) Clay Dry Brick (CDB), B) Clay Wet Brick (CWB) and C) Kiln Dry Brick (KDB).

Of these, all the palletising tasks were chosen to be assessed (see Figure 8), as these were comparable and showed the move from manual to a more mechanised version of the same task. These tasks all involved trunk flexion, twisting and bending to different degrees, resulting in a need for spinal observations. Workers from the three tasks reported varied levels of discomfort in different areas of the body. The three tasks were set in different environments, as shown in Figure 8 and Table III; the CDB task was done outdoors where there was natural lighting and minimal noise, but no shelter from the elements, exposing the workers to dust and brick particulates, which were exacerbated with windy conditions. The CWB task was carried out indoors and was well sheltered, but had minimal lighting and sounds were amplified, this task had a loud warning siren that went off before bricks were cut. The KDB task was partially sheltered, with a roof and was closed in on two sides. This task had natural lighting and minimal noise.

Table III: The environmental conditions of the three palletising tasks.

	Clay Dry Brick (CDB)	**Clay Wet Brick (CWB)**	**Kiln Dry Brick (KDB)**
Indoors/ Outdoors	Outdoors	Indoors	Partially covered
Lighting	Ample Natural Light	Minimal lighting	Natural Light
Noise	Constant background noise of vehicles operating.	Constant noise of machines, intermittent loud warning siren when bricks are cut.	Constant noise of machines and vehicles.
Particulate exposure	Constant clay dust, brick particulate and carbon smoke exposure.	Exposure to clay dust when the side door opens to recycle damaged bricks.	Exposure to brick particulates and clay dust when windy.
Vibration	No vibration	No vibration	No vibration

Although the basic movements of the palletising tasks are the same (see Table IV) the CWB and KDB tasks are more mechanised due to the conveyor belt allowing easier access to the bricks. The bricks of the CWB task were the heaviest at 4.4kg, whereas the bricks of the CDB and KDB tasks were lower, at 2.8kg and 2.4kg respectively. The CWB task workers moved the most bricks per day and lifted the highest weight per day, but the KDB task workers packed the most bricks per minute and the CDB task took the longest period of time to pack one pallet.

Table IV: The task characteristics of the three MMH palletising tasks

	Clay Dry Brick (CDB)	**Clay Wet Brick (CWB)**	**Kiln Dry Brick (KDB)**
#Workers per task	24	12	12
Brick weight (kg)	2.8	4.4	2.4
Basic movement (manu-manual; mech-mechanised)	Move bricks from **man kiln** to pallet (manu)	Move bricks from **left side** of **conveyor belt** to pallet (mech)	Move bricks from **both sides** of **conveyor belt** to pallet (mech)
Pallets /day /person minimum-maximum	8- 15 (self-selected)	18- 20 (task-determined)	13- 15 (task-determined)
Bricks stacked/ day (thousand)	4.00 – 7.50	9.34 - 10.17	6.67 - 7.50
Weight lifted /person /day (tons)	11.20 - 21.00	41.07 – 44.73	16.00 -18.00
Mean bricks packed in 1minute	21.5 (±3.78)	26.33 (±15.49)	30.13 (±18.125)
Mean time to stack 1 pallet	23min 47s	18min 59s	16min 36s
Mean lift rate (lifts.hr^{-1})	250.00	583.44	416.56

EXPERIMENTAL DESIGN

This current study is divided into two parts; Part I: Worker Capacity and Part II: Task demands. The worker sample was taken from the same Eastern Cape brick making industry and the same ethical considerations were taken into account for both parts of testing, therefore the participant selection and ethical considerations will be discussed together. The selection of independent and dependent variables and the equipment used were, for the most part, different between Part I and II of testing. The testing parts were therefore discussed separately for those sections.

SELECTION OF PARTICIPANTS

Unskilled workers performing manual labour at a brick manufacturing industry in the Eastern Cape were recruited. For Part I of testing, 113 Black African male (n=101) and female (n=12) workers volunteered to participate. The order in which participants performed the strength tests was permutated to control for a fatigue effect. For Part II of testing, 45 male subjects volunteered from three palletising work tasks; Clay Dry Brick Sorting (n=21), Clay Wet Brick Palletising (n=12) and Kiln Dry Brick Sorting (n=12). All workers were required to be older than 20 years of age, to ensure they are able to self-consent and were required to have at least one month of experience in this industry to ensure the workers had been habituated to the various tasks. Workers with any current or recent (within 6 months) musculoskeletal injuries were excluded from the study to ensure the testing procedures did not injure them further, and to ensure the results obtained were not affected by injuries. Women who were pregnant or who had given birth within 6 months of testing were excluded in order to protect the participants and to ensure the results obtained are not affected by factors related to pregnancies and related fatigue.

ETHNIC CONSIDERATIONS

The focus of this research was to understand the worker characteristics and task demands of manual labourers in the manufacturing industry, jobs which are dominated by Black African workers in South Africa (Mwabu and Schultz, 2000); therefore this group was chosen to be assessed. This choice was necessary due to the performance differences between Black and White individuals, who for example experience differences in oxygen consumption differences, seen in the VO_2 of runners of different races/ ethnicities (Boulay *et al*., 1988). Ethnic differences have also been seen in morphological characteristics (Goedecke *et al*., 2005) and health status (O'Keefe and Wood, 1996; Westaway, 2009) in South African males.

SELECTION OF LIFTING PROTOCOL DURATION

Part II of this research required an assessment of the task demands of a palletising task in a brick manufacturing industry. Due to the large amount of lifting required for palletising tasks (from the field observations) and the associated risk of lower back pain and injury, it was deemed necessary to assess the spinal kinematics of the workers. Although it would be ideal to assess the workers' responses to stacking an entire pallet, this amount of time could impact on the performance of the workers, and the large amount of data that would be obtained would be unnecessary. Due to the palletisers taking 1 minute to stack between 22 and 30 bricks (task dependent) as shown in Table IV, the palletisation of 60 bricks was chosen to represent the testing protocol. This would therefore take workers between 2 and 3 minutes to complete and would not impact greatly on the performance on the conveyor belt line. In addition to this, in order to ensure the movements remained constant throughout the protocol, six lifts (the palletisation of 12 bricks) were recorded at the start (lifts 1-6), middle (lifts 13-18) and end (lifts 25-30), discarding the lifts 7-12 and 19-24.

SELECTION OF INDEPENDENT VARIABLES

PART I INDEPENDENT VARIABLES

Additional areas of concern are firstly that females in South Africa are more frequently being asked to perform the same jobs as males despite the lack of knowledge surrounding the difference in capacity between the sexes (Botha *et al*., 2012). Secondly, first world countries have shown a trend of the ‘aging workforce’, in which the average age of the workforce is rapidly increasing (Kenny *et al*., 2008). It is unknown whether the South African workforce is following the same trend and in addition to this, the effect of aging on the strength capacity of South African workers is unknown. Therefore the purpose of the current study is to define the anthropometric characteristics and the strength capacity of male and female workers and males of different ages in a South African context. The selection of sex and age as independent variables for Part I of testing will be discussed further, followed by a design matrix depicting the interaction of these factors.

AGE

The ‘aging workforce’ is due to decreased mortality rates and increased life expectancies (from improving health care) and decreasing natality in these countries (Kenny *et al*., 2008). Workers are, therefore, being employed for longer and retiring later, hence accounting for a greater percentage of the workforce and increasing the average age of the workforce. An aging workforce is problematic because as individuals age, there is a decline in their overall muscle strength capabilities (Metter *et al*., 1997: Ivey *et al*., 2000; Kenny *et al*., 2008), therefore an increased chance of injury risk. This strength decline with age is seen in both males and females (Laforest *et al*., 1990; Metter *et al*., 1997; Ivey *et* al., 2000; Mosekilde, 2000). In addition to this, reaction time and endurance can also be affected with aging, resulting in performance decrements (Kenny *et al*., 2008). These performance decrements were not measured in this research, as the tasks assessed were unskilled tasks which do not require a fast reaction time and allow for sufficient rest either with within task rotation or self-selected rest periods. Strength, as an important worker capacity factor to consider in all MMH tasks, was assessed to consider differences in the strength capacity of workers of different age groups. This will increase understanding of the biomechanical capacity of workers and can be used as a comparison for IACs strength profiles.

Despite having an increased level of task automation, IACs still incur a high incidence of work-related injuries (O'Neill, 2005). Therefore in a less developed country where workers are required to do more manual labour, potential injuries may be greatly exacerbated. In labour intensive MMH tasks (which are common in South African industries), individuals of all ages are required to perform the same tasks (Kenny *et al*., 2008), despite the potential for injury of weaker workers (Kenny *et al.*, 2008). This is of concern as there is no research covering the strength changes across a selection of South African workers of different ages. It is therefore unknown whether South African workers show the same strength trends as IACs workers. A further area that may impact the aging process within the South African context is the highly prevalent HIV and AIDS pandemic, highlighted in the review of literature. Due to the high prevalence of HIV/AIDS in the younger adult generations of South Africans (age groups 30-34 for males and 25-29 for females), these generations in SA may be less physically strong (Harrison *et al*., 2010). It is therefore important to research the change in the strength capacity of South African workers as a result of aging.

There are no standard ages used to define 'young' and 'old' workers in order to determine changes with age. Each study utilises their own age classifications to define these groups; for example, Ivey *et al*. (2000) described males between the ages of 21 and 29 to be young and males between 65 and 75 to be old. In contrast, Laforest *et al*., (1989) used males between 25 and 35 as a young sample and males between 60 and 70 as his old sample. Metter *et al*., (1997) in his study on loss of power and strength in males and females looked at each decade separately (i.e. 20-29, 30-39, etc.). This split allows a possible decrease in age previously seen after age 40 (Metter *et al*., 1997) to be observed and will show any strength and anthropometric changes related to a decreased serum testosterone level (Snyder *et al*., 1999). Therefore, for this research, individuals from the age of 20 were assessed (to ensure adequate training and experience on the job after finishing school at 18). Workers were then split into four age groups 20 - 29, 30 – 39, 40 – 49 and ≥50, similar to the study by Metter *et al*., 1997.

SEX

Women are more commonly being appointed to do physically demanding work tasks which were previously deemed too taxing for females to perform. In South Africa, the introduction of the ‘women in mining’ project, which aims to introduce more women into manual labour in the mining sector (Botha *et al*., 2012) is an example of this increase in female workers. It is therefore predicted that this will be a trend throughout South African industries (Botha *et al*., 2012), with women more readily being offered work positions which are more physically taxing and previously only performed by male workers, despite the lack of knowledge surrounding the difference in capacity between the sexes. This trend could be problematic as women in industrially advanced countries are shown to have 66% of the strength capabilities of their male counterparts (Ivey *et al*., 2000). Although there is no research on strength differences of male and female industry workers in South Africa, South African military research shows that female workers are capable of 60% of the force production of males from the same work force (Nolte and Bredenkamp, 2008). The currently large differences in the obesity rates between African men and women (Bourne *et al*., 2002; Puoane *et al*., 2002; Goedecke *et al*., 2005) are far greater than in most other race groups. Therefore differences between these groups in the current study could be greater than expected.

Sex-related strength differences are important to consider when appointing individuals to work tasks, as the highly physical tasks would require a greater percentage of total effort for weaker individuals. In order to ensure that tasks are designed acknowledging the importance of compatibility between the task demands and worker capabilities it is first necessary to ensure that we have an understanding of what those capabilities are. In terms of the South African female worker there is currently a lack of information available establishing their strengths and limitations. Although some research has been done on the South African military population, epidemiological evidence would need to be collected for industry workers to determine if there is a similar trend, leaving an important area of research that needs to be covered.

DESIGN MATRIX

Part I of this study therefore aimed to assess the worker capacity of workers in the brick manufacturing industry. It compared the strength capacity and anthropometric characteristics of males and females of various age groups. The company being assessed does not have a very large employee base; therefore, in order to ensure a large enough sample size, all unskilled males and females over 20 were approached and informed of the study. All willing participants were then measured. The male sample was split into four age groups to allow for age comparisons, however, due to the small sample size of the female group, this sample could only be considered as a whole. This can be seen in the design matrix (Table V).

Table V: Research design displaying the interaction of the independent variables in Part I of testing.

	DESIGN MATRIX				
	Age Group 1 20-29	Age Group 2 30-39	Age Group 3 40-49	Age Group 4 ≥50	All Ages
MALES (n = 101)					
FEMALES (n = 11)	▨	▨	▨	▨	

PART II INDEPENDENT VARIABLES

TASK

Task observations indicated (see the field observation section) that workers performing palletising tasks used mainly their upper bodies, back and legs when lifting, lowering and moving the materials. Due to the movement towards increased automation of tasks, it is important to research whether the more mechanised tasks are beneficial or detrimental to workers. In this example, the responses of workers to the task demands of three tasks, varying in manual and mechanised advancements will be assessed. Of the three palletising tasks assessed, two (CWB and KDB) were more automated/mechanised in that the bricks were transported to the workers on conveyor belts, whereas the third (CDB) task was entirely manual. Due to the move towards increasing mechanisation in South Africa, understanding the differences between these tasks is important to show whether the mechanisation reduces the risk of injury.

DESIGN MATRIX

Part II of testing therefore measured the task demands placed on workers performing three tasks in this manufacturing industry, namely the sorting and palletising tasks of dry bricks in the kiln organisation (n=12) and clay operation (n=21) and palletising the wet bricks in the clay operation (n=12). All workers in these sections were approached and informed about the study; all the male workers who met the inclusion criteria were then assessed.

Table VI: The research design of Part II of the study, comparing the task demands placed on males from three different tasks.

Task 1 Clay dry brick palletising	Task 2 Clay wet brick palletising	Task 3 Kiln dry brick palletising

SELECTION OF DEPENDENT VARIABLES

PART I: DEPENDENT VARIABLES

In a study which aims to increase understanding of the worker capacity, it is essential to take a holistic approach and attempt to understand all characteristics of the worker, anthropometric, biomechanical, physiological and psychophysical (Dempsey, 1998). For this part of the research, however, only the first three factors were measured, with psychophysical measures assessed in Part II (task demands) of the research. This was done as psychophysical measures are the workers perceptual responses to stimuli, measured in Part II, whereas Part I was measuring the workers' abilities to perform work.

ANTHROPOMETRIC PARAMETERS

Anthropometric measures form a part of the 'Personal Characteristics' of the worker capacity. These measures will provide a greater understanding of the characteristics of an Eastern Cape manual industry worker, so the worker capacity and task demands can be more closely matched. In addition, these data provided a foundation for comparisons against data from IACs.

BODY MORPHOLOGY

Although issues such as malnutrition, poverty and infectious diseases, including HIV and AIDS, are commonly associated with South Africa, obesity and its co-morbidities also negatively affect many South Africans, resulting in increased cost of health care (Goedecke, 2005). Body morphology measures, such as body mass index (BMI) through the measurement of stature and mass will assess the incidence of the weight category of workers (underweight, normal, overweight or obese). Body morphology measures have a positive correlation with strength capabilities (Hardy *et al*., 2013) and measures of obesity have been connected to health problems such as hypertension and heart disease (Goedecke *et al*., 2005) and has been linked to a lower work ability. Obesity can be determined by a several methods, the ones use in this study were; body mass index, waist to hip ratio, waist circumference and body fat percentage.

BODY MASS INDEX

The mean BMI of South African industry workers is currently unknown and therefore needs to be studied in order to understand the worker capacity. BMI was calculated by the equation;

$$\frac{\textbf{Mass (kg)}}{\textbf{Stature (m)}^{2}}$$

Therefore, in order to calculate this index, mass and stature were measured. Research shows that body mass alone can impact the force that a subject can exert, in that a greater body mass will result in a greater force production (Kroemer, 1969; Chaffin *et al*., 1973).

WAIST TO HIP RATIO

Waist to hip ratio (WHR) provides a quantitative measurement of the balance of weight distribution, i.e. abdominal fat and peripheral fat (Rankinen *et al*., 1999; Puoane *et al*., 2002) and can therefore be used together with BMI to get a more in-depth view of the size and body type of the South African worker. This measure is also associated with a greater risk of mortality (Price *et al*., 2006) so it is important to measure to consider when understanding the worker capacity. Waist to hip ratio was calculated with the equation:

$$\frac{\textbf{Waist circumference (cm)}}{\textbf{Hip circumference (cm)}}$$

BODY FAT PERCENTAGE

Where BMI is not entirely accurate, particularly for males and older individuals, as it does not differentiate between fat mass and muscle mass (Romero-Corral *et al*., 2008), the body composition data will ensure a more complete understanding of the workers body composition. Together with the BMI and WHR measurements, body composition will provide a more in-depth understanding of the morphology of the workers.

BIOMECHANICAL MEASURES

Manual materials handling tasks, particularly in South Africa (as an IDC), involve manipulation of weighted objects. Therefore, task performance will be greatly affected by the strength of the worker, in that a weaker individual would take longer to complete the task or fatigue earlier. Strength is consequently an essential factor to understand in a MMH environment.

STRENGTH

Muscular strength can be considered one of the most important physical capacity factors in manual materials handling which require a great deal of physical exertion (Kumar, 1995; Mital and Kumar, 1998). Manual materials handling industries require awkward work postures including squatting, lifting, bending, pushing, pulling and handling heavy machinery in order to complete the manufacturing process (Hagg *et al*., 1997; Carey and Gallway, 1998). Workers with a higher strength capacity are less likely to be injured during the work tasks and will complete the tasks with a lower percentage of overall effort than weaker workers (Chaffin and Park, 1973; Chaffin *et al*., 1978). Strength, as a measure of physical capacity, is therefore an essential factor to consider for research pertaining to the capacity of the workers and the concurrent task demands, as it could be a predictor of future injuries. Therefore, as mentioned in the field observations and pilot studies, eight strength measures were assessed, namely; back, leg, shoulder, bicep, grip, pinch, push and pull strengths.

PHYSIOLOGICAL AND HEALTH MEASURES

A reduced physiological capacity and/or health status can lower the overall capacity of workers, resulting in a decline in work ability and task performance. Understanding these factors is therefore pertinent to the overall understanding of the worker capacity. Physiological measures included, resting heart rate and blood pressure, as well as a series of health questionnaires.

HEART RATE AND BLOOD PRESSURE

Resting heart rate is a basic measure of the cardiovascular fitness of an individual according to their age and sex and acts as a predictor of cardiovascular mortality (Fox *et al*., 2007). This would therefore provide a basic understanding of the change in cardiovascular fitness with age in males and the differences in cardiovascular fitness between the sexes, as well as the cardiovascular risk of these groups.

High blood pressure (hypertension) is common in South Africa and is a risk factor for many forms of heart disease (Bradshaw *et al*., 2003; SANHANES, 2013). In conjunction with other measurements, blood pressure will provide an understanding of the potential heart disease risk of the participants.

HEALTH STATUS

Because South Africa is faced with the unique quadruple burden of disease, it is important to determine the prevalence of various diseases in industry workers (Bradshaw *et al*., 2003). The World Health Organisation states that the wealth of poor people depends largely on their health. Good health allows them to participate in the job market and is essential to ensure adequate productivity in the manual-based tasks of South Africa. Poor health can result in injury to the worker and/or decreased productivity for employers and is therefore a liability. Understanding the health status of the population is therefore essential to maximize productivity and minimize injuries in industry.

PART II: DEPENDENT VARIABLES

When aiming to increase the understanding of task demands in industries, it is essential to consider all contributory factors and the workers' responses to these, especially in a unique South African example. Biomechanical, physiological and psychophysical responses were measured in order to develop a more complete understanding of the requirements for the palletising tasks.

BIOMECHANICS

Manual brick manufacturing has been associated with a high prevalence of low back injuries associated with the lifting and carrying tasks (Chung and Kee, 2000). In order to accurately determine the cause of high risk in the low back, trunk/ spinal movements and forces of the spine need to be determined.

SPINAL KINEMATICS

In any manual materials handling industry, task enactment often requires significant amounts of flexion, extension, lateral bending, twisting and rotation, due to the dynamic nature of these tasks. In this brick manufacturing industry in particular, the workers were given minimal space to move while palletising bricks. In order to quantitatively assess these movements, and compare the spinal movements between tasks, spinal kinematics must be measured. Due to the dynamic, multidimensional nature of spinal/trunk movements in the current MMH task, it was necessary to measure movement angles in all three planes (sagittal, lateral and transverse), as well as the associated velocity and acceleration of these movements.

JOINT FORCES

A correlation has been found between lifting-related low-back disorders and predicted compressive forces on the L_5/S_1 joint (Granata and Marras, 1999). Compressive forces at the lumbosacral joint will differ depending on posture and load (Ayoub and Mital, 1989). Due to repetitive lifting in the brick palletising tasks, it is necessary to determine the forces on the spine; as well as to determine whether slow paced manual tasks or faster, more mechanised tasks have increased spinal joint forces. Therefore both the compression and shear forces at the lumbosacral junction were determined.

PHYSIOLOGICAL MEASURES

Posture, lifting frequency, lifting technique and load are key determinants of physiological measures in MMH tasks (Garg and Saxena, 1979; Hagen *et al*., 1993). Therefore, physiological measures will determine which tasks place the workers at an increased cardiovascular strain. Physical activity, however, is not the only factor which impactson physiological responses. Due to the differing environmental conditions of the workplaces of the three palletising tasks, assessing physiological demands is important, as physiological factors have also been shown to be affected by environmental factors (e.g. temperature and sun exposure) (Qutubuddin *et al*., 2013). Differences in symmetry and asymmetry of tasks have also been shown to affect the physiological responses (Gallagher, 1991).

HEART RATE

Heart rate changes have been linked to the degree of physical exertion of an individual (Vogt and Metz, 1977). This will allow the change in exertion throughout the testing session to be observed. However, heart rate changes have also been recorded in relation to changes in breathing rate, blood pressure, hormones, working postures, environmental factors and health status, making the specific effect of physical exertion difficult to measure. Heart rate measurements will therefore show the workers' physiological responses to the varied environmental, mechanisation and task factors of the three brick palletising tasks.

Energy expenditure is an important factor to consider in fast-paced manual materials handling tasks as a measure of the energy requirements needed to complete these tasks (Hagen *et al*., 1993). However, as this is an *in situ* study, testing is done on workers on the production line, and testing can therefore not interfere with the task. A portable metabolic system would possibly interfere with the workers visual field and may hinder movements and was therefore not tested in the current study.

PSYCHOPHYSICAL MEASURES

Psychophysical measures demonstrate perceptions of exertion and discomfort in this work place, which have been linked to pain and injury (Cameron, 2006). Workers' perceptions of the effects of task demands, in addition to biomechanical and physiological factors can therefore provide a multifactorial etiology to aid in better understanding the responses to task demands and the associated risks.

BODY DISCOMFORT

Due to the large number of reported work-related musculoskeletal disorders, body discomfort responses were measured, as this will provide insight into the areas of the body which are being affected. Previous studies on brick manufacturing workers have shown that the majority of these workers report pain and discomfort due to the presence of many work-related risk factors (Pandey and Vats, 2013). Due to the effect of load, asymmetry and lifting technique on the psychophysical responses, body discomfort reports should demonstrate task-related differences in injury risk of various body areas.

EQUIPMENT

PART I

ANTHROPOMETRIC MEASURES

In order to understand the body morphology; body mass index (BMI), waist to hip ratio (WHR), waist circumference and body fat percentage were all measured. These measures will provide an understanding of the level of obesity of the workers.

PORTABLE SECA SCALE

Body mass was measured on a portable Seca analogue-dial scale to the nearest 0.25 kilogram (kg). The accuracy of the scale was ensured by comparing the weights of objects obtained from this scale to weights of the same objects on a calibrated Toledo scale. For this measurement, workers were required to step onto the middle of the scale and stand still until an accurate reading was obtained and recorded. Workers were weighed wearing their work overalls and work shoes, which were standard and therefore of a relatively equal weight for all workers in order to reduce time away from the production process. The weight of the overalls and shoes were measured and subtracted from the recorded body weight for final mass measurement provided.

STADIOMETER

Stature was recorded using a stadiometer against a wall (see Appendix 2B) to the nearest millimeter (mm). The accuracy of the stadiometer was validated prior to testing, by comparing statures obtained with the stadiometer, to those obtained with tape measures. Workers were required to stand directly under the stadiometer, on a marked area. Stature was measured in a straight line from the fixed stadiometer to the top of the head in the mid-sagittal plane. Participants kept their shoes on for this measurement as the shoes were standardized and provided to workers by the company and therefore had a set height which was subtracted from the measured height. The limitations of the stature and mass measurement methods have been acknowledged in Chapter I (Limitations).

Thereafter waist and hip circumferences were measured. The waist was defined as the smallest area around the torso, and the hip measurement taken at the widest area of the hips. These were measured using a standard, non-elastic tape measure. Waist circumference has shown to be a better indicator of trunk fat/abdominal visceral fat (Rankinen *et al*., 1999) than waist to hip ratio, so this measurement will also be used.

HARPENDEN SKINFOLD CALIPERS

Although hydrostatic weighing and more recently, dual-energy x-ray absorptiometry and air displacement plethysmography have been considered to be the most accurate methods of assessing body composition (Hedley *et al*., 2004; Romero-Corral *et al*., 2008), these are expensive and often not available (Reinert *et al*., 2012). In addition, these pieces of machinery are fixed and cannot be easily transported for work in the field. Field assessment methods commonly used are skinfolds and bioelectrical impedance (Reinert *et al*., 2012). Because bioelectrical impedance was deemed the least accurate method of body fat assessment (Reinert *et al*., 2012) and results obtained from skinfold measurements are closely correlated (r=0.70-0.90) to that of hydrostatic weighing (American College of Sports Medicine, 2000), the skinfold method was selected to assess body fat.

As this research was performed in the field and workers could not be away from their tasks for long durations (as production could not be affected), a quick method of body composition measurement was required. Therefore, the four skinfold sites; bicep, tricep, subscapular and suprailiac were measured as per Durnin and Womersley (1974). The skinfold measurements were all taken from the right side of the body, halfway between the base and crest of the anatomical site, using Harpenden skinfold calipers which were placed 1cm away from the thumb and forefinger, perpendicular to the skinfold. Duplicate measures were taken to ensure accuracy of the recordings, if the margin of error between the two measurements was greater than 3% then a third measurement was taken. Using the equations from Durnin and Womersley (1974), the percentage of body fat was calculated. For photographs of these measurements, see Appendix B2.

BIOMECHANICAL MEASURES

Due to the dynamic movements required in order to complete the palletising tasks, strength measures from several muscle groups were taken. Although an isokinetic dynamometer is more accurate than a portable isometric dynamometer, its use was not practical due to the testing being done in the field. Therefore various hand held dynamometers were used to measure; back, leg, bicep, shoulder, grip, push and pull strength. Participants were told when to start and stop the contraction (after a 3 second exertion) and were encouraged to perform at maximal level. To reduce the risk of muscle strain, while maintaining measurement validity and consistency of the strength tests, a three-repetition maximum was performed. If the second measurement was within 5% of the first then a third measurement was not performed. If a third measure was taken and was within 5% of one of the other measures, then the mean of the two measurements was calculated. If the third measure was within 5% of both other measures, then the mean of the closest two measures was recorded. If the third measurement was taken and was not within 5% of one of the other two measures, the data was discarded. Photographs of participants performing the strength tests can be seen in Appendix B3.

BACK AND LEG STRENGTH

Back and Leg strength were measured using a Baselline Back-Leg-Chest dynamometer, with positioning based on postures as set out by Chaffin *et al*. (1978). For Back strength; participants were required to stand on the base of the dynamometer with legs shoulder-width apart, with the back flexed at the hip (so that with outstretched arms, the fingertips reached the level of the patellae) and knees straight but not locked (Chaffin *et al*., 1978), see Appendix B3. While the participant was in this position, the handle was placed in the participants hands and the chain of the handle was linked to the base of the dynamometer so the chain was taut. The participant was then required to pull the handle as forcefully as possible for three seconds by contracting the back muscles to produce the force. Leg strength was measured using a back dynamometer and a modified positioning of that set out by Chaffin *et al*. (1978) and Coldwells *et al*. (1994). Participants were required to stand on the base of the dynamometer with legs shoulder-width apart, with the back flat against the wall and knees bent at a 110º angle (Chaffin *et al*., 1978) (see Appendix B3). While the participant was in this position, the handle was placed in the participant's hands and the chain of the handle was linked to the base of the dynamometer so the chain was taut. The participant was then required to pull the handle as forcefully as possible for three seconds by isolating leg muscles to produce the force.

BICEP STRENGTH

Bicep strength was measured using a back dynamometer and positioning was developed by performing pilot tests. Pilot EMG tests revealed that the biceps were the muscle most recruited in this test, the only other area which showed notable activity was the forearms, but this was minimal compared to the activity of the biceps. In order to ensure that the effort was isolated, participants were required to sit in a chair with their back flat against the backrest (to avoid any influence of the back muscles, upper arms were against the sides of the torso and elbows were at 90 degrees with palms facing upwards, to ensure a maximal contraction (Petrofsky and Phillips, 1980). Feet were required to be on the base of the dynamometer in order to keep it in place. While the participant was in this position, the handle was placed in the participants hands and the chain of the handle was linked to the base of the dynamometer so the chain was taut. The participant was then required to pull the handle as forcefully as possible for three seconds by pulling the handle inwards, towards the shoulder, therefore isolating the bicep brachii muscles to produce the force.

SHOULDER STRENGTH

Shoulder strength was measured using a back dynamometer and positioning which was developed with pilot testing. Pilot tests showed that primarily middle deltoids were recruited for this exercise, but anterior deltoids and Trapezius I muscles were also recruited to a lesser extent. Participants were required to sit on the edge of a chair, to ensure the force was being exerted straight upward, with feet on the base of the dynamometer. Elbows were raised laterally to slightly under the level of the shoulders and were bent so the hands sat anteriorly to the body at the level of the Xiphoid process. This positioning was chosen as it resulted in the highest Trapezius 1 and Trapezius 2 activation during pilot testing. While the participant was in this position, the handle was placed in the participants hands and the chain of the handle was linked to the base of the dynamometer so the chain was taut. The participant was then required to pull the handle as forcefully as possible for three seconds by isolating the shoulder muscles to produce the force.

PINCH STRENGTH

Pinch grip was assessed using a pinch strength dynamometer. The research assistant held the dial end of the dynamometer in order to keep it stable, while the participant pinched the other end using the pad of the thumb and lateral aspect of the index finger, with a neutral wrist and the elbow at 90 degrees so the forearm was perpendicular to the torso (Zimmerman *et al*., 1989). The participant was required to squeeze the dynamometer as hard as they could for three seconds, which the research assistant counted, and could then release to allow the dynamometer to be reset.

GRIP STRENGTH

Grip strength was measured using a handheld dynamometer. Participants were required to stand with feet shoulder width apart and hold the dynamometer above the head in their dominant hand with a straight arm, palm facing inwards, as this positioning results in the highest strength capabilities (Balogun *et al*., 1991). The dynamometer was then required to be gripped as tightly as possible while moving the arm anterior-inferiorly, the maximum reading was then recorded.

PUSH AND PULL STRENGTH:

Push-pull forces were measured using the Chatillon Hand-Held Dynamometer. For Push strength a circular, flat edged attachment was used. Participants stood near to a wall so their upper arms were against the side of the torso and the forearms were perpendicular to the torso (normal reach), palms facing down (Das and Wang, 20004). In an overhand grip, participants took hold of the handle and on request from the research assistant were required to push for three seconds, using their arms only. For the Pull strength, a medium sized hook attachment was used. This was attached to a vertical bar in the testing room. Participants stood in the same position as the Push test, but in front of the vertical bar. When requested, the participant pulled the handle towards the body for three seconds using only arm strength.

PHYSIOLOGICAL AND HEALTH MEASURES

Blood pressure and resting heart rate measures were taken using an Arden digital blood pressure meter prior to performing the strength tests. The participants were asked to sit at a bench and rest their left arm, palm facing upwards, on the table, as this position results in the most accurate readings (Khoshdel *et al.*, 2010). After the completion of the informed consent and questionnaire, and additional one minute of rest was mandatory (to ensure the worker was at rest, as this affects results; Sala *et al.*, 2006), the strap was attached around the upper arm, above the elbow and the research assistant started the measuring process. The Systolic and Diastolic blood pressure, as well as the resting heart rate readings were all recorded.

A questionnaire was given to the participants at the start of the testing session with the intention of increasing understanding of lifestyle and health status. The questionnaires were only completed by participants who were willing. The responses of this, interpreted with the results of other measurements, are important in providing a more substantial image of the health and lifestyle of third world country unskilled workers in a manual materials handling industry.

PART II

BIOMECHANICAL

Due to the dynamic nature of manual materials handling tasks in South Africa (Scott and Christie, 2004), a multifaceted approach is a more accurate method of assessing biomechanical ability than any individual measure (Granata and Marras, 1999).

However, due to this study being *in situ*, workers cannot have large amounts of experimental equipment attached (i.e. electromyography) that may impair efficiency of movement on the production line. Therefore the best option for this study is a combination of assessments which do not interfere with the manufacturing process.

SPINAL KINEMATICS

Because the spine is a three dimensional structure which undergoes movements in three planes, it was important to ascertain these movements in order to classify the overall risk (Hindle *et al*., 1990). Ferguson *et al*. (2004) recommended that trunk kinematic assessments are possibly the best prediction models and that spinal kinematics can be quantified measured using the Lumbar Motion Monitor (LMM). The Chattecx LMM was designed as an exoskeleton mimic of the spine by replicating the three-dimensional movement of the vertebral column, with potentiometers- a force measuring system of the Chattecx LMM. These potentiometers measured the position, velocity and acceleration of the spine in three planes (Allread *et al*., 2000; Ferguson and Marras, 2004).

Prior to placing the LMM on participants, calibration was carried out while the LMM was still fixed in the casing, this was done every morning before the start of testing. The length of the LMM was then adjusted to the stature of participants and securely fitted to the participants using the various straps provided; a thick strap around the hips at the level of the lumbosacral joint, two straps crossing over from the back to attached on the opposite side at the front, and two straps, one each around the upper thighs of the participants. Once secure, the participant was required to stand motionless in a neutral posture while a second calibration was performed, setting the LMM to the participants' normal spinal curvature. Once this was completed, the testing protocol could commence.

JOINT FORCES

The three-dimensional static strength prediction program (3DSSPP) is a biomechanical measurement tool developed by the University of Michigan (2004), which provided information on the load characteristics needed to perform tasks assessed. It is used to assess simulated job design, and is useful as a pre- and post-intervention evaluation tool and can therefore be used to make recommendations to reduce risk. As only photographs and certain weight measurements need to be taken, this assessment did not interfere with the production in the industry and it was therefore useful for this type of field study. The limitation of this assessment method is that it is a static strength prediction program, whereas the majority of work tasks today are dynamic in nature. Therefore this data in conjunction with the Lumbar Motion Monitor data will provide a sound understanding of spinal movements and imposed forces.

Photographs of the most extreme posture in the work task processes, placing bricks on the lowest level of the pallet, were taken for all tasks during the work shifts. These photographs were then imported into the University of Michigan's 3DSSPP analyses program (version4.3.7) for modelling and assessments, which were done after the testing (Marras *et al*., 1992).

PHYSIOLOGICAL

Polar heart rate monitors were used to measure physical exertion of the workers during the testing protocol. The transmitter belt of the heart rate monitor was attached around the worker's chest at the level of the inferior border of the pectoral muscles (Scott and Christie, 2004). A watch receiver was used to measure the initial reference heart rate, which was taken at the start of the testing session. Heart rate was recorded half way through the protocol and on the last lift of the protocol.

PSYCHOPHYSICAL

The Corlett and Bishop body discomfort scale was developed in 1976 as a quantitative measure of perceived discomfort in various areas of the body and to isolate and identify potential areas of injury risk in the workers. This scale identifies 28 body areas which the workers may rate to describe any discomfort in the areas on a scale between 1- minimal discomfort to 10- extreme discomfort (Appendix B1). These will provide insight into the role of the psychophysical aspects of the worker capacity, and will show if the workers are uncomfortable with their work conditions and where/ why they are feeling this.

Body Discomfort measurements were taken at three stages throughout the day in the first hour of work, just before a lunch break and at the end of the work shift. These measurements provide an indication of how the perceived exertion of the individuals changes throughout the work shift (i.e. if workers get progressively more tired or if they feel the same throughout the day).

ETHICAL CONSIDERATIONS

Prior to investigation, all protocols and techniques adopted within this investigation were approved by the Department of Human Kinetics and Ergonomics Ethical Committee, Rhodes University, South Africa.

INFORMED CONSENT

Prior to testing, participants were informed about the aims of the study, the procedures involved and the potential risks and benefits of the study both verbally and in writing (see Appendix A1). An interpreter was available during this process to ensure understanding of the procedures. After asking questions, participants voluntarily signed consent forms (see Appendix A2) to agree to participate in the study. Participants were reminded before and during testing that they may withdraw from the study at any stage without any negative consequences.

PRIVACY AND ANONYMITY

Throughout data collection, a coding system was used to ensure that the results for each of the participants remained anonymous and could not be linked back to the participants. Participants were informed that participation in the study was confidential and that the names of all participants would be deleted.

EXPERIMENTAL PROCEDURE

PART I

Testing was performed between 7.30am and 9.30am on thirteen consecutive workdays. Participants were informed of the study by the industry the day before and on the days of testing. Interested participants were then called by a runner (who doubled as an interpreter) who was assigned to assisting with the research. On arrival workers were presented with a letter of information (Appendix A1) which was explained to them in full verbally, first by the researcher and then by an interpreter who was available to assist with this process for workers who did not fully understand. Once participants fully understood the testing procedure, they were asked if they would like to participate in the study. Workers who chose to participate signed an informed consent form (Appendix A2) and were given a questionnaire (Appendix B5); those who did not want to participate left the testing area. Once the questionnaire was completed the participants' blood pressure and resting heart rate was measured. Following this, anthropometric measurements of; stature (m), mass (kg), body composition (% fat), waist and hip circumference were measured. These measurements were explained to the participants in full and were performed only if permission was granted by the participant. The participant was asked if they had any current or recent (within 6 months) injuries. Workers who had injuries were not included in the research; workers who were not injured were given a permutated order in which to complete the strength tests.

At each strength-testing station, the equipment and correct form of testing procedure was explained, and participants were habituated to this and able to ask any questions. Once the individual was comfortable with the equipment, three maximal tests were performed. The research assistant then told the participant which station to go to according to the individualised permutation tables attached to each data collection sheet. The same process occurred at each station until all eight strength tests had been performed. Once the eighth test was completed, the research assistant ensured the data sheet was complete, asked the participant if there were any questions and then allowed them to leave the testing room.

PART II

Prior to the day of testing, each of the three tasks was visited and the testing procedures (including body discomfort) were explained to the workers in full. On the day of testing the workers were approached individually on the production line and asked whether they were willing to participate in the data collection. Workers who were interested had the testing procedure explained to them again and were required to sign an informed consent form. Stature and mass were measured and the heart rate belt was attached to the participant. The lumbar motion monitor was placed against the participant and changes in size setting were made if necessary. This was then attached to the participant. The participant then moved back onto the production line while one researcher (A) operated the computer for lumbar motion monitor data collection and another (B) recorded the heart rate throughout the data collection process.

Researcher A told the participant when to start moving bricks. At this point researcher B wrote down the first heart rate measure and researcher A started the recording of the Ballet 2.0 software for the lumbar motion monitor. Both researchers counted out loud as the participant moved two bricks (one in each hand) off a starting platform (a conveyor belt in the Clay Wet Brick and Kiln Dry Brick tasks, and a stack of bricks in the Clay Dry Brick task) onto an empty pallet. After six counts (12 bricks moved), researcher A stopped the lumbar motion data recording, at 12 counts it was switched back on. At 15 counts (30 bricks moved) researcher B recorded the mid-way heart rate. At 18 counts the lumbar motion data was stopped again and was started for the third time at 24 counts. When the participant reached 30 counts (60 bricks moved) the final heart rate reading was recorded and the lumbar motion data was stopped. The equipment was then removed from the participant and cleaned before approaching the next worker.

In addition to this, on a following day, the workers from these tasks were approached at the start of their shift and were reminded how the body discomfort scale works. They were then asked if they felt any pain and if so to what numerical degree. This process was repeated mid-way through the day and at the end of the work shift.

Time-motion studies were also conducted in order to understand how much time in a work shift was spent moving bricks and how much time was spent resting or waiting, in order to determine the amount of time spent in the positions measured.
Examples of the two data sheets used in Part I and II of this research can be seen in Appendix B4.

DATA REDUCTION AND ANALYSES

The spinal kinematics data, recorded by the lumbar motion monitor, was reduced using Ballet 2.0 Software and exported to Microsoft Excel. All other measures were manually entered into Microsoft Excel spreadsheets. All statistical analyses were conducted using STATISTICA (version 10) software to determine significant differences and to graphically display some of the information. Shapiro-Wilks tests ensured the normality of the data. One-way analyses of variances were performed to compare sex and age differences (Part I) and task differences (Part II). A 95% confidence level was used to determine significance for all analyses and Tukey post-hoc tests were conducted were appropriate.

CHAPTER IV

RESULTS

INTRODUCTION

The present study aimed to assess; a) the effect of age and sex on personal, biomechanical and physiological worker capacity factors and b) the biomechanical, physiological and psychophysical responses to the task demands of three MMH palletising tasks in a brick making industry in the Eastern Cape. For Part I of the study worker capacity factors were evaluated as a function of Age and Sex. For Part II of the study, the responses to task demands of the three tasks were compared. The results of this study will be presented both graphically and in table form with the use of means and standard deviations in conjunction with ANOVAs performed. Comparisons and observations of these results were made, to determine the match or mismatch between the worker capacity (Part I) and task demands (Part II), which will be discussed separately. Note: Tukey tests showing significant difference are shown in Appendix C1.

PART I: WORKER CAPACITY

Part I of this study looked at the effect of sex and age on the worker capacities of male (n=101) and female (n=11) workers aged between 20 and 60. Participant age data is shown in Table VII for male and female samples. Table VII shows that of the 101 males, 35 of males from the sample population were from the 30-39 group, followed by 30 from the 20-29 group, 26 from the 40-49 age group and the remaining 10 of males were from the 50-59 group. There were only 11 females in the sample.

SEX EFFECT

The female population of the current sample made up 9.82% of the sample, which is in agreement with South African research and legislature (the Mining Charter) which states that at least 10% of the working population must be female (George *et* al., 2004); due to the small sample size of females in this industry population (n=11), the statistical power of the observations made would be questionable. Therefore, the results obtained from the female sample are not presented as a part of the results or discussed further, but can be found as measures of interest in the Appendices (Appendix C2). As a result of this, the effect of sex on the capacity of workers could not be statistically determined.

Table VII: The mean age (±SD) and number of participants in each age group for the male and female samples.

	MALES (90.18%)		**FEMALES (9.82%)**	
	Number of Participants (% of total)	Mean Age (±SD)	Number of Participants (% of total)	Mean Age (±SD)
20-29	30 (29.70)	25.1 (±2.50)	3 (27.27)	28.33 (±1.15)
30-39	35 (34.65)	34.34 (±2.80)	5 (45.45)	35.80 (±2.86)
40-49	26 (25.74)	43.92 (± 2.61)	2 (18.18)	44.50 (±2.12)
≥50	10 (9.90)	52.00 (±3.94)	1 (9.09)	50.00 (±0)
Total	101 (100)	35.81 (±9.28)	11 (100)	36.64 (±7.43)

AGE EFFECT

The effect of age on the worker capacity factors was determined using data collected from the male participants only. Males and females data could not be combined, due to the many differences in strength, anthropometry and morphology highlighted in Chapter II. The numbers of workers in each age group, as well as the mean ages of these groups, are shown in Table VII. Anthropometric, biomechanical, physiological and health measures were considered as determinants of the overall worker capacity for this research. The effect of age on these factors will be discussed further.

ANTHROPOMETRICS AND HEALTH

BODY MORPHOLOGY

The mean ***body mass index*** (BMI), as well as the corresponding standard deviations, of male workers from all age groups was within the ‘normal’ category, 20-25kg.m^{-2}, as show in Figure 9. The oldest group, 50-and-above, had the greatest mean BMI (23.03kg.m^{-2}), whereas the two youngest groups, 20-29 (21.56kg.m^{-2}) and 30-39 (21.30kg.m^{-2}), had the lowest BMI ratings. Although the oldest group was 6.38% and 7.51% higher than the 20s and 30s groups respectively, there were no significant differences in the body mass index of male workers between the four age groups ($p > 0.05$).

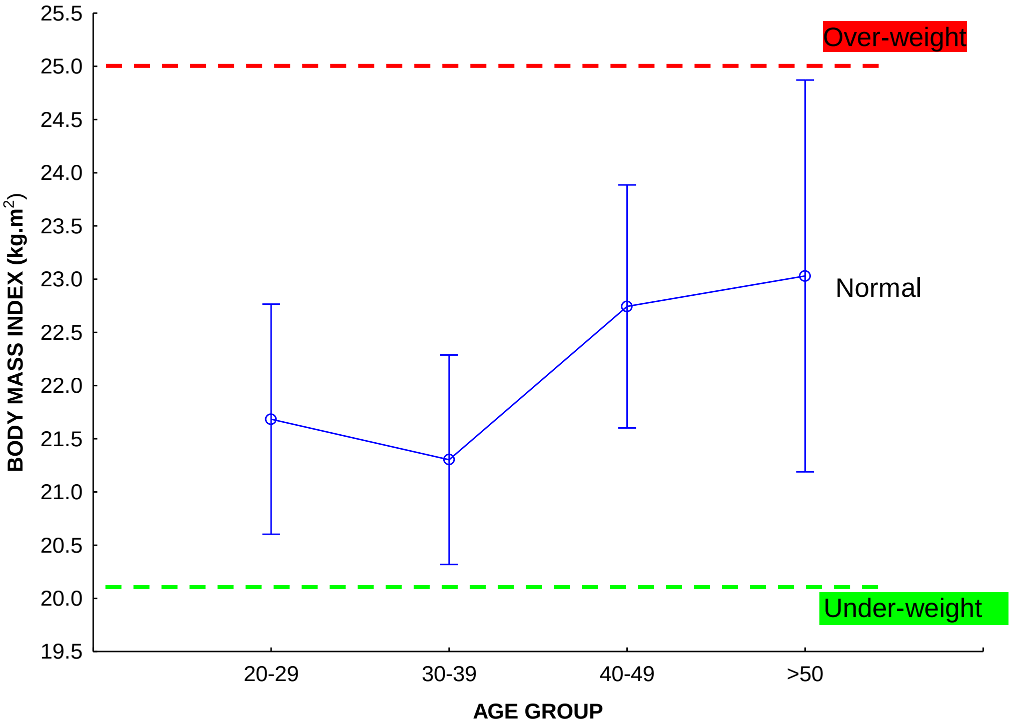


Figure 9: The effect of age on the body mass index (BMI) of male workers.

Figure 10 shows that the mean ***waist to hip ratio*** (WHR) measures for all age groups were within the “low risk” category (<1.0). Risk categories were adapted for age, due to the natural increase of waist circumference with age. Therefore, although males in the over-50 group (WHR= 0.87) had a WHR significantly higher than the 20-29 (WHR= 0.80; $p < 0.01$) and 30-39 (WHR= 0.81; $p < 0.01$) groups, this measure was not considered to be high risk for this age group (see Figure 10 for details). Therefore the WHR of the over-50 group was 8.04% higher than in the 20s group and 6.90% higher than men in the 30s age group.

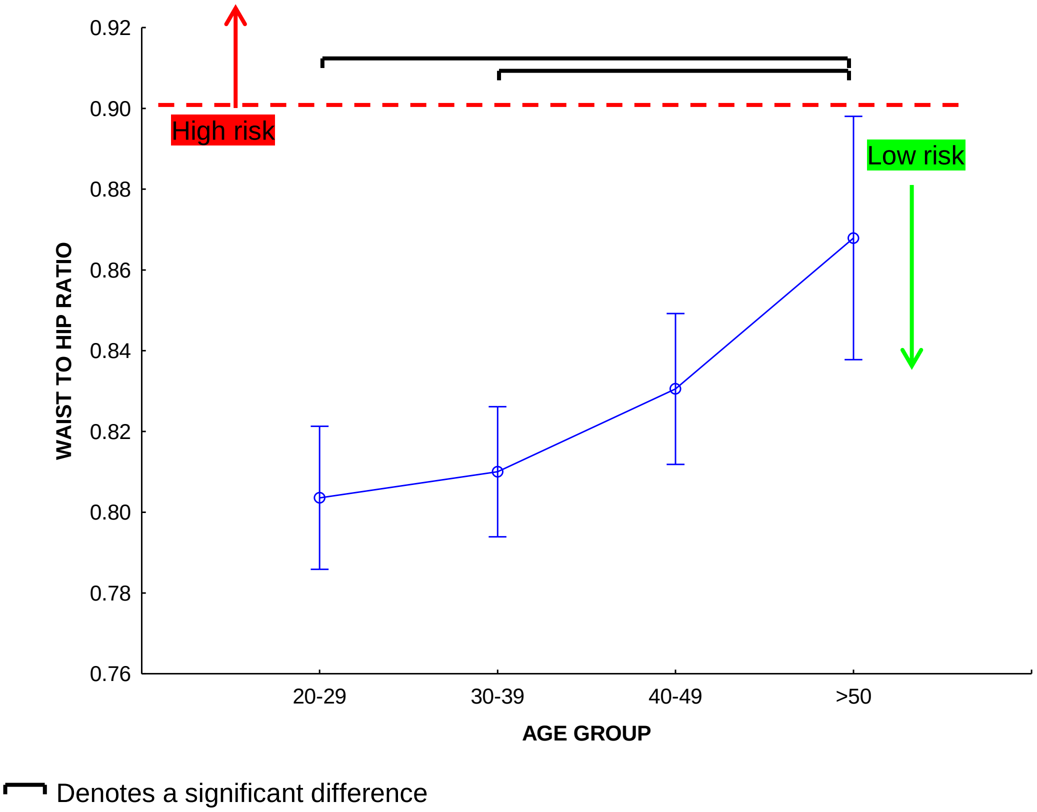
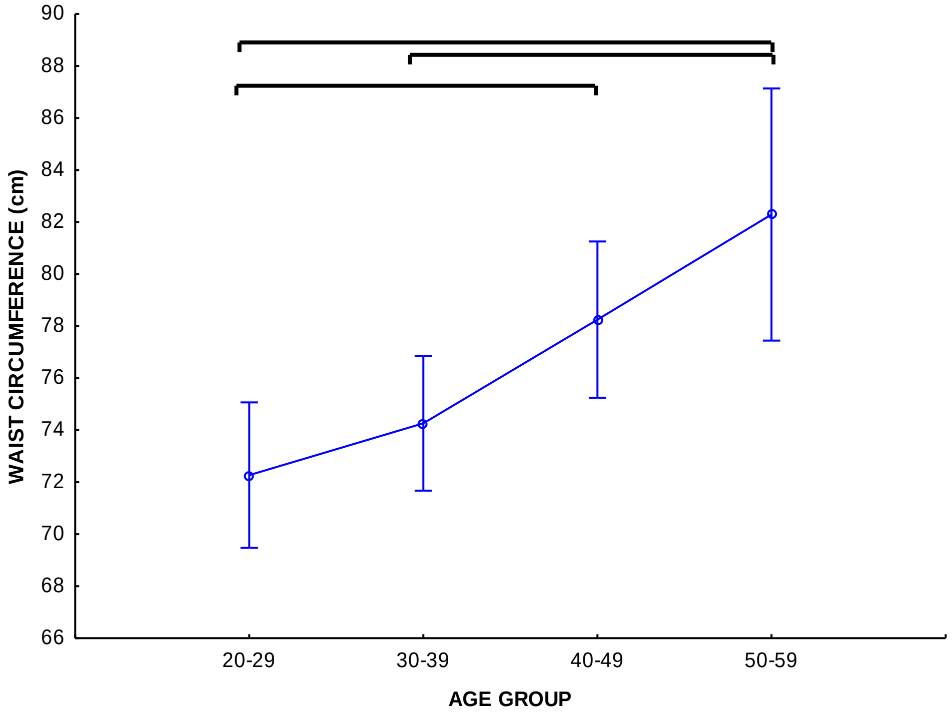


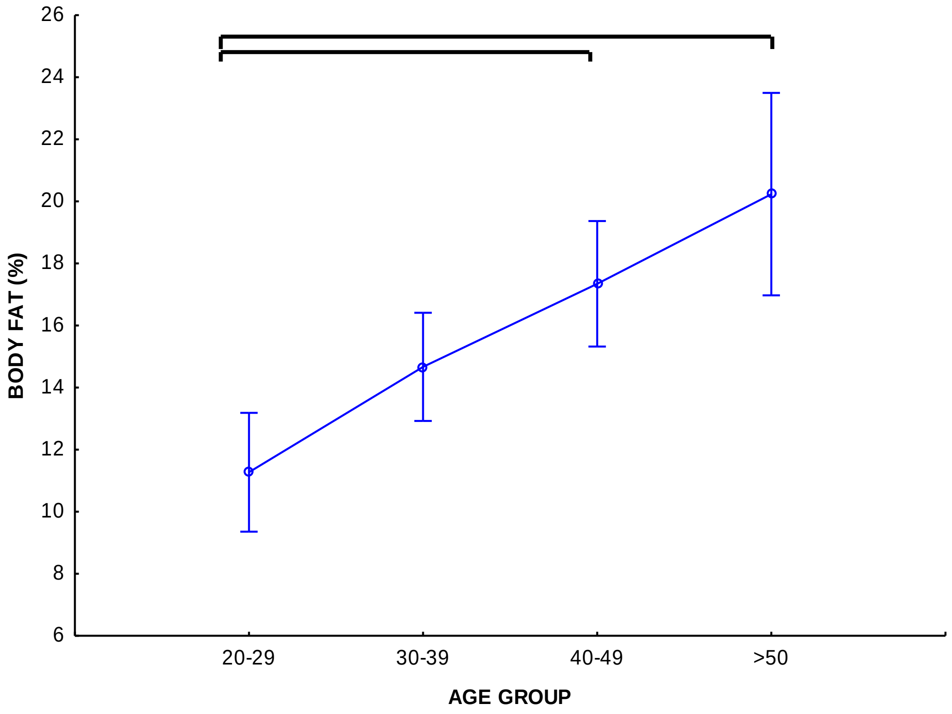
Figure 10: Mean waist-to-hip ratio (WHR) and of male workers of various age groups (limits from Heyward and Stolarcyzk, 1996).

In terms of ***waist circumferences***, all men were in the 'low' risk category, i.e. <90cm (WHO, 2007) as seen in Figure 11. Despite this, men from the oldest age group had significantly larger mean waist circumference (82.29 ±4.86cm) than the 20-29 and 30-39 age groups (72.27 ±2.81 and 74.26 ±2.56cm respectively), a trend similar to that of the WHR data. In addition to this, males in the 40-49 age group also had a significantly greater waist circumference than the youngest group of males.



⊓ Denotes a significant difference

Figure 11: The effect of age on the mean waist circumference (cm) of males



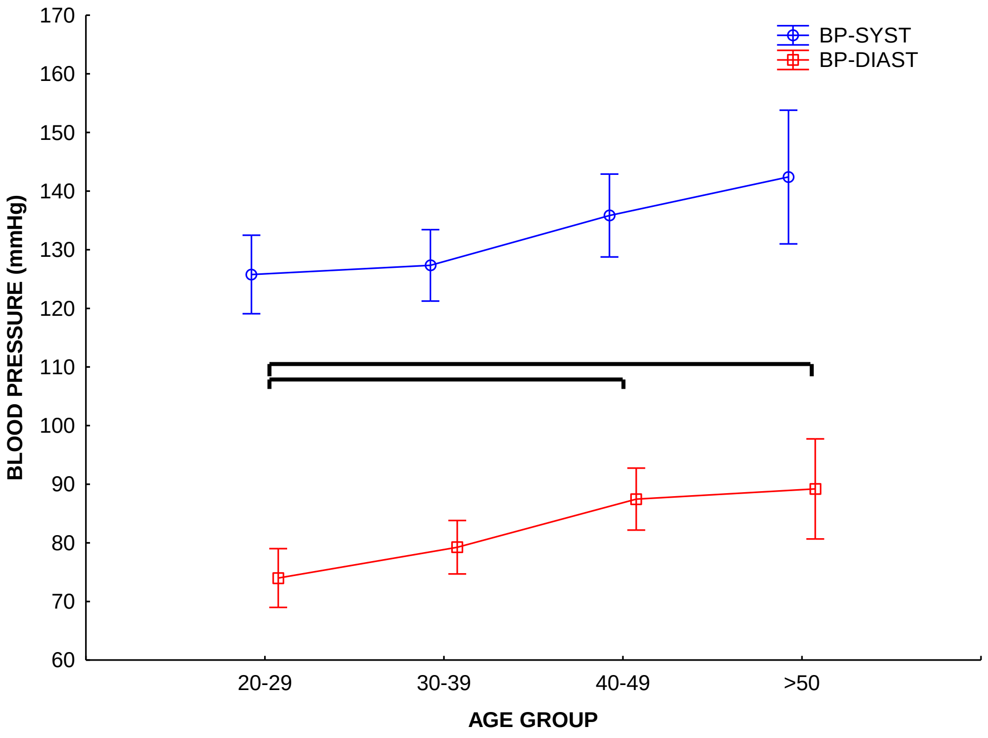
⊓ Denotes a significant difference

Figure 12: The effect of age group on the body fat percentage of male workers.

The ***body fat percentages*** for males of all age groups fell within the ‘ideal’ body fat percentage ranges for their age groups, rather than the ‘lean’ or ‘average’ categories. The 11.57% body fat of the 20-29 year old male participant group was found to be significantly lower ($p < 0.001$) than the 40-49 and ≥50 groups, 20.23% and 19.06% respectively. Furthermore, Figure 12 shows that the body fat percentage of the oldest group of participants was 23.48% higher than that found for the 30-39 age group, a statistically significant difference ($p = 0.02$). It is therefore apparent from the results that age appears to be an important indicator of body composition amongst this group of manual materials handlers.

BLOOD PRESSURE

The systolic blood pressure (SBP) and diastolic blood pressure (DBP) of men in the four age groups are shown in Figure 13. Although both SBP and DBP values increased steadily from the youngest to the oldest groups, only two of the increases were significant. Diastolic blood pressure of men in the 40-49 (87.46 ±5.13mmHg) and ≥50 (89.20 ±8.61mmHg) groups were significantly higher than those in the 20-29 group ($p = 0.002$ and $p = 0.016$ respectively).



Denotes a significant difference

Figure 13: The effect of age on the mean systolic and diastolic blood pressure of male workers

Although no groups were classified as having ‘high’ DBP (i.e. >90mmHg), the mean DBP of the oldest group was 0.8mmHg lower than the ‘high’ DBP rating. Diastolic blood pressure of the youngest group increased significantly by 13.46% to the 40-49 group and by 15.2% to the oldest age group. Age, therefore, does have a significant effect on the diastolic blood pressure values. No significant differences were seen between the SBP of men in the four age groups ($p > 0.05$), but the mean SBP of men in the ≥50 group (142.40 ±11.46mmHg) fell into the ‘high’ SBP group (≥140mmHg). Values for other groups were between 120 and 140mmHg and therefore within the ‘normal’ range. Age did not have a significant effect on SBP, but the oldest group was the only group whose SBP was categorized as high.

*R*ESTING HEART RATE

The resting heart rate of males of different ages is shown in Figure 14. These values were not significantly different ($p > 0.05$) between male workers of the four age groups, with a maximum range of 8.68 bt.min^{-1} between the oldest group (66 ±8.11 bt.min^{-1}) and the 40-49 group (74.68 ±4.94 bt.min^{-1}). The heart rates of the youngest and 30-39 age groups were within one beat of each other; 68.90 (±4.76) bt.min^{-1} and 69.54 (±4.34) bt.min^{-1} respectively. Age, therefore, did not have a significant effect on resting heart rate.

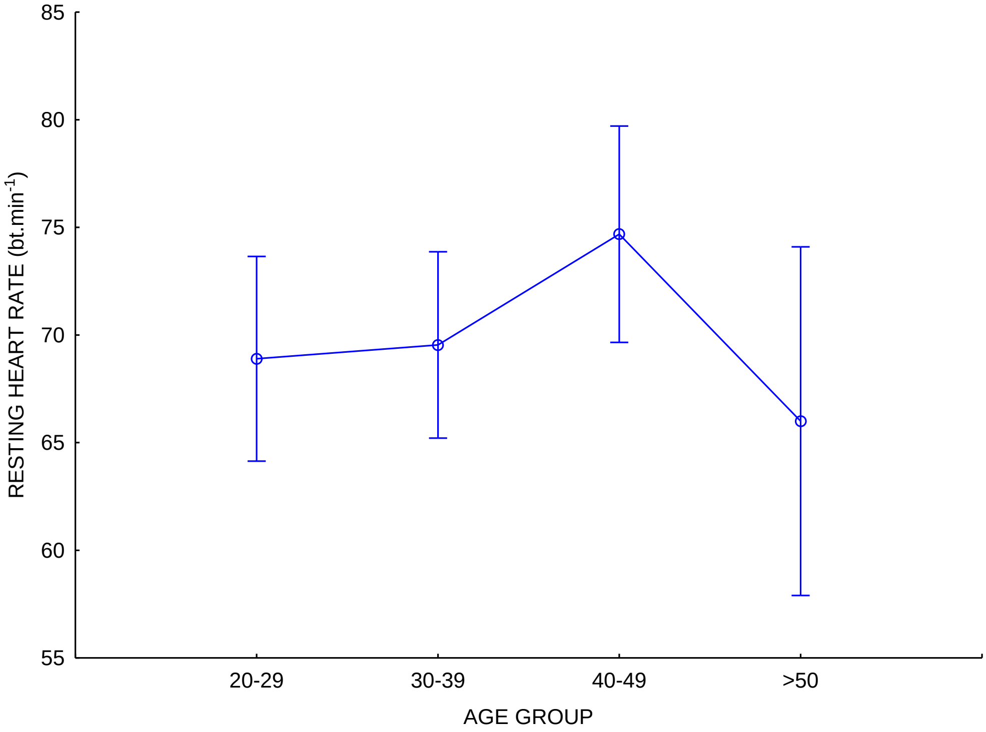


Figure 14: The effect of age on the mean (±SD) resting heart rate of male workers

Disease and risk factor prevalence

From the health section of the questionnaire which was filled out by the participants (n=101), there were five self-reported recordings of diabetes (one in both the youngest group and the 40-49 age group and three in the oldest group), shown in Figure 15. There were three reports of high cholesterol, one in the 20-29 age group and two in the 40-49 age group. Of the 15 reports of high blood pressure, three were in the youngest group, six in the 30-39 group, four in the 40-49 group and two in the ≥50 group. Only four of these participants reported taking medication for hypertension, two in both the 30-39 and 40-49 groups.

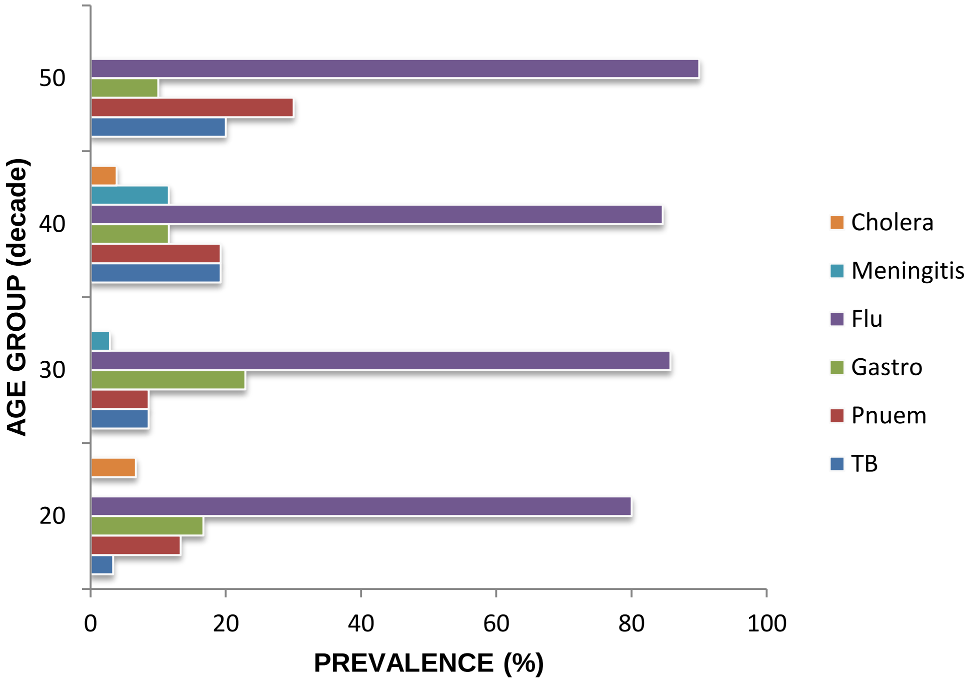


Figure 15: The self-reported history of disease prevalence of workers from various age groups.

There was one report of heart disease, in the 20-29 group. In terms of past illnesses, shown in Figure 15, influenza was the most common throughout all age groups. The ≥50 group had the highest reports of Pneumonia, followed by the 40-49 age group. Gastroenteritis was most reported in the 30-39 group, followed by the 20-29 age group. Tuberculosis was highest in the ≥50 group, followed by the 40-49 group. Reports of Cholera were only observed in the 40-49 and 20-29 age groups, whereas Meningitis was only reported in 40-49 and 30-39 age groups.

Table VIII: The prevalence of males from each age group who smoke cigarettes and consume alcohol, as well as, the quantity of use.

	CIGARETTES		ALCOHOL	
	Smokers (%)	# Cigarettes (±SD)	Drink Alcohol (%)	Amount (±SD) (L)
20 (n=30)	66.67	9.30	86.67	2.82 (1.64)
30 (n=35)	60.00	9.10	71.42	3.86 (3.22)
40 (n=26)	80.77	8.41	61.53	2.65 (1.68)
50 (n= 10)	80.00	7.88	80.00	2.42 (1.11)

Reported cigarette and alcohol use, in Table VIII, shows that males in the two older age groups 40-49 and ≥50 have the highest percentage of smokers (80.77% and 80.00% respectively), but they smoke fewer cigarettes daily (8.41 and 7.88 respectively) than the two younger groups. The younger males, 20-29 and 30-39 smoke an average of 9.30 and 9.10 cigarettes daily (respectively), but only 66.67% of 20-29 and 60% of 30-39 year old males are smokers. The youngest group of males had the highest percentage of alcohol drinkers (86.67%), whereas the 40-49 age group had the lowest percentage (61.53%), shown in Table . Of the 71.42% of men in the 30-39 group who drink alcohol, the mean daily consumption (over weekends) was 3.86L, the highest of all age groups. The other groups drank between 2.42L (for the ≥50 group) and 2.82L (for the youngest group).

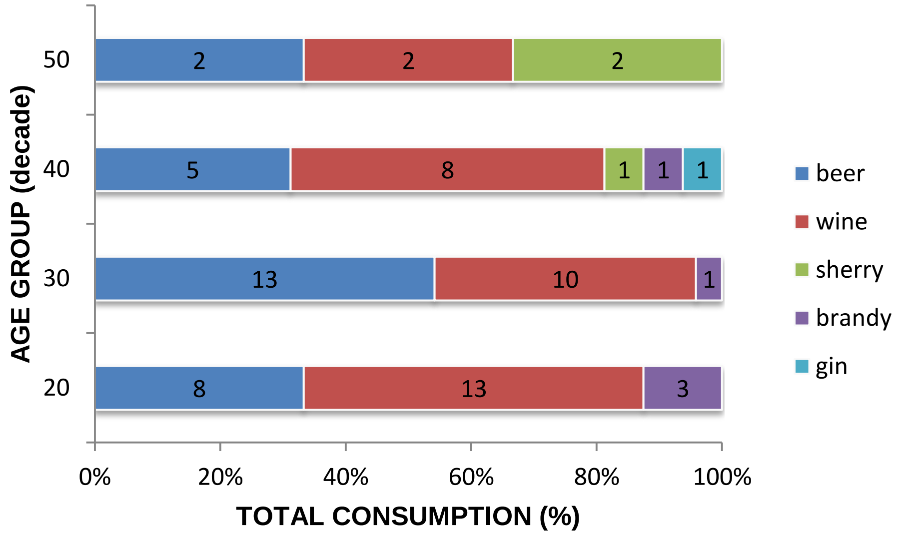


Figure 16: The percentage of various alcohols consumed by men in the four age groups (number of reports of each alcohol type are shown in figure).

Beer and wine were reported as the most commonly consumed alcohol types, as shown in Figure 16; wine was more popular in the 20-29 and 40-49 groups, beer was most popular in the 30-39 group and wine, beer and sherry were equally popular in the oldest age group. Brandy was the most commonly consumed spirit and was most often reported by the 20-29 age group.

BIOMECHANICS

STRENGTH

The mean (±SD) strength changes with age of six muscle groups, and two functional movements namely; Leg, Back, Bicep, Shoulder, Pinch, Grip, Push and Pull, are shown in Figures 4-11 below, and will be discussed in this order.

Leg strength, as seen in Figure 17, was highest in the youngest age group (117.47 ±21.04kgF) and lowest, by 25.67%, in the eldest group of males (87.32 ± 49.35kgF), but these results were not significantly different. The leg strength of males aged 30-39 and 40-49 were similar (93.56 ±19.17 and 93.41 ±21.95kgF respectively). Therefore age did not have a significant effect on leg strength.

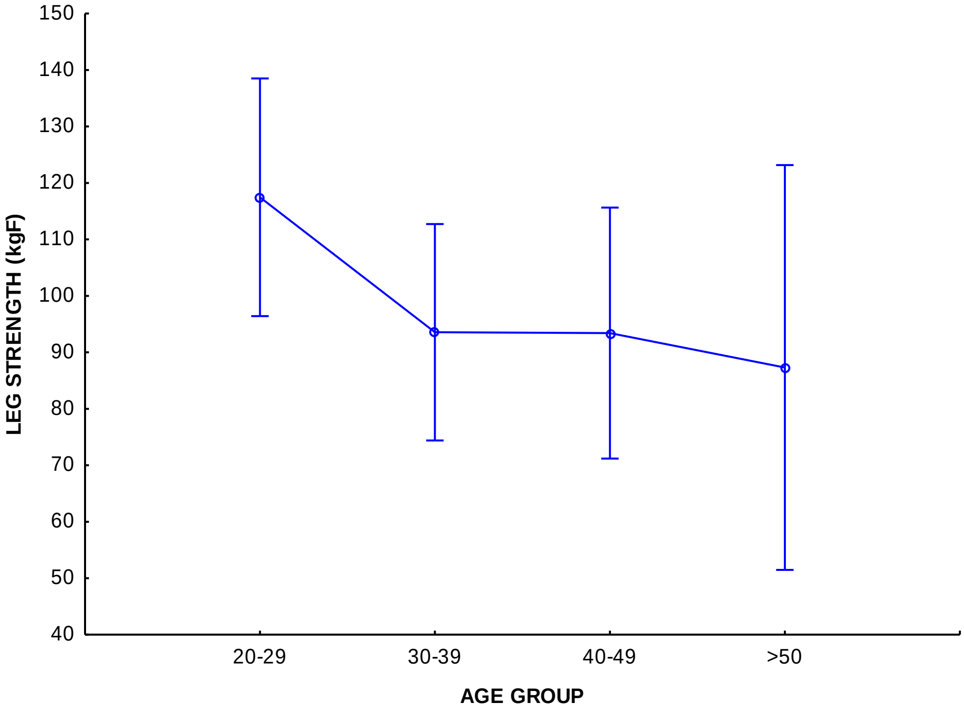


Figure 17: The effect of age on the mean (±SD) leg strength of male workers.

Figure 18 shows that the differences in ***back strength*** between the age groups were minimal, with a maximum difference of 6.65kgF between the oldest group (90.95 ±22.73kgF), who produced the greatest value and the 40-49 age group who produced the lowest force (84.30 ±13.82kgF). There were no significant differences in the back strength forces produced by the various age groups (p > 0.05). Therefore age did not have a significant effect on the back strength of male workers.

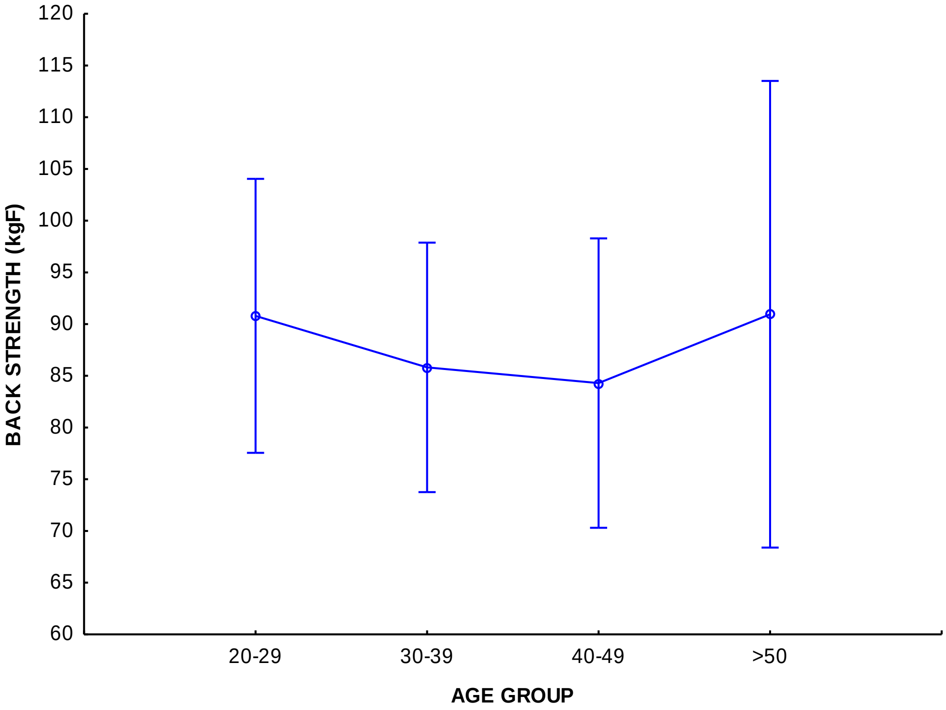


Figure 18: The effect of age on the mean (±SD) back strength of male workers.

Shoulder strength of the 20-29 age group (49.89 ±3.59kgF) was significantly higher (p = 0.03) than the ≥50 group (39.91 ±6.09kgF) with a 20.00% difference in the two forces produced (see Figure 19). The shoulder strength of the oldest group was also 11.51 and 12.71% lower than that of the 30-39 and 40-49 age groups respectively, although these values were not significantly different. Therefore age did have an effect on the shoulder strength of males aged 20-29 and ≥50.

Age related changes in shoulder and bicep strength were similar to each other (Figure 19 and Figure 20); with the highest strength values obtained by the youngest age group and the lowest by the eldest age group, with the two middle age groups 30-39 and 40-49 showing similar results.

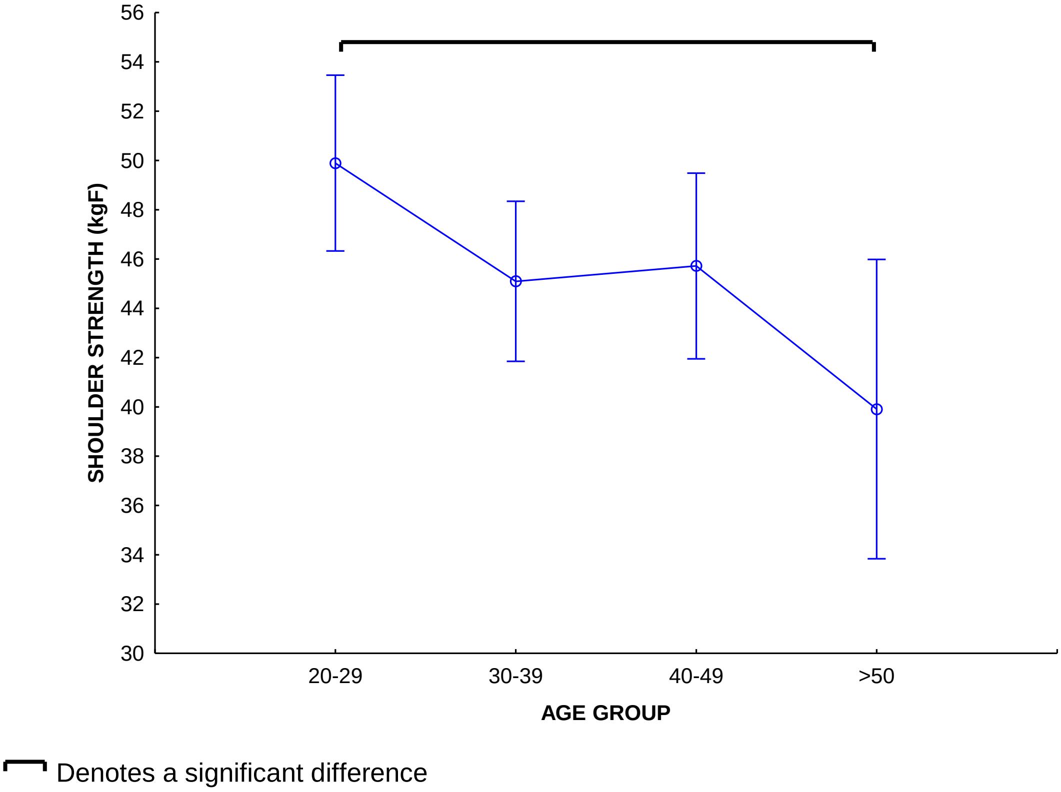


Figure 19: The effect of age on the mean (±SD) shoulders strength of male workers.

Although Figure 20 shows that the trend for ***bicep strength*** changes with age were similar to shoulder strength, the differences were much smaller. The bicep strength for the ≥50 age group (35.92 ±4.80kgF) was 9.25% lower than the 20-29 group (39.58 ±2.81kgF), 4.39% lower than the 30-39 group (37.57 ±2.59kgF) and 4.65% lower than the 40-49 age group (37.67 ±2.96kgF). None of the differences in bicep strength with age were statistically significant. Age therefore has no effect on the bicep strength of male workers.

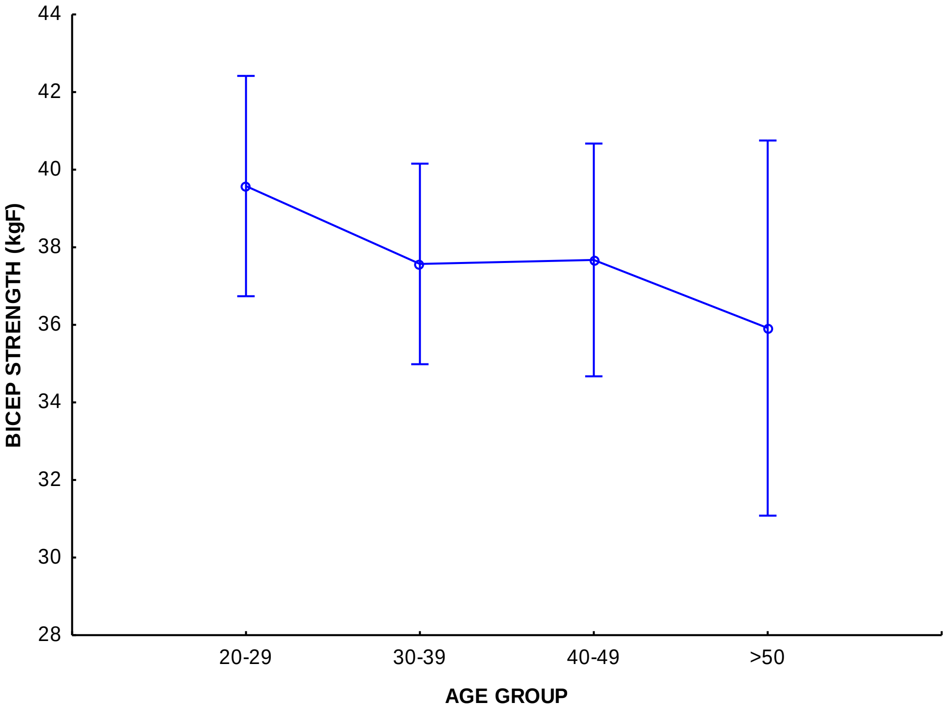


Figure 20: The effect of age on the mean (±SD) bicep strength of male workers.

Pinch strength, shown in Figure 21, was similar in all age groups with the maximum difference of 0.66kgF between the youngest group (10.59 ±0.78kgF) and the 30-39 age group (9.93 ±0.72kgF). Due to these similar values, there were no significant differences in the pinch strength of the four age groups.

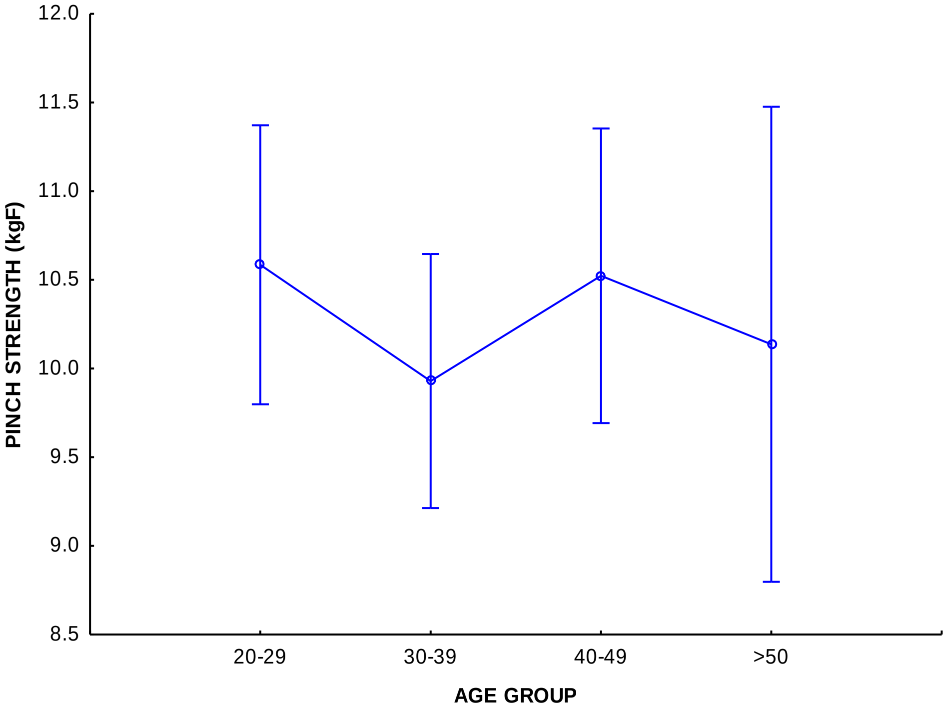


Figure 21: The effect of age on the mean (±SD) pinch strength of male workers.

The results from the effect of age of ***grip strength*** (Figure 22) show that the 20-29 group produced the highest strength (42.63 ±2.67kgF), the 40-49 and 30-39 age groups produced the in the second and third highest results middle of the range (40.43 ±2.75 and 40.43 ±2.46kgF respectively), with no significant differences between age groups. The ≥50 group produced the lowest grip strength (Figure 22), in this case 37.05 (±4.52) kgF which is 13.09% lower than the strength of the youngest group and 8.36% lower than both the 30-39 and 40-49 age groups. There were no significant differences in grip strength of the four age groups; therefore, age did not have a significant effect on grip strength in males.

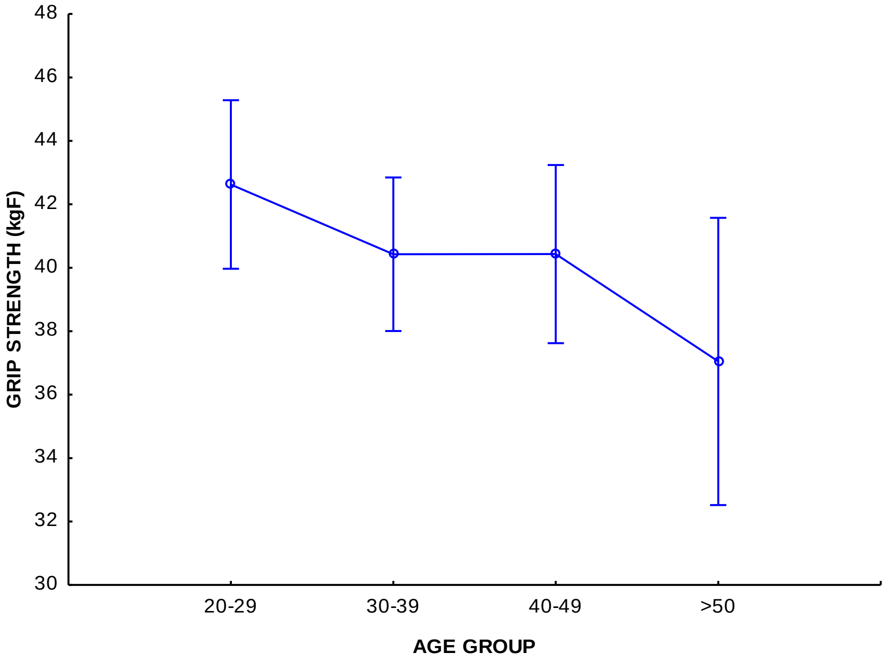


Figure 22: Mean (±SD) grip strength changes with age in male workers.

Push strength, as shown in Figure 23, decreases with age from the 20-29 age group (10.57 ±1.12kgF) to the 30-39 and 40-49 age groups (9.77 ±1.04kgF and 9.34 ±1.22kgF), although these differences were not statistically significant (p>0.05). The push strength production of the ≥50 group, 13.05 ±1.95kgF, was the greatest and was significantly higher than the push strength of the 30-39 (p = 0.02) and 40-49 (p = 0.01) groups. Therefore age had an effect on the push strength of males in the age groups between 30 and 59.

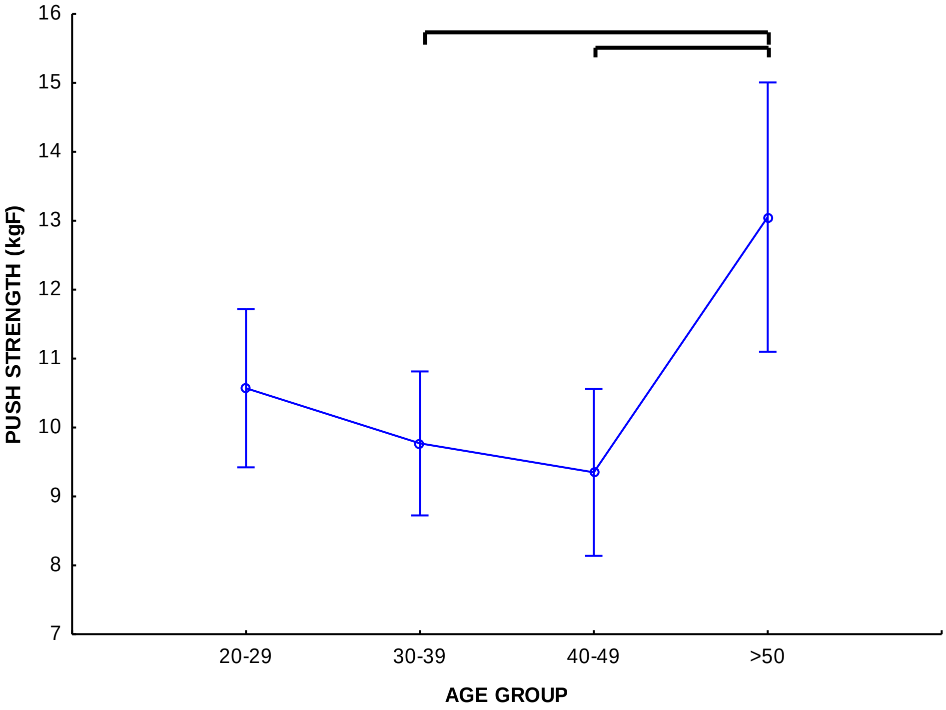


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Figure 23: The effect of age on the mean (±SD) push strength of male workers

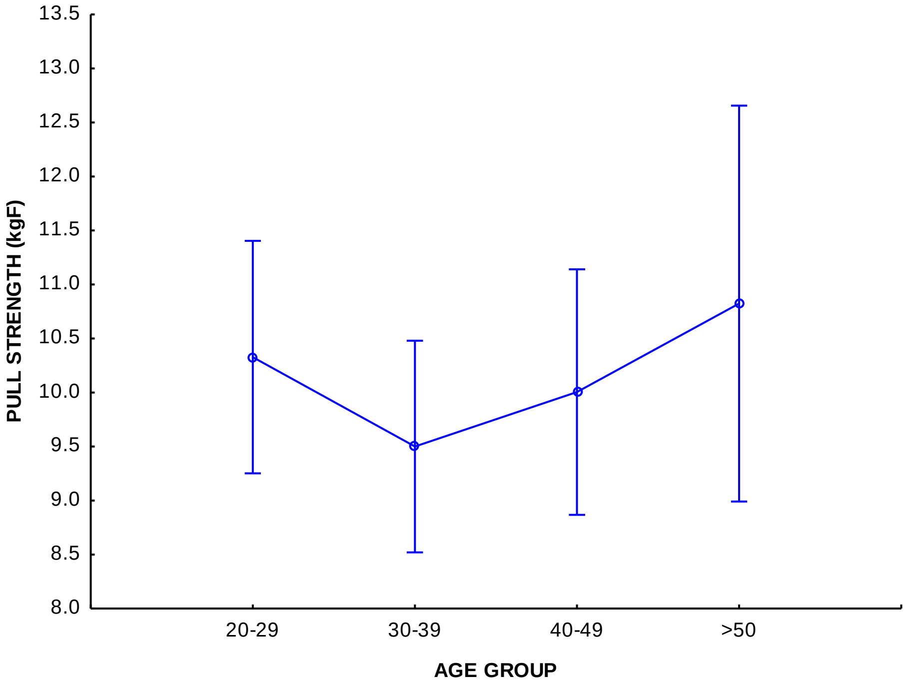

Figure 24: The effect of age on the mean (±SD) pull strength of male workers.

Figure 24 shows that the oldest group of males also had the greatest force production for ***pull strength*** (10.82 ±1.83kgF), followed by the youngest group (10.33 ±1.08kgF), with the 30-39 age group producing the lowest force production (9.5 ±0.98kgF).

Despite this, the effect of age on pull strength of males was not significantly different between the four age groups.

In summary, no significant differences were observed in; leg (Figure 17), back (Figure 18), bicep (Figure 20), pinch (Figure 21), grip (Figure 22) and pull (Figure 24) strength measurements ($p > 0.05$). Leg, grip, and bicep strength all showed declines with age, but these were not significant changes. Shoulder strength showed a significant decline with age ($p = 0.03$) from the 20-29 group to the over 50s group (Figure 19). Males over 50 had a significantly higher push strength than the 30s ($p = 0.02$) and 40s ($p = 0.01$) groups (Figure 23). Therefore age had an effect on force production of one muscle group and one functional movement.

SUMMARY

In terms of health, males in the 50 and over group had a significantly higher waist to hip ratio and body fat percentage than workers in the 20s and 30s groups. Workers in their 40s had a higher body fat percentage than the workers in the 20s age group. Despite this, workers in all age groups fell within the low risk or ideal categories for waist to hip ratio and body fat percentage respectively. The Diastolic blood pressure of workers in their 40s and 50s was significantly higher than workers in their 20s. The Systolic blood pressure of workers in the 50 and over age group was in the ‘high’ blood pressure category. Workers in the 40s and 50s age groups smoked fewer cigarettes, but the percentage of workers who smoked was greater in these two groups. More than or equal to 80 percent of workers in the 20s and 50s age groups drank alcohol. Workers in the 50 and over age group showed the highest occurrences of Flu, Pneumonia and Tuberculosis. Males in the 50s age group had a significantly lower shoulder strength than workers in their 20s and a significantly higher push strength than workers in their 30s and 40s.

PART II: TASK DEMANDS

The second part of this study aimed to increase the understanding of the task demands of three similar manual materials handling tasks in the brick making industry. This was done not only to aid in the understanding of task demands in a South African MMH context, but also to ascertain whether the increasing mechanisation of tasks in IDCs are a step towards reducing injury risk in industry. Only male workers were assessed for this section of research, as these tasks were male dominated.

TASK COMPARISON

Of the three tasks measured; the clay dry brick (CDB) task was entirely manual, requiring picking dry bricks off a coal-fired stacked kiln and placing them on pallets at or below floor level. The clay wet brick (CWB) task was partly mechanised, with a conveyor belt carrying wet bricks to the right hand side of the workers, who then stacked the bricks onto pallets on their left. The kiln dry brick (KDB) task also consisted of partial mechanisation, with a conveyor belt transporting dry bricks, to the workers who were on both the left and right hand side of the conveyor belt and placed the bricks onto pallets on their left and right respectively. This will provide a more thorough representation of the task demands in the industry and will also show the effect that increased mechanisation/automation has on the task demands.

BIOMECHANICAL ASSESSMENT

SPINAL KINEMATICS

The maximum lateral, sagittal and twisting ranges of the three tasks are displayed in Figure 25. This shows that the CDB task had the greatest range in all three planes, followed by the CWB task, with the KDB task presenting the lowest ranges in all three planes. The ***lateral ranges*** of both the CDB and CWB tasks were significantly higher than the lateral range of the KDB task ($p < 0.001$ and $p = 0.03$ respectively). The KDB task therefore has the lowest lateral range of the three tasks (13.59º ±9.13), 35.71% and 27.24% lower than the CDB and CWB tasks respectively. The ***sagittal range*** of motion for the CDB task of 20.36º (±12.59) was significantly higher than the sagittal ranges of the CWB, 13.46º (±3.68), and the KDB, 11.81º (±7.62) tasks ($p = 0.002$ and $p < 0.001$ respectively) as seen in Figure 25.

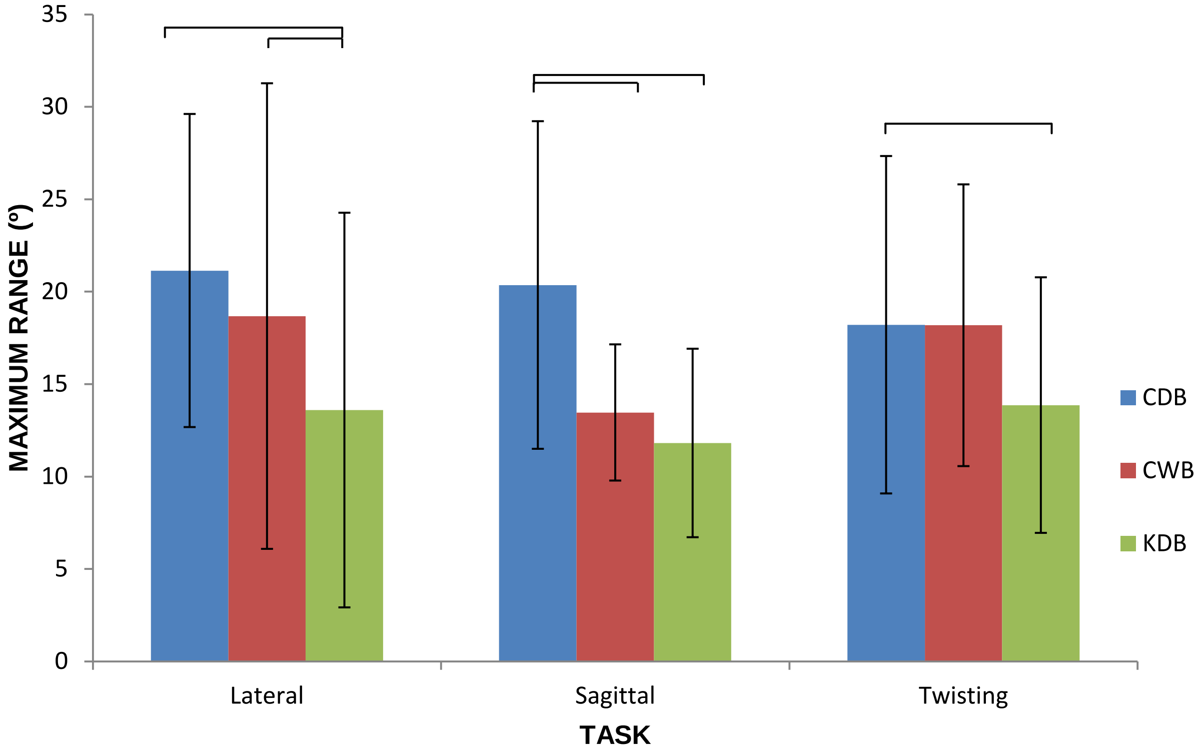

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Figure 25: Overview of the maximum lateral, sagittal and twisting angles of the three tasks.

The ***twisting range*** of the CDB (18.21º ±10.67) task was significantly higher than that of the KDB (13.86º ±6.91) task ($p = 0.03$) as shown in Figure 25. The maximum twist range of the CWB (18.18º ±5.10) task, which was similar (0.16% lower) to the CDB task, was 23.76% greater than the KDB task; this however was not statistically significant ($p > 0.05$). The large sagittal range of the CWB task is due to the starting point of the CDB workers ranging from foot height to overhead, whereas the other two tasks start at above hip height and the lowest bend needed is to place bricks at ankle height. With all tasks, however, the workers are all in a constant state of flexion throughout the task which opens up all the workers of these tasks to potential lower back pain.

Lateral bend

Both the Clay dry brick (CDB) palletising and the Kiln dry brick (KDB) sorting tasks required more of a ***right lateral bend*** (14.75 ±8.11 and 10.22 ±6.75º respectively) and the right bent of the Clay dry brick (CWB) task was significantly higher than that of the other CWB and KDB tasks ($p < 0.001$ and $p = 0.008$ respectively) (Figure 26).

The CWB palletising task required more of a ***left lateral bend*** (-11.81 ±5.98°), and this was significantly higher than the CDB and KDB tasks ($p = 0.005$ and $p < 0.001$ respectively). This is due to all the workers receiving bricks from the conveyor belt on the right side and placing them on the pallet on their left. The biggest variation in the maximum bend was seen in the CDB task, as the height at which they are picking up bricks, as well as, placing the bricks are constantly changing, whereas only the placing height differs on the other tasks.

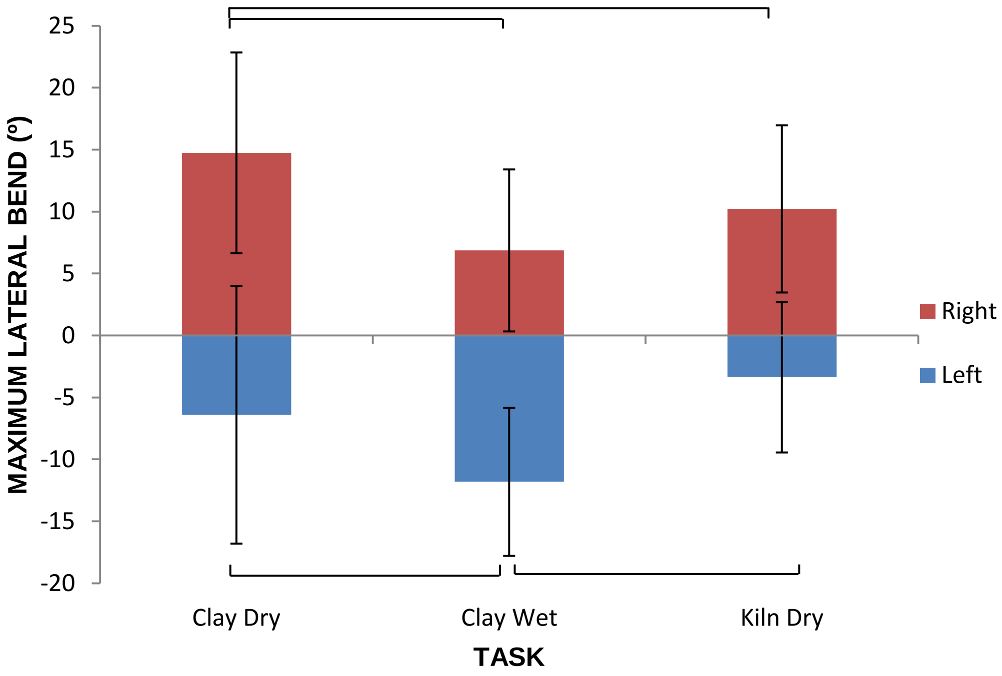

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Figure 26: The maximum left and right lateral bend angles of the three tasks.

Taking all of this into consideration, the KDB task showed the lowest risk, whereas the CDB showed the highest risk for maximum right bend (with a 53.42% and 30.71% higher right bend than CWB and KDB tasks respectively) and the CWB showed the greatest risk for maximum left bend (with a 45% and 71.46% higher left bend for the CDB and KDB tasks respectively).

The ***average lateral velocity***, shown in Figure 27, was significantly higher for the CWB task (12.45º ±4.81) than the CDB (7.91º.s^{-1} ±3.15) and KDB (9.31º.s^{-1} ±6.13) tasks ($p < 0.001$ and $p = 0.009$ respectively). Despite the CDB task exhibiting the highest maximum acceleration and the second highest maximum velocity (Figure 28), this task showed the lowest average lateral velocity.

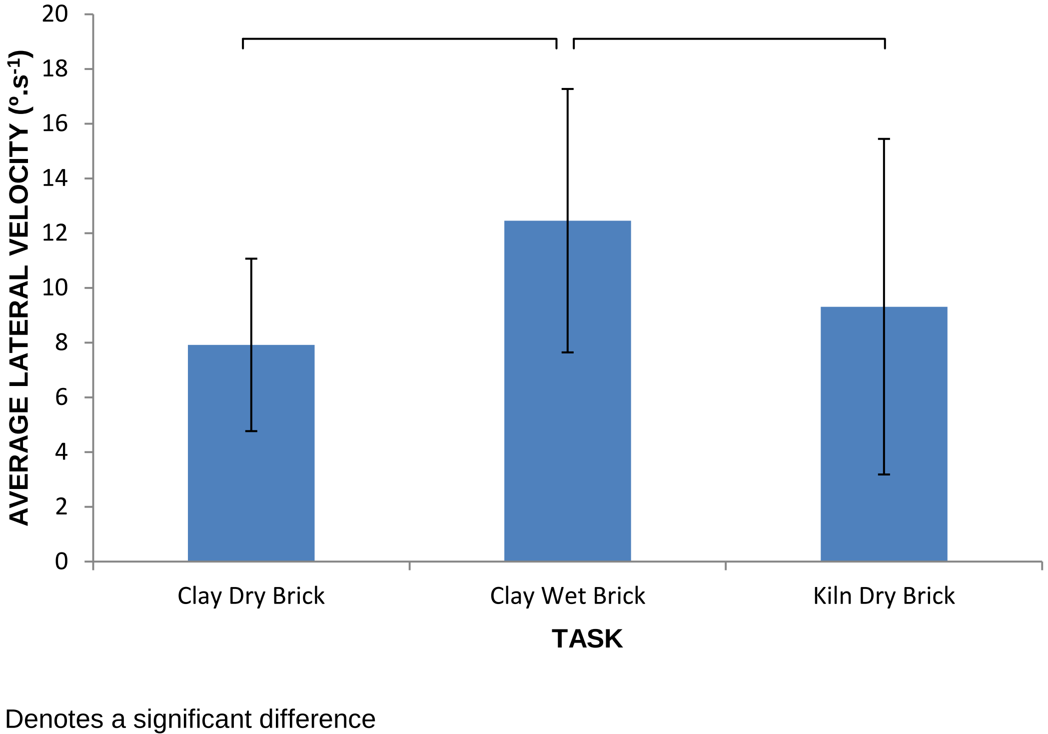

Figure 27: The average lateral velocity (º.s^{-1}) of the three tasks.

Although no significant differences were seen in the ***maximum lateral velocities*** and acceleration of the three tasks ($p > 0.05$), Figure 28 shows that the KDB task had the lowest values for both (30.45 ±15.68º.s^{-1} and 199.81 ±90.91º.s^{-2} respectively). The maximum lateral velocity was greatest in the CWB task (38.66 ±12.26º.s^{-1}) and the CDB task had the highest maximum lateral acceleration (245.74 ±125.26º.s^{-2}). Despite this, due to the lack of significance in the differences; the three tasks did not have an effect on lateral bending velocity and acceleration speeds.

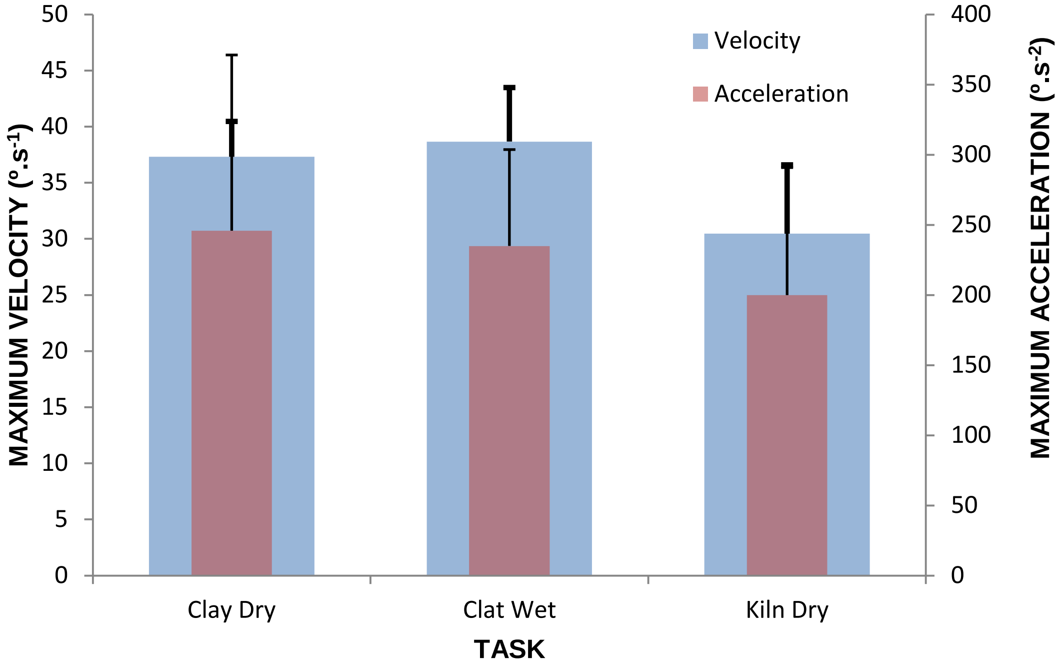

Figure 28: Maximum acceleration and velocity in the lateral plane of the three tasks.

Sagittal bend

None of the tasks had spinal extension past 0 degrees, but within the state of flexion there were similar angles of extension in all tasks; 10.53º (±12.23) for the CDB task, 10.71º (±5.58) for the CWB task and 10.45º (±7.87) for the KBD task (Figure 29).

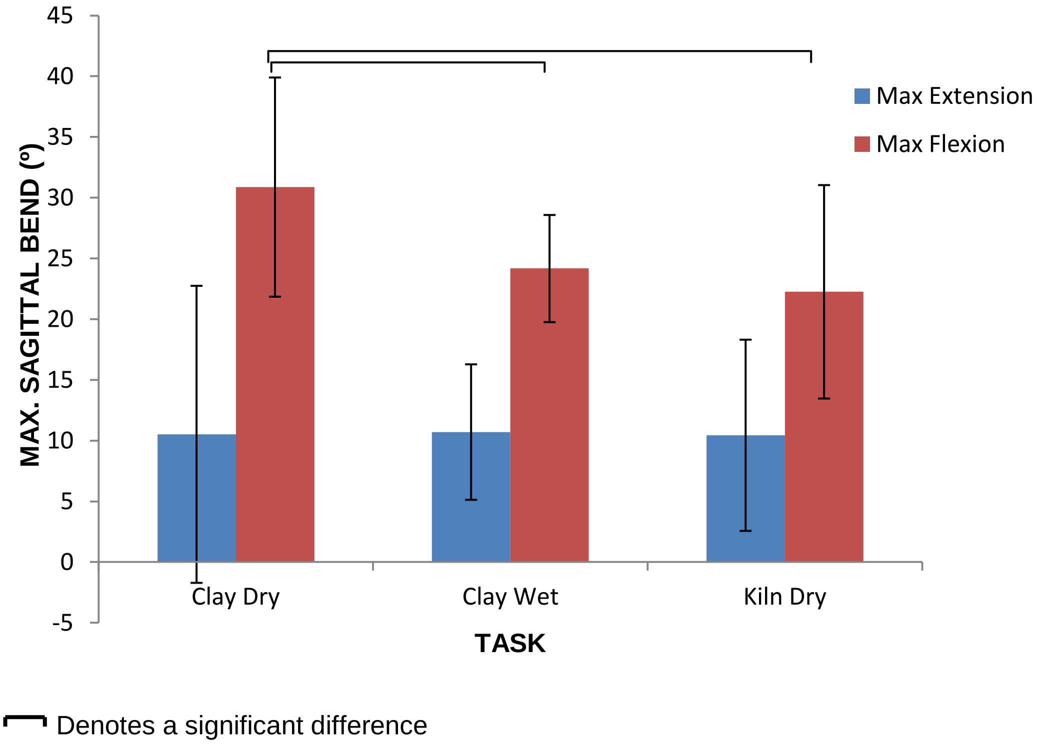

Figure 29: The maximum sagittal angles (flexion and extension) of the 3 tasks.

For extension, the CDB task had the highest variation of the angles and CWB had the least variation. The CDB task required a significantly greater flexion (30.88º ±9.02) than both the CWB (24.17º ±4.41) and KDB (22.26º ±8.79) tasks ($p < 0.001$ in both). Therefore the CDB task showed the highest risk, with a mean flexion 21.73% greater than the CWB task and 27.91% greater than the KDB task.

The average sagittal velocity of the CWB (9.54º.s^{-1} ±3.65) task was significantly higher than that of the CDB (6.47º.s^{-1} ±4.14) task ($p = 0.002$) as shown in Figure 30. In addition the CWB task was 14.99% greater than the KDB (9.11º.s^{-1} ±5.39) task, but this difference was not significant. Therefore the task did have a significant effect on the average sagittal velocity.

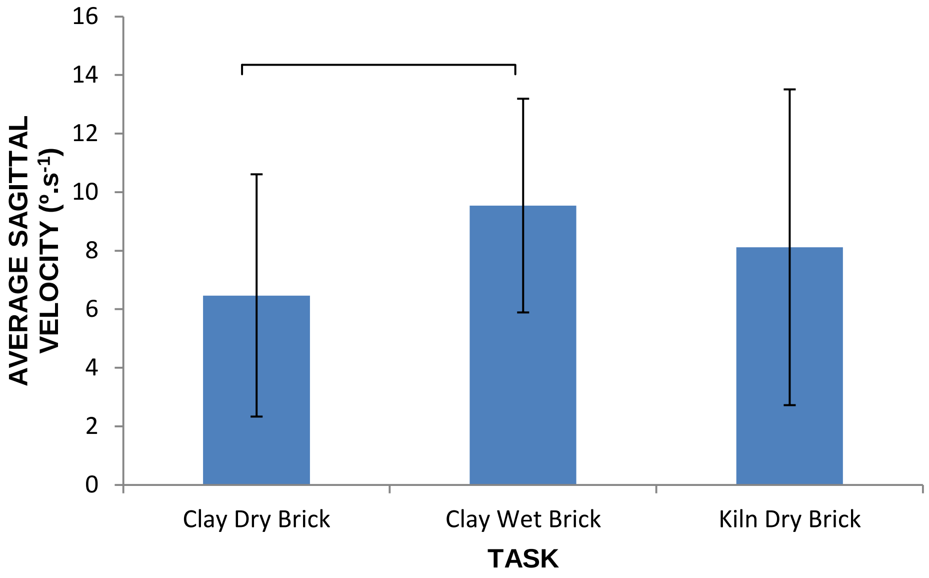

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Figure 30: The average sagittal velocities (º.s^{-1}) of the three tasks.

The maximum sagittal accelerations of the three tasks are similar (Figure 31), between 200.30 (±118.20)º.s^{-2} the KDB task and 212.90 (±112.37º.s^{-2}) for the CDB task, with no significant differences between the tasks. Similarly for the maximum sagittal velocity there were no significant differences; the CDB and CWB tasks showed similar values (34.65 ±20.02º.s^{-1} and 33.99 ±11.42º.s^{-1} respectively), whereas the value for the KDB task was slightly lower (30.12 ±18.71º.s^{-1}).

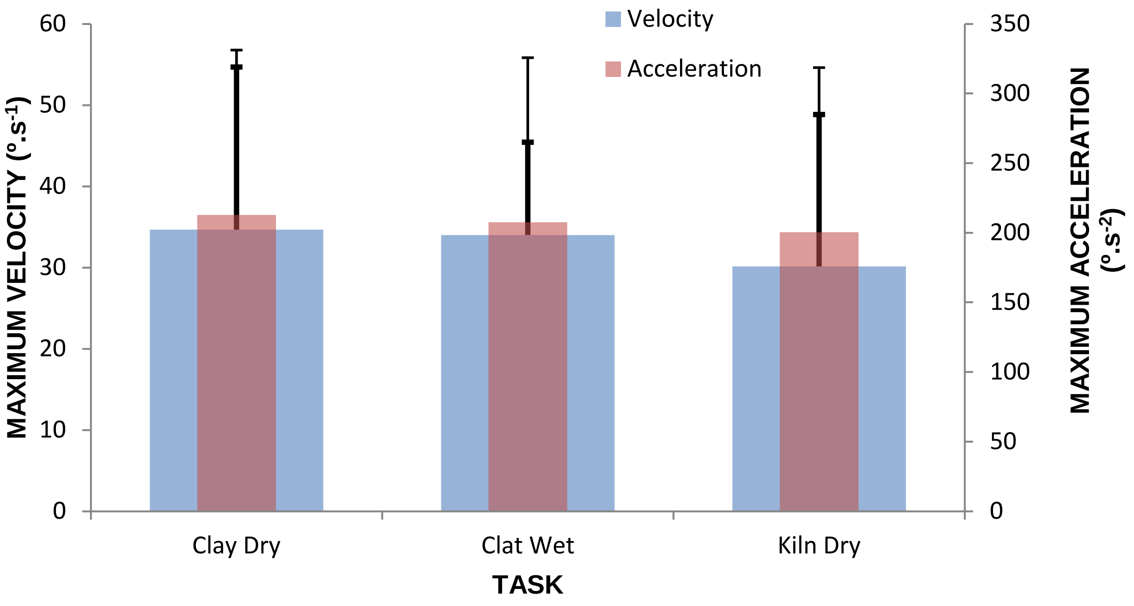

Figure 31: The maximum sagittal velocity and acceleration of the three tasks.

Axial twist

The right maximum twist, as shown in Figure 32, of the CWB task was the highest (18.22 ±5.63º) and was significantly higher than the other two tasks ($p < 0.001$ for both), which were 8.98º (±9.49) for the CDB task and 5.68º (±4.35) for the KDB task. The CDB and KDB tasks had a significantly higher left twist than the CWB task ($p < 0.001$ for both), where the mean maximum twist was only slightly above zero (0.05 ±4.41º). The CDB and KDB tasks involved both left and right twists. While the CDB task had almost equal twist angles on both sides, the KDB task had a slightly higher left twist.

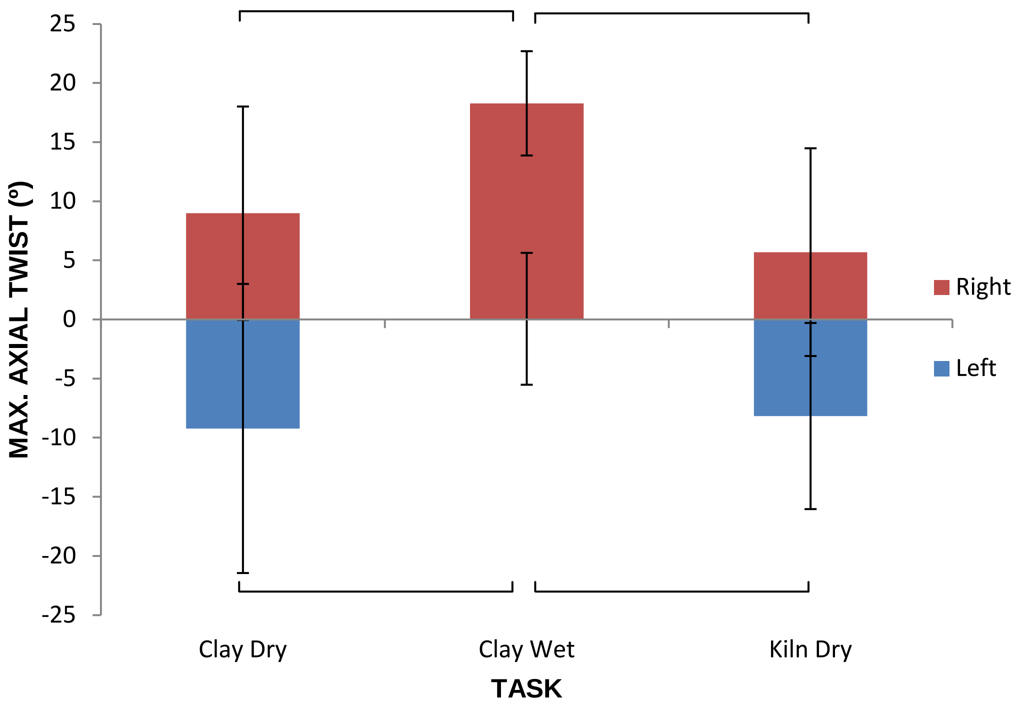

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Figure 32: The maximum transverse angles (left and right twist) of the 3 tasks.

Figure 33 shows that the average twist velocity of the CDB (6.53º.s^{-1} ±3.62) task was significantly lower than the average twist velocities of both the CWB (12.53º.s^{-1} ±4.02) and the KDB (10.84º.s^{-1} ±5.28) tasks ($p < 0.001$ for both).Therefore the task has a significant effect on the twist velocities.

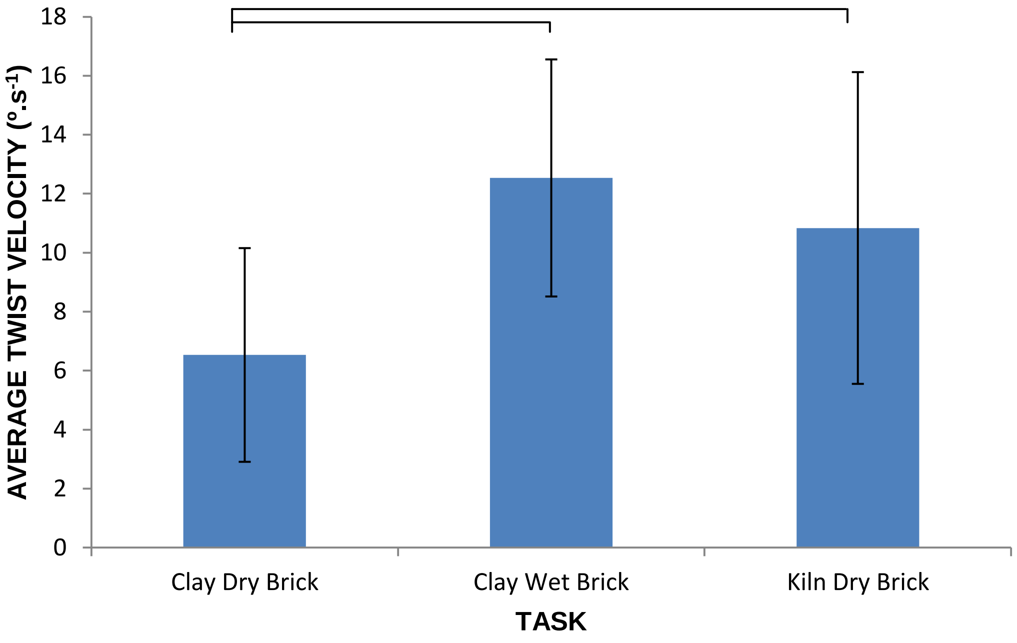

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Figure 33: The average twist velocities (º.s^{-1}) of the three tasks.

The CWB task produced the greatest maximum twist velocity and acceleration of the three tasks (49.99 ±13.23º.s^{-1} and 321.39 ±78.21º.s^{-2} respectively) and the KDB task had the lowest (39.10 ±17.91º.s^{-1} and 260.52 ±120.73º.s^{-2}); the differences between all tasks were not significantly different as shown in Figure 34.

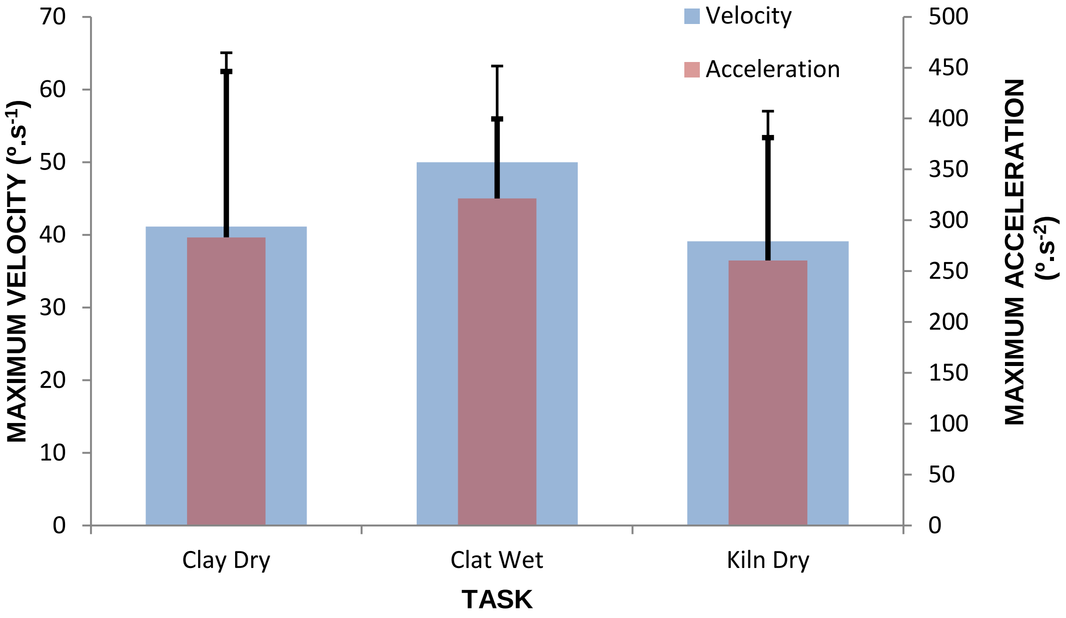

Figure 34: The maximum twist velocity and acceleration of the three tasks.

This means that the workers performing the CWB task had the fastest lateral bend and that the workers performing the CDB task had the slowest twist velocity and were the slowest overall. This could be due to the areas of brick collection and brick placing being further apart than the other two tasks, so workers were moving slower to pace themselves.

Summary

In summary, of the spinal kinematics of the three tasks, shown in Figure 35; for most of the work task duration; the workers in the clay dry brick task were between an 11 and 30 degree flexed position with a -6 (left) to 15 (right) degree lateral bend and twisted equally left and right by approximately 8 degrees. The clay wet brick task workers were between an 11 to 25 degree flexed position with a 7 (right) to -12 (left) degree left lateral bend and a 0 (left) to 18 (right) degree twist. Lastly, the Kiln dry brick task involved a 10 to 22 degree flexed position with a -3 (left) to 10 (right) degree right lateral bend and a -8 (left) to 6 (right) degree twist.

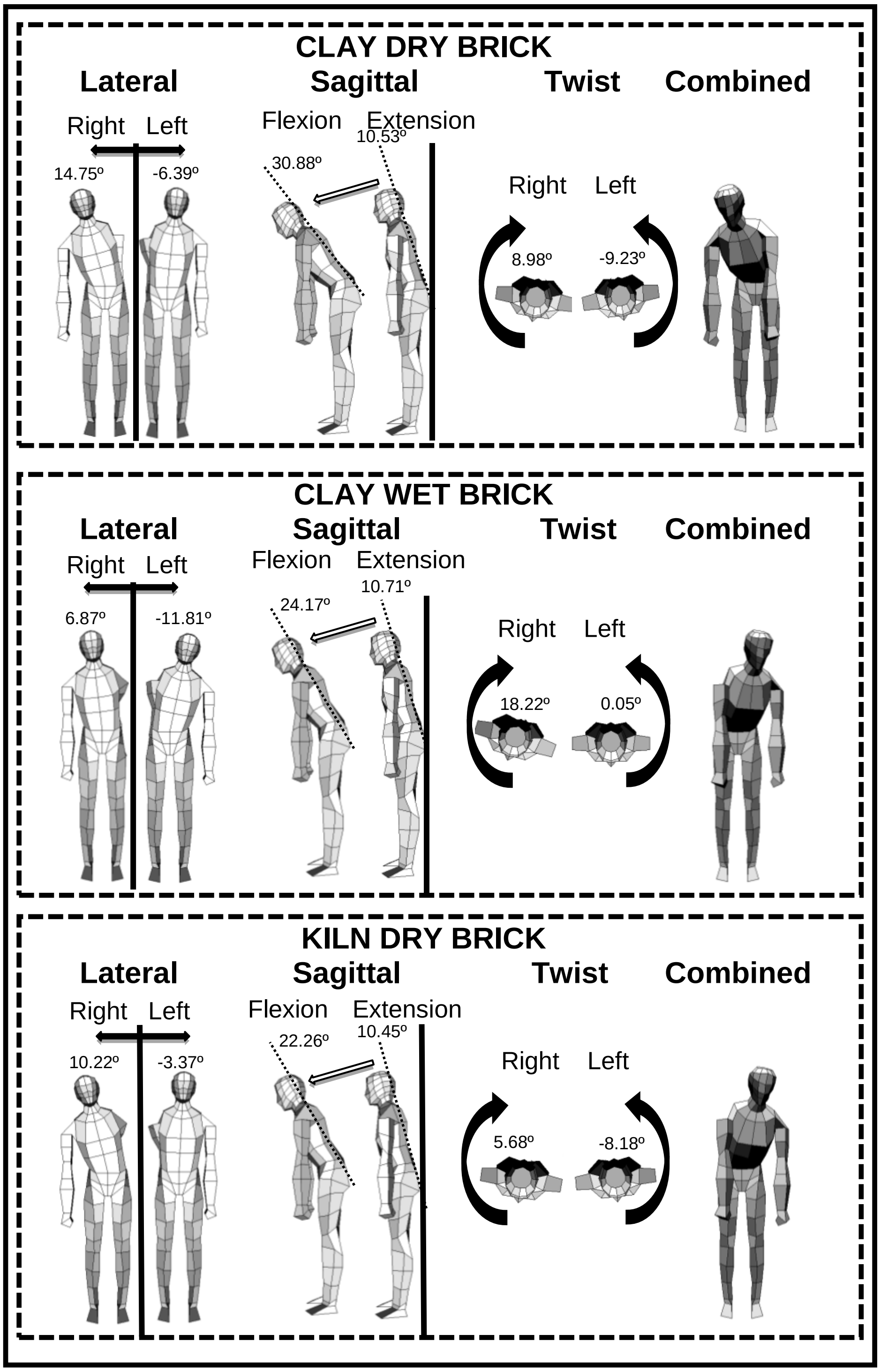

Figure 35: A summary of the lateral, sagittal and twist angles of the three tasks, as well as an example of the combined effect of these angles. Figure developed with the 3DSSPP software (University of Michigan, 2001).

Figure 36 shows samples of the simultaneous degrees of movement between the sagittal, lateral and twist movements in the three tasks. These movements are occuring as an entity and not as individual parts.

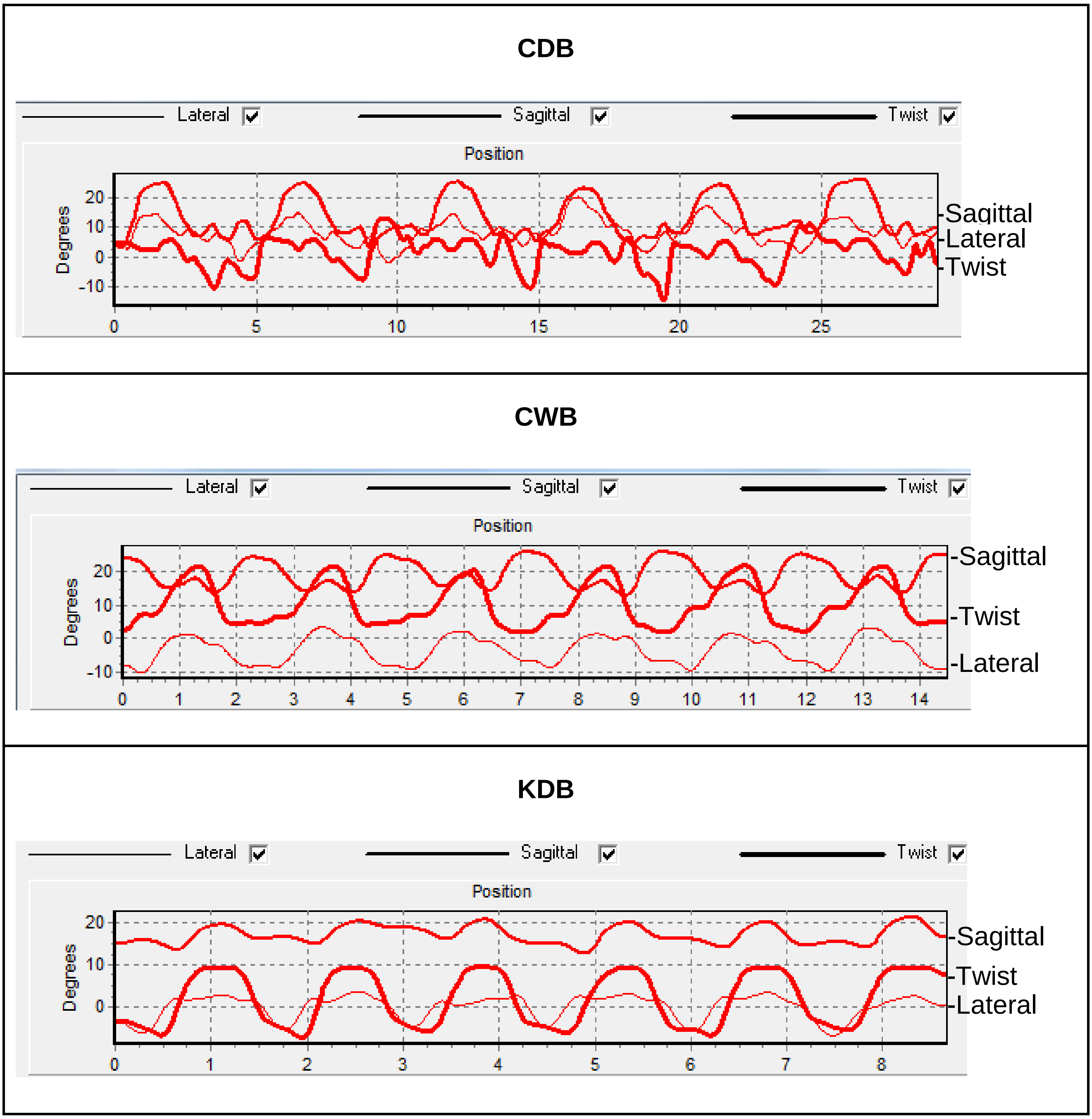

Figure 36: Samples of the simultaneous movements in the lateral, sagittal and twist (transverse) planes, as observed in the three tasks with the Ballet 2.0 software.

It is, therefore, important to note that in addition to movement happening in all three planes (Figure 35), these movements are happening concurrently (Figure 36), therefore exacerbating the potential risk associated with the tasks.

JOINT FORCES

The predicted compression and shear forces on the lower back, specifically the L_5/S_1 and L_4/L_5 joints, as well as the predicted left and right erector spinae muscle forces will be presented, in relation to the three tasks. Analyses using the three dimensional static strength prediction program (3DSSPP) showed that the total compression of the three tasks were, as shown in Figure 37, between 2125.10(±335.81)N for the CDB task and 2380.75(±426.53)N for the CWB task. These forces were not significantly different between tasks and all tasks were below the maximum permissible compression limit of 350kg (3432.33 N) put forward by Jager and Luttman (1999) and lower than the NIOSH (1981) threshold values of 346.70kg (3400N).

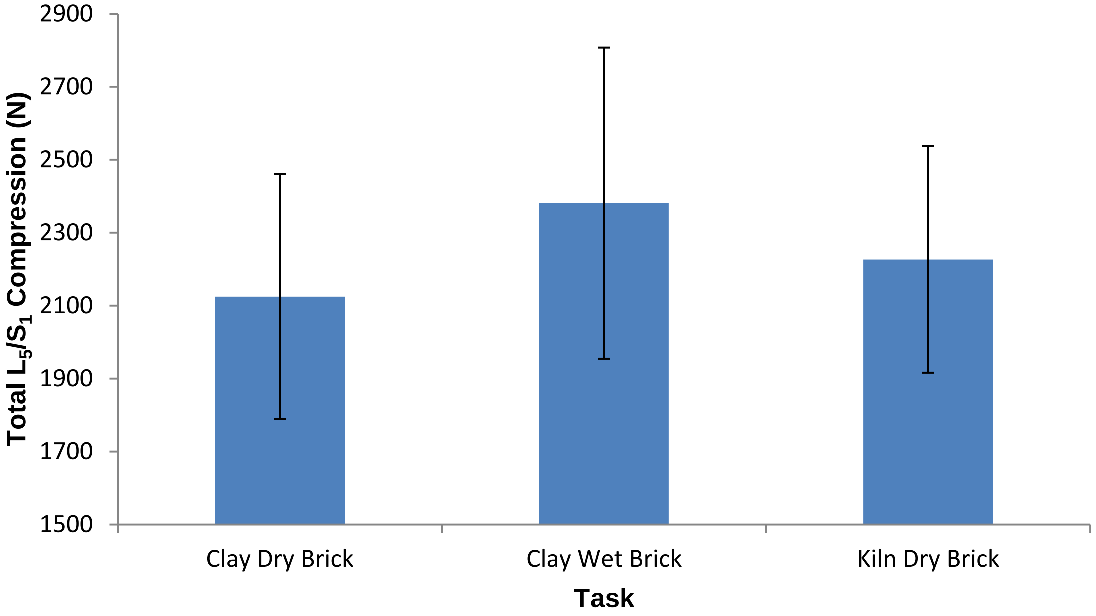

Figure 37: The total lower back compression forces (N) a L5/S1 of the three tasks assessed (mean ±SD).

The task comparison of the total sagittal shear forces of the lumbosacral disc are shown in Figure 38. The CDB task (340.33 ±42.43N) presented the highest sagittal shear forces, significantly greater than the KDB task (298.92 ±49.64N) with p= 0.04. The CWB task was not significantly different to the two other tasks, with a mean sagittal shear force of 302.25(±42.41)N. These values were below previously reported tolerance limits (Farfan *et al*., 1970; McGill, 1997; Yingling *et al*., 1999).

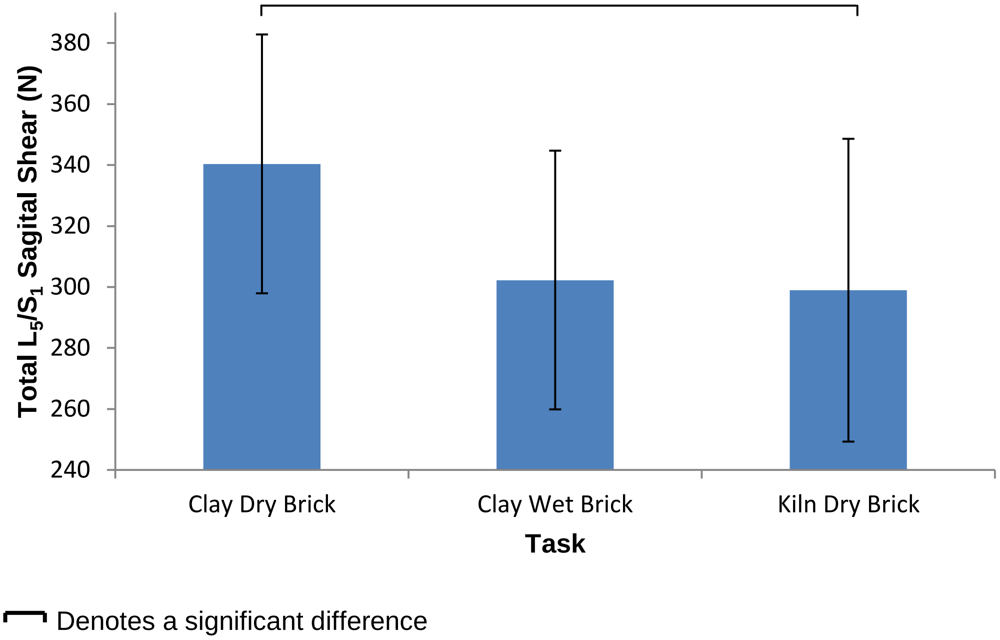

Figure 38: The total sagittal shear forces (N) at the L5/S1 (mean ±SD), of workers from the three tasks.

The left and right erector spinae forces of the three tasks are shown in Figure 39. Although the left erector spinae force of the CWB task (627.92 ±391.06N) was lower than both the CDB and KDB tasks (826.76 ±130.02N and 826.75 ±128.55N respectively), no significant difference was observed between the tasks. In terms of the right erector spinae force, however, the CWB task (1096.08 ±116.22N) was significantly higher than both the CDB (806.24 ±126.69N) and KDB (836.00 ±137.46N) tasks, with $p < 0.001$ for both. No significant difference was found between the CDB and KDB tasks.

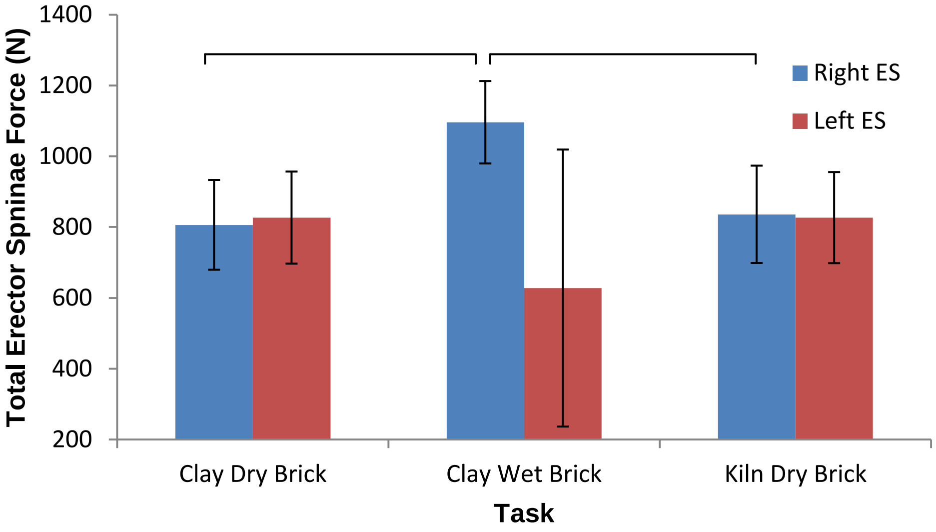

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Figure 39: Total left and right erector spinae muscle forces (N) of workers from the three tasks (mean ±SD).

PHYSIOLOGICAL ASSESSMENT

HEART RATE

Figure 40 shows that heart rate was not significantly different between the tasks at the start of the protocol ($p > 0.05$), with between 84 bt.min^{-1} (±9) for the KDB task and 91 bt.min^{-1} (±13) for the CWB task. At the halfway mark (after 30 bricks had been palletised), the heart rate of the CDB (125 bts.min^{-1} ±19) and CWB (116.82beats.min^{-1} ±15) task workers was significantly higher than the KDB (98.25bt.min^{-1} ±11) task ($p < 0.001$ and $p = 0.016$ respectively) (Figure 40). Similarly, Figure 40 shows that at the end of the protocol (60 bricks lifted) the workers of the CDB (132 bt.min^{-1} ±16) and CWB (128 bt.min^{-1} ±17) tasks had heart rates higher than that of the KDB (106 bt.min^{-1} ±12) task workers ($p = 0.002$ and $p = 0.01$ respectively).

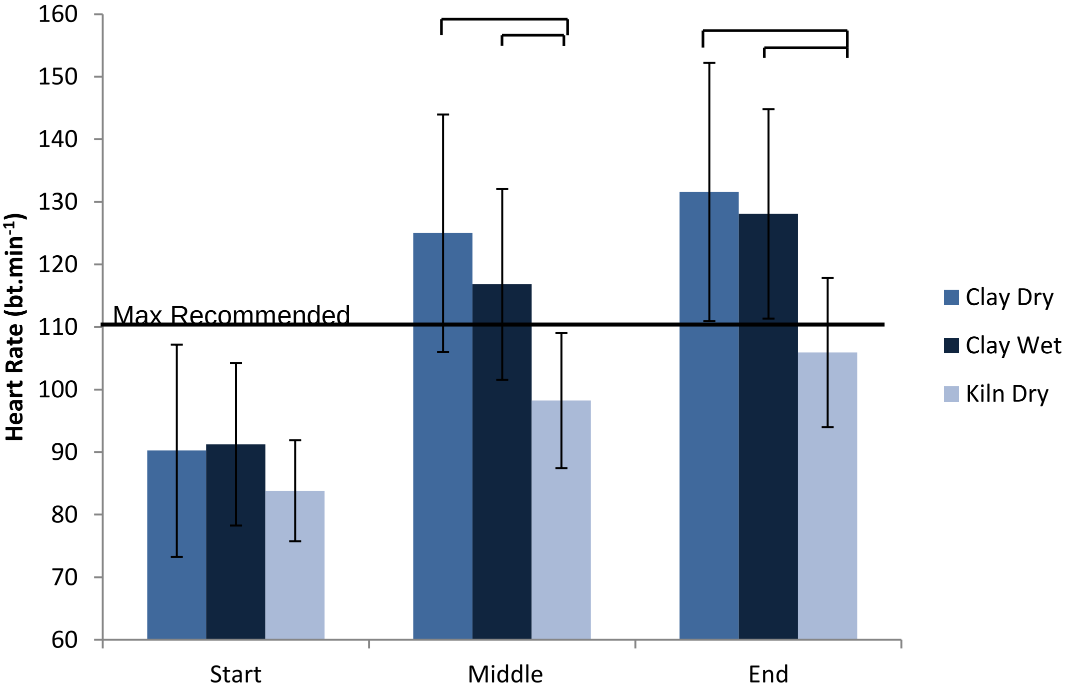

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Figure 40: The average Heart Rate of all three tasks at the start, middle and end of the testing session. The 'max recommended' line represents the maximum acceptable heart rate over the 8 hour work shift

In all tasks the heart rates increased throughout the protocol, by 31.41%, 28.76% and 21.33% from start to finish in the CDB, CWB and KDB tasks respectively (Figure 40). Both halfway and at the end of the protocol, the heart rates of the workers of the CDB and CWB tasks, were above the 110bt.min^{-1}, which is the maximum recommended heart rate of an 8 hour work shift.

PERCEPTUAL ASSESSMENT

BODY DISCOMFORT

Table IX shows that the most common perceived pain was in the Lower back region for the:

- Start of the CDB (29% of workers reported a mean Level 2.5 discomfort) and CWB tasks (17% prevalence of Level 2 discomfort).
- Start of the KDB task, in addition to the Forearm, Shoulder and Elbow (8% prevalence each for Level 5, 7, 1 and 4 perceived discomforts respectively).
- Middle of all the tasks (29% prevalence of a mean Level 2.8 discomfort for CDB, 17% prevalence of mean Level 2 discomfort for CWB and 33% prevalence of Level 6.5 reported discomfort for the KDB tasks).
- End of all the tasks: 29% prevalence of reports of Level 3.3 discomfort for CDB, 17% prevalence of Level 2 discomfort for CWB and 42% prevalence of Level 5.6 discomfort for KDB tasks (Table IX: The anterior and posterior body discomfort ratings at the start, middle and end of the work day; frequency of reports as well as mean rating (in brackets).)

The highest rating of perceived pain, Table IX, for the;

- CDB task was in the Gluteal region for the Start (Level 5), Middle (Level 6) and End (Level 6) of the work shift, with one report for each.
- CWB task was the abdominal region (one reporting of Level 3 discomfort) at the start of the work shift, and two reports of the Lower back region for the middle (Level 2 discomfort) and end (Level 2 discomfort) of the work shift.
- KDB task was the Forearm for the Start (Level 7 discomfort) and End (Level 8 discomfort) of the work shift and was the Forearm and Elbow (Level 7 discomfort) for the Middle of the work shift, with one report of each (Table IX).

The Lower back caused discomfort to the most number of people for each of the three tasks. The highest frequencies of reports were from workers in the KDB task at the middle and end of the work shift (33% and 42% prevalence respectively).

Table IX: The anterior and posterior body discomfort ratings at the start, middle and end of the work day; frequency of reports as well as mean rating (in brackets).

Highest Frequency, Highest Rating, Highest Frequency and Rating

ANTERIOR	START			MIDDLE			END		
	CDB	CWB	KDB	CDB	CWB	KDB	CDB	CWB	KDB
SHOULDERS	5 (2)			5 (2)		8 (6)	5 (2)		
BICEPS	5 (2)			5 (2)			5 (2)		
FORE-ARM			8 (7)			8 (7)			8 (8)
WRISTS	10 (3)			10 (3)			10 (4)		
HANDS	10 (3)			10 (3.5)			10 (4)		
ABDOMINAL		8 (3)							
POSTERIOR	START			MIDDLE			END		
	CDB	CWB	KDB	CDB	CWB	KDB	CDB	CWB	KDB
SHOULDERS	5 (2)		8 (1)	5 (1)		17 (6)	5 (2)		17 (5)
ELBOW			8 (4)			8 (6)			8 (6)
WRISTS	5 (4)			5 (5)			5 (5)		
HANDS	5 (4)			5 (5)			5 (5)		
MID-BACK	10 (2)			10 (2)			10 (3)		8 (1)
LOWER-BACK	29 (2.5)	17 (2)	8 (5)	29 (2.8)	17 (2)	33 (6.5)	29 (3.3)	17 (2)	42 (5.6)
GLUTEAL	5 (5)			5 (6)			5 (6)		8 (2)

SUMMARY

Overall the manual tasks (CDB and CWB) showed a greater risk than the more mechanized KDB task. This was seen with the high spinal range movements of the CDB task and the high velocities of the CWB task, whereas the KDB task only showed risk with the left twist angle and twist velocity.

The workers of the KDB task also had a significantly lower heart rate than those from the CDB and CWB tasks. Lastly, the CDB task had the highest frequency of reported discomfort and the highest number of areas of discomfort. In all tasks, heart rate increased throughout the test protocol. The CDB and CWB tasks had significantly higher heart rate values than the KDB task at the mid-point and end of the protocol. The highest frequencies of discomfort reports throughout the day were from the CDB task. The lower back region was most commonly reported area in which discomfort was experienced in all tasks throughout the day.

CHAPTER V

DISCUSSION

INTRODUCTION

Despite the substantial contribution that ergonomics has made to workplaces globally, there is still a high prevalence of musculoskeletal disorders in both IACs (Marras, 2000) and IDCs (O'Neill, 2000). One of the possible reasons for the failure of ergonomics to have the desired impact is the predominance of laboratory based research, whereas research needs to assess the responses of workers in their work-place settings (Zalk, 2001, Scott and Christie, 2004). Due to the primarily manual nature of work tasks in IDCs and the large number of musculoskeletal injuries in these countries, there may be a need to compromise the scientific control of the research - by being unable to control many extraneous variables in the field - in order to better understand the South African worker in the work setting. By assessing the workers *in situ*, the responses obtained are more likely to be an accurate representation of the daily workplace responses, therefore allowing more appropriate conclusions to be drawn and more suitable interventions to be implemented. The trade-off of this, however, is the large number of extraneous variables which cannot be controlled in a workplace environment (Scott and Renz, 2006).

The discipline of ergonomics aims to identify potential incompatibilities between worker capacities and task demands (Dempsey, 1998; Scott and Christie, 2004). South Africa is a country with unique characteristics: For example; the quadruple burden of disease and the unique position as an IDC with an increased movement towards mechanisation. Due to these distinctive characteristics, there is a need to focus research on understanding both the worker capacity and task demands in a specific South African industry setting. Therefore, the effect of age on worker capacity factors and the effect of task type on workers' responses to task demands were measured in a brick manufacturing industry.

It was predicted that an integration of two trends would be seen with the impact of age on worker capacity. Firstly, the common trend that aging workers would have a higher cardiovascular, morbidity and mortality risk as per their morphological characteristics, decreased strength capabilities and lower health status. Secondly, a unique trend showing the influence of communicable diseases in the younger age groups of workers, resulting in a lower weight, a decline in strength abilities and a greater prevalence of disease.

PART I - WORKER CAPACITY

In order to understand the capacity of workers, a holistic view needs to be taken, including biomechanical, physiological and personal factors. There is substantial evidence (Larsson *et al*., 1979; Era *et al*., 1992; Evans and Hurley, 1995) demonstrating the effect of age on strength capacity within IACs, however these data on IDCs, and more specifically on South Africa, remain sparse. Therefore this was selected as a key area of interest in the current study. In addition, the effect of age on personal worker capacity factors, including health and anthropometric factors was measured to more clearly understand the characteristics of the Eastern Cape manufacturing worker in South Africa.

AGE COMPARISONS

Aging has been associated with a decline in physical work capacity related to deterioration in various components of fitness, such as body morphology and strength (Kenny *et al*., 2008). In order to determine the effect of aging on worker capacity factors, a summary of the results will be provided (with a link to understanding risk in the case of body morphology) and potential explanations for the results will be discussed. Following this, comparisons of the current study with South African data (if available) and IAC data will be made to determine where the current population sample lies.

Age had an effect on worker capacity factors, but had a greater impact in specific areas. The majority of morphological results supported the predictions, in that the younger males had lower weight results and the older males had increased risk (although the risk was still classed as ‘low’). The older males were also at a higher risk in terms of diastolic blood pressure and this group fell into the ‘high’ systolic blood pressure range. Overall, the majority of strength measurements (bar two) were not affected by age.

ANTHROPOMETRICS

BODY MORPHOLOGY

Overweight and obesity have been linked to an increased risk of type 2 diabetes, coronary heart disease, hypertension, cancer and osteoarthritis (Goedecke *et al*., 2005; Ryan, 2011). BMI is most commonly used as a measure to assess weight status, but this measure does not distinguish between fat mass or lean tissue (Goedecke *et al*., 2005). Therefore additionally measuring body fat percentage and abdominal/central adiposity will provide a more complete understanding of body morphology.

Risk classifications

Table X shows the ‘normal’ classifications of various body morphology measurements. It has been acknowledged, however, that these cut-off values may be affected by age and ethnicity (WHO, 2007; WHO, 2008).

Table X: 'Normal' classifications of body morphology measurements.

Body mass index	18.5 - 25 kg.m^{-2} (National Institutes of Health, 2007)
Waist to hip ratio	< 0.90 (WHO, 2007)
Waist circumference	<102cm (National Institutes of Health, 2007)
Body fat percentage	below 25% (Okorodudu *et al*., 2010)

Due to the lack of research into appropriate cut-offs in African countries (WHO, 2008) the validity of the cut-off values in assessing a South African population is unclear. Further research should therefore be done to determine the correct cut-offs for this population, so future studies and risk assessments in South Africa can be more relevant. However, due to the lack of alternative classifications, these globally accepted measured will be used. According to these specifications, all four age groups’ morphology measurements were within the ‘normal’ ranges and therefore placed the workers in the low risk categories of mortality and morbidity.

Despite the low risk, several significant differences were seen in the age groups within the ‘normal’ categories. Body mass index was the only body morphology factor which did not increase significantly with age, but prevalence of BMI ≥25kg.m-2 increased from 6.67% and 11.43% in the 20-29 and 30-39 age groups to 23.08% and 30% in the 40-49 and 50-59 groups respectively. WHR values were significantly higher in the 50-59 than the 20-29 and 30-39 age groups. Waist circumference was also significantly higher in the oldest group when compared to the youngest and 30-39 age groups, but in addition to this, the 40-49 group also had measurements significantly greater than the 20-29 age group. Lastly the body fat percentage of males aged 20-29, was significantly lower than males aged 40-49 and 50-59. Due to the higher prevalence of overweight and obesity in the older age groups, there is a concern that once these older workers retire they are at risk of increased weight and body fat percentage due to the reduced physical activity. Therefore, although not currently at risk, there are potential dangers of post-work situation.

Comparison to South Africa and IAC findings

Despite the minimal research on South African capacity factors, a study done by Puoane *et al*. (2002), looked at the body composition of 13 089 males and females in South Africa. This study in addition to a study by Goedecke *et al*. (2005) showed that the mean BMI of South African men (of all races) increased steadily with age, which differs to the results obtained in the current study, as no significant differences were found, see Table XI. Also shown in Table XI, Goedecke *et al.* (2005) also showed an increasing BMI with age, males between 15 and 44 were within normal categories, whereas those aged 45-59 were overweight (i.e. >25kg.m^{-2}). Puoane *et al*. (2002) showed that BMI, WHR and WC measures all increase with aging. Despite these increases, all measures were found to be within the normal ranges, which is in agreement with the current research. Similarly, the current study showed significant increases in WC, WHR and BF% values with age (shown in Table XI). Therefore, in terms of the current study, the South African male MMH population does not have an obesity problem, as it is not only within the current ‘normal’ categories, but is also lower than research focusing on other South African males. The discrepancies with the results could be due to the MMH nature of the current sample. These types of jobs require the workers to be physically active, delaying the natural increase of weight and body fat with aging.

Table XI: Summary of the body morphology changes with age in previous research from South Africa.

SOUTH AFRICA	Goedecke *et al*. (2005)		**15-29**	**30-44**	**45-59**		
		BMI	21.5	24.2	25.3		
	Puoane *et al*. (2002)		**15-24**	**25-34**	**35-44**	**45-54**	**55-64**
		BMI	20.7	23.0	23.9	24.6	24.4
		WHR	0.82	0.85	0.89	0.91	0.91
		WC	73.4	80.7	85.5	89.4	89.0
	Current		**20-29**	**30-39**	**40-49**	**50-59**	
		BMI	21.6	21.3	22.7	23.0	
		WHR	0.80	0.81	0.83	0.87	
		WC	72.27	74.26	78.25	82.29	
		BF%	11.57	15.48	19.06	20.23	

Because the current sample is from a unique population group, a South African MMH industry population, the data should be compared to a similar group in order to make accurate comparisons. There is however, a lack of this specific data in South Africa, making the current data an important addition to the limited South African data collection.

When considering industrially advanced countries (IACs), Reas *et al*. (2007) showed that the mean BMI of Black Norwegian men ranged from 26.1 to 26.6kg.m^{-2} for men between the ages of 20 and 66. Therefore the mean results showed men to be classified as 'overweight'. In addition to this Ogden *et* al. (2006) and Wang and Beydoun (2007) showed the prevalence of Black males, from a representative sample of the United States (US) general population, who are overweight and obese (calculated by adding the 'obese' and 'extremely obese' categories), as shown in Table XI. This prevalence of overweight and obesity in these men increased with age in both studies (Wang and Beydoun, 2007), with data from Ogden *et al*. (2006) showing higher prevalences.

Table XII: The prevalences (%) of overweight and obese males in IACs compared to the current research.

			20-39	**40-59**
INDUSTRIALLY ADVANCED	Wang & Beydoun, 2007	Overweight	55.4%	65.0%
		Obese	53.6%	60.2%
	Ogden *et al*. (2006)	Overweight	65%	73.1%
		Obese	37.4%	43.8%
Current study		Overweight	0.12%	0.45%
		Obese	0.03%	0.08%

In contrast, the current study showed no significant increase in the prevalence of BMI-classified overweight individuals with age and the values (shown in Table XII) were considerably lower. The values from the current research showed that the overweight prevalence in the 20-39 and 40-59 age groups was 541.67% and 122.44% lower than US data respectively. In addition to this, the obesity prevalence was 1246.67% and 543.75% lower than US prevalence in the younger and older age groups respectively, but these changes were not significant. It can therefore be concluded that the trends seen in IACs of increasing BMI with age, are not seen in the current study and prevalence of BMI-classified overweight and obese males in the measured MMH industry worker sample, was lower than that of IACs. These lower body morphology measures in the current population could be a result of several contributory factors. As the workers are in a highly physical MMH industry, the daily physical 'training' could reduce age-related weight gain, therefore maintaining a healthy body composition. Alternatively, these South Africans could have lower body compositions due to the large burden of disease, seen particularly in the Black rural South Africans. The exact causes, however, are difficult to definitively determine.

The body fat percentage results from the current study are in line with previous literature from IACs which show that lean muscle mass decreases and body fat increases with age (Forbes and Reina, 1970; Snyder et al., 1999). In the current study, the body fat percentage increased significantly with age, as shown in Table XII. Despite these changes all males in the current study had a healthy body fat percentage (<25%) Contrastingly, Lynch et al. (1999) showed that there was only a significant increase in body fat percentage from the values of the youngest group after the age of 50.

Explanation of findings

The lack of a significant change in BMI with age could be due to either a higher BMI than expected in the younger age groups, or a lower BMI than expected in the older age groups. It is more likely that the BMI of the 50-59 group is lower than expected, as the mean BMIs from the oldest group the current study were lower than those found in the SANHANES study from 2012. The BMI of the younger groups were similar 21.3 and 21.56kg.m^{-2} for the 18-24 and 20-29 age groups (of Shisana *et al*., 2013 and the current study respectively), whereas the 45-54 and 55-64 age groups of the SANHANES study sample had BMIs of 26.0 and 25.2kg.m^{-2}, which are in the 'overweight' BMI category (Shisana *et al*., 2013). The men in the 50-59 age group of the current study had a 'normal' BMI of 23.03kg.m^{-2}. This discrepancy in results could be due to the higher physical activity of the men in the MMH industry or the 'healthy worker effect' as mentioned by Kenny *et al*. (2008). This effect explains that workers who have lower capacities will retire from more physically demanding jobs (such as those measured in this research). The results therefore appear biased as the more capable, healthy workers are left to perform the tasks and were assessed in this research.

The increases seen in the WHR, waist circumference and body fat percentage with age, could be as a result of several factors. Firstly, the increase in obesity (in terms of WHR, waist circumference and body fat percentage) with age can be attributed to the decrease in testosterone and human growth hormone with age, which has been linked to an increase in obesity (Snyder *et al*., 1999). The increase in body fat percentage in the 40-49 and over 50 age groups from the current research could be attributed to the decreasing serum testosterone levels with age (Snyder *et al*., 1999).

Due to the large burden of disease in South Africa, it is necessary to mention the potential impact it may have on worker capacity factors. Due to the majority of HIV related deaths occurring between the ages of 25 and 40 (Arndt and Lewis, 2000), any workers affected by the disease could have a lower BMI, WHR, waist circumference and body fat percentage as a result of weight loss which can be seen early in the disease progression (Mars, 2000). This could be a factor influencing the lower body composition results in the younger age groups.

From this knowledge, two areas of interest emerge: Firstly that obesity is not a problem in the sample population (in a MMH industry), the prevalence of obesity is not only lower than IACs, but also lower than the South African population at large. Secondly that the BMI of the population assessed did not follow the age related trends expected. This could be as a result of the more active lifestyle of the MMH workers, which is particularly important in males over 50 age group as they have minimise the effect of gaining weight.

HEALTH

BLOOD PRESSURE

Hypertension is the most common risk factor for congestive heart failure (Haider *et al*., 2003) and as a risk factor contributed significantly to the burden of strokes and coronary heart disease (Shisana *et al*., 2013). Although systolic blood pressure has been more strongly associated with coronary heart disease than diastolic blood pressure, particularly in older males (Stamler *et al*., 1993) risk is associated with both systolic and diastolic blood pressure measures in the high and the high-normal categories (Stamler, 1991).

Risk classification

The normal, pre-hypertension and hypertension classifications of systolic and diastolic blood pressure are shown in Table XIII.

Table XIII: The classifications for diastolic and systolic blood pressure (Chobanian *et al*., 2003).

	Normal	Pre-hypertension	Hypertension
Diastolic	< 120mmHg	80-89mmHg	≥90mmHg
Systolic	< 80mmHg	120-139mmHg	≥140mmHg

Although age did not have a significant effect on systolic blood pressure (SBP) in this study, the SBP of the 50-59 age group was above 140mmHg and therefore in the high blood pressure range, whereas the other three age groups were below this in the prehypertension category (120-139mmHg). Males in the oldest and 40-49 age groups had significantly higher diastolic blood pressure (DBP) measures than the men in the youngest (i.e. 20-29) age group. The DBP results for workers of the 40-49 and 50-59 age groups were in the prehypertension categories, whereas the two youngest age groups were in the normal DBP range. Therefore the males aged 40-59 are at the greatest risk of developing heart disease.

Comparisons to South Africa and IACs

A previous study in South Africa (Shisana *et al*., 2013) showed that 47.3% of hypertensive men were overweight or obese. In the current study, men aged 40-59 (the group with the greatest SBP and DBPs) had the highest mean BMI, WHR, waist circumference and body fat percentage, suggesting a link between these two factors, as previously reported by Goedecke *et al*. (2005). A survey by Statistics South Africa (2013) showed that hypertension prevalence increased from 1.5% in the 25-34 age group and 6.6% in the 35-44 age group, to 19.2 and 32.2% in the 45-54 and 55-64 age groups respectively. The current study showed higher prevalence of high blood pressure with age (Table XIV).

Table XIV: The prevalence (%) of systolic and diastolic pre-hypertension and hypertension with age in the current study.

		AGE GROUP			
		20-29	**30-39**	**40-49**	**50-59**
Pre-hypertension	**Systolic**	46.67	42.86	53.85	40.00
	Diastolic	33.33	25.71	34.62	30.00
Hypertension	**Systolic**	30.00	20.00	38.46	50.00
	Diastolic	6.67	25.71	38.46	50.00
Combined	**Systolic**	76.67	62.86	92.31	90.00
	Diastolic	40.00	51.43	73.08	80.00

In terms of SBP hypertension, prevalence increased from 30% and 20% (in the 20-29 and 30-39 age groups respectively) to 38.46% and 50% in the 40-49 and 50-59 age groups. Diastolic blood pressure hypertension prevalence increased steadily with age, from 6.67% in the 20-29 group and 25.71% in the 30-39 age group to 38.46 and 50% in the 40-49 and 50-59 age groups respectively. The combined systolic pre-hypertension and hypertension prevalence, shown in Table XIV, was extremely high, ranging from 62.86% in the 30-39 group to 90.00% in the 50-59 group. The combined diastolic prevalence was lower, ranging from 40.00% in the 20-29 age group to 80% in the 50-59 age group. The prevalence of hypertension in US males increased from 7.3% in an 18-39 age group, to 32.4% in a 40-59 age group (Nwankwob *et al*., 2013) showing results considerably lower than those found in the present study. Supporting Nwankwob *et al*., a study by Joffres *et al*. (2013) showed the effect of age on diastolic and systolic blood pressure means in three IACs (Table XV).

Table XV: The effect of age on the systolic and diastolic (mmHg) means of men in three IACs (Joffres *et al*., 2013) and the current study.

		AGE GROUP			
		20-29	**30-39**	**40-49**	**50-59**
England	**Systolic**	**127.30**	127.15	128.7	133.4
	Diastolic	70.85	73.8	77.6	78.5
Canada	**Systolic**	107.75	112.15	114.7	119.25
	Diastolic	68.8	74.25	77.1	78.1
USA	**Systolic**	117.8	119.35	121.25	124.75
	Diastolic	67.6	73.15	76.00	75.55
Current study	**Systolic**	125.98	**127.34**	**135.85**	**142.40**
	Diastolic	**74.43**	**79.26**	**87.46**	**89.20**

When these data were compared with the current research, SBP of the 30-39, 40-49 and 50-59 groups was highest in the current research, with the English individuals showing the greatest mean SBP in the 20-29 age group. Males in the current study showed the highest DBP throughout all age groups. It can therefore be concluded that the Black MMH industry males in the current research, show a higher prevalence of hypertension and higher mean blood pressure values and should therefore be at a greater risk of cardiovascular disease than males in IACs.

Explanation of findings

Previous research supports an increase in systolic blood pressure with aging, as a result of baroreceptor blunting (Bolton and Rajkumar, 2011). Although the current research did not show a significant increase in SBP with age, the oldest males were hypertensive, whereas the 20-49 year old males were pre-hypertensive. The lack of significance in these data could be as a result of the high inter-individual variability and hence large standard deviation in the 50-59 age group. The significant increase in DBP with age and diastolic blood pressure increases until 50 and then begins to decrease with further aging (Miall and Lovell, 1967). These changes are important as they have been linked to an increase risk of cardiovascular disease and mortality (Bolton and Rajkumar, 2011).

Smoking has been linked to a decline in blood pressure (Green *et* al., 1986) and it would therefore be expected that the groups with highest prevalence of smokers would have lower blood pressure. There has also been a link between increased hypertension prevalence with alcohol consumption (Arkwright *et al*., 1982). In addition to these factors, 20% of obese men have been shown to be hypertensive (Zhu *et al*., 2002), therefore the increased hypertension prevalence of males aged 40-49 and 50-59, could be as a result of the increased prevalence of overweight males in these age groups. The highest body composition correlation with SBP and DBP was body fat percentage (with 0.46 and 0.55 respectively). However, due to the effect of age on hypertension, the isolated impact of smoking, alcohol and body composition cannot be determined.

REFERENCE HEART RATE

Heart rate can be used as a prognostic factor for cardiovascular disease (Fox *et al*., 2007). Despite the effort made to collect valid resting heart rates by ensuring the workers were seated for a 4 minute period prior to testing, due to the unfamiliarity with the testing environment and the highly physical nature of the work workers may have had elevated heart rates. Therefore the values obtained are more likely to represent reference heart rates at work and should therefore be interpreted with caution.

The heart rate values collected were not significantly affected with age. In addition, the values recorded were considered to be 'normal' heart rate measures (<90bt.min^{-1} as in Fox *et al*., 2007), with a range of 66 (±8.07) bt.min^{-1} to 74.68 (±13.75) bt.min^{-1}. Resting heart rate is an independent predictor or cardiovascular and all-cause mortality in men, with a continuing increase in risk from 60bt.min^{-1} (Fox *et al.*, 2007). Although there is currently no agreed upon 'optimal' resting heart rate value, it is advised that individuals maintain a resting heart rate substantially lower than the tachycardia threshold of 90-100bt.min^{-1} (Fox *et al*., 2007). Therefore, with regard to resting heart rate, all the men in this research are at a low risk of cardiovascular mortality, although men in the 40-49 age group are at the highest risk, as they are the only group with a resting heart rate above 70bt.min^{-1}. In addition to age, heart rate can be affected by; aging, circadian rhythm, posture and surrounding environment, which may have impacted on the results.

QUESTIONNAIRE RESULTS

Table XVI: The prevalence (per decades of life) of various diseases on the four age groups in South African male workers in this study.

	20-29 (N=30)	30-39 (N=35)	40-49 (N=26)	≥50 (N=10)
TUBERCULOSIS	1.67	2.86	4.81	4
PNEUMONIA	6.67	2.86	4.81	6
GASTROENTERITIS	8.33	7.62	2.88	2
INFLUENZA	40	28.57	21.15	18
MENINGITIS	0	0.95	2.88	0
CHOLERA	3.33	0	0.96	0

The more common diseases (i.e. influenza and gastroenteritis) were most prevalent in the 20-29 and 30-39 age groups as shown in Table XVI. Tuberculosis prevalence peaked in the 40-49 age group, followed by the 50-59 group and pneumonia was greatest in the 20-29 group, followed by the 50-59 age group. Cholera had the highest number of reports in the 20-29 group and Meningitis had the most reports in the 40-49 group. The two oldest groups had the highest percentage of smokers and the youngest group had the highest percentage of workers who consumed alcohol.

The over 50 group should show the highest percentage of occurrence of all infectious diseases, due to immunosenescence (Weiskopf *et al.*, 2009). This was only the case in six of the ten ailments reported. Due to the association between HIV infection and the diseases tuberculosis and pneumonia (Arozullah *et al.*, 2003), it could be tentatively assumed that the largest proportion of males with HIV, would be within the ages of 40-59.

BIOMECHANICS

STRENGTH

Loss of strength with age has been linked to the decline in muscle mass in senescence (Evans and Campbell, 1993; Hughes *et al*., 1999). The loss of muscle mass is associated with two main causes; firstly as a result of disuse atrophy and secondly as a result of physiological factors (Luff, 1998). The first of these should not occur in the current study's population due to the daily physical labour required of them, so more focus will be placed on the physiological reasoning. The current research showed that of the eight strength tests measured, significant differences were only found in two; the 50-59 age group showed significantly greater push strength than the 30-39 and 40-49 age groups and significantly lower shoulder strength than the youngest group. All other strength values were not significantly different across age group. A summary of the findings is shown in Table XVII.

Comparison to previous findings

Lynch (1999), reports that muscle strength peaks in the 20s and 30s, remains stable or marginally declines in the 40s and declines approximately 12-14% after the age of 50. Luff (1998) however, states that muscle strength starts to decline at the age of 50, with a 15% loss per decade from 50-70 years. Contrastingly, Lexell *et al*. (1991) found a 10% decline in muscle strength from the age of 24-50, with a 30% strength decrease between the ages of 50 and 80. The common trend in these studies, is the decline in strength with age.

Table XVII: Summary of the results of the eight strength tests with age, mean (+/- SD).

	AGE			
MUSCLE STRENGTH (kg of Force)	**20-29**	**30-39**	**40-49**	**50-59**
Leg	115.11 (28.87)	93.56 (16.14)	93.41 (17.63)	87.32 (35.30)
Back	90.80 (14.32)	85.81 (12.36)	84.30 (12.64)	90.95 (29.96)
Shoulder	49.36 (4.12)	45.10 (3.33)	45.72 (3.11)	39.91 (7.65)
Bicep	39.31 (3.06)	37.57 (2.59)	37. 67 (3.02)	35.92 (5.25)
Pinch	11.32 (1.66)	9.93 (0.77)	10.52 (0.92)	10.14 (1.31)
Grip	41.55 (3.29)	40.43 (2.58)	40.43 (3.05)	37.05 (4.84)
Push	11.19 (1.73)	9.77 (1.13)	9.35 (1.23)	13.05 (1.52)
Pull	10.30 (0.97)	9.50 (0.85)	10.00 (1.56)	10.82 (1.56)

Kallman *et al*. (1990) and Aloia *et al*. (1991) showed, however, that loss of muscle strength begins shortly after the age of 30 and will occur in the upper extremities before the lower extremities. Most of these studies look at general populations, not necessarily working populations, therefore mention must be made of the ‘healthy worker effect’ as described by Kenny *et al*. (2008), where healthy workers will continue to work for longer periods of time and unhealthy workers will either retire earlier or find jobs which are less physically demanding. It is likely that this is the case in the present research, as the number of workers aged 50-59 only made up 10% of the sample population.

A summary of the strength results found in the current research and previous literature is shown in Table XVIII. Back strength is a particularly important measure, as an increased back strength results in a lower incidence of back pain and risk of injury (Carpenter and Nelson, 1999).

Table XVIII: The current trends seen with age in comparison to other studies (including the population samples), as well as, which of these showed higher values.

	STUDY		
MUSCLE STRENGTH	**Current study**	**Other research**	**Higher values**
Leg	No change	Dynapenia after 50* (Marcell *et al*., 2003)	N/A
		No change between 20 & 59 (Hurley *et al*., 1998)	CR
		Dynapenia after 40 (Teimoori *et al*., 2009)	CR
Back	No change	Dynapenia after 21-24 (Roy and Pal, 2003)	OR
Shoulder	20s>50s (dynapenia)	Dynapenia- rotation, abduction and flexion (Yian *et al*., 2005 – Swiss)	N/A
Bicep	No change	Dynapenia in upper body strength (Shock and Norris,1970; Metter *et al.*, 1997)	N/A
Pinch	No change	Peak at 35-44 then decrease (Werle *et al*., 2009 - Swiss)	CR=OR
Grip	No change	No change (Haward and Griffin, 2002).	OR
		Peak at 35-39 then decrease (Werle *et al*., 2009)	OR
		Decrease with age (Kallman *et al*., 1990 - USA)	N/A
Push	50s>40s 50>30s (strength increase)	Dynapenia (Voorbil and Steenbekkers, 2001)	N/A

Pull	No change	Dynapenia after 50 (Voorbil and Steenbekkers, 2001)	N/A

N/A – exact data not available, CR – values in the current study were greater than other research, OR – values in other research were greater than the current study, CR=OR – values are similar between the current study and other research.

Only three strength changes with age found in the current study were supported by previous literature. No change in leg strength with age was supported by Hurley *et al*. (1998). The decline in shoulder strength was supported by Yian *et al*. (2005), although Yian *et al*. showed a steady decline with age. Finally, no change in grip strength was supported by Haward and Griffin (2002) with a British male population. Although leg and more particularly grip strength changes with age have been highly debated. The leg strength data is unique, as the values from the current study were greater than those previously found. In addition previous literature shows that there is either no change in strength with age (Hurley *et al*., 1998), as seen in the current study, or that decreases with age only occur after the ages of 40 (Teimoori *et al*., 2009) or 50 (Marcell *et al*., 2003). Grip strength has been used as an indicator of overall muscle strength and can be a predictor of mortality (Rantanen *et al*., 1998). Werle *et al*. (2009), showed that Swiss males grip strength showed a curvilinear relationship, peaking in the 35-39 age group at 55.0kg and Kallman *et al.* (1990) showed a decrease in grip strength with age in males from the United States, which was attributed partially to a declining muscle mass. Due to the inconclusive nature of previous research on the grip strength trend with age, the current research adds value to the standing body of knowledge. All other results found in the present study are not supported by previous literature, as shown in Table XVIII.

Explanation of findings

The declining strength with age (as seen with shoulder strength in the current study), may be a result of the lower muscle mass (Kenny *et al*., 2008) in older males from decreased serum testosterone levels (Snyder *et al*., 1999; Doherty, 2001). This loss in muscle mass is usually greater in the lower body (Doherty, 2003), but is not seen in trained athletes until the age of 65 (Shephard, 1999). A decline in muscle mass is linked to the decrease in the number and size of muscle fibres (Knapik *et al*., 1996; Kenny *et al*., 2008). Additional changes with age which may contribute to strength declines include; changes in muscle composition and muscle metabolic activity, reduced neurogenic motor control efficiency, decreases in the active motor units in skeletal muscle, increases in connective tissue and intramuscular fat, as well as, alterations in the muscle contractile abilities (Chaffin and Ashton-Miller, 1991; Knapik *et al*., 1996; Kenny *et al*., 2008).

In contrast to previous literature, back, bicep, pinch and pull strengths did not change with age in the current study, see Table XVIII. Potential reasons for this difference could be due to the lack of a decrease in the older age groups or a decrease in the strength in the younger groups, but the causes of these cannot be definitively determined. There are several factors which could contribute to these results of the current research.

The lack of a strength decrease in older males could also likely be due to the ‘healthy worker effect’, where only the strongest and most healthy older workers remain in the more physically demanding tasks. In addition to this, the physically demanding nature of the current workers’ MMH workplace would result in daily strength ‘training’, in performing their work tasks. This would result in a delay in the decrease of muscle mass and strength seen with aging, as supported by Ivey *et al*., 2000a; Kenny *et al*., 2008). An additional factor to consider is that of the burden of disease affecting the South African population. Bradshaw *et al*. (2003) showed that there is a high prevalence of HIV/AIDS between 30 and 45 which have been previously shown in South African males, which could result in a decreased strength capacity of the affected workers. In order for more accurate international comparisons to be made, workers from a similar MMH industry would need to be assessed.

SUMMARY

In summary, the current population showed the following changes with age; significant increases in WHR, WC and BF%, increases in prevalence of pre-hypertension and hypertension in SBP and DBP and lastly, no change in strength, except shoulder and pull strength. Body composition data was all within normal ranges, decreasing the risk of cardiovascular disease, but the high prevalence of pre-hypertension and hypertension in the current sample will increase this risk. Due to the lack of data available on MMH workers globally, and particularly in South Africa, comparisons between samples are not entirely reliable, as there are many factors in addition to age which could have an effect. In order to make valid international and national comparisons, the age groups would need to be matched to similar populations, therefore introducing an area where more research is required.

Due to the unique and complex nature of South Africa, in particular the rural MMH workforce, the causes of the changes found with age cannot definitively be determined. Possible contributory factors, however, include commonly observed trends and South Africa specific differences. This comprises of, commonly stated natural changes which occur with aging (e.g. a decreased serum testosterone concentration and muscle mass in males) which will increase body weight and fat percentage and reduce strength capabilities with age.

In addition to these factors, the highly manual nature of the current tasks will keep the workers physically trained, which could delay the common age changes (Ivey *et al*., 2000; Kenny *et al*., 2008). The older workers will also have been in the industry for longer and are therefore often more work-hardened than the younger males, which could again, limit the age-related strength differences. This is in line with the 'healthy worker effect' in which only the older workers who can maintain the work tasks by having a sufficient work ability would remain in these jobs. The burden of disease in South Africa can also influence the results obtained. Bradshaw *et al*. (2003) showed that individuals between the ages of 20 and 40 will be the most heavily impacted by the burden of disease and could have a lower worker capacity. Older workers should be less affected, as a lower number of people over 45 are infected with HIV/ AIDS, as individuals who were infected, are likely to have died and many of the remaining individuals will have a single sex partner, reducing the risk of infection. Contrastingly, the self-reported questionnaire reports from the current research showed that the two older groups had the highest prevalence of tuberculosis and pneumonia - the two communicable diseases most closely associated with HIV. This information, however, may not be accurate due to either language barriers limiting understanding or due to the negative connotations.

In order to more thoroughly substantiate the impact of South Africa- specific differences, however, further research would need to be done with these factors as the focal point.

PART II- TASK DEMANDS

Manual materials handling, lifting in particular, represents a major health and safety risk in the industry workplace (Lin *et al*, 2006). The tasks analysed in the current study comprised of highly repetitive lifting tasks which therefore may be exposing the workers to excessive task demands. Lower back injury and musculoskeletal disorders are often attributed to overexertion when workers cannot meet the given task demands. Several whole body assessment tools are available to determine task risk, but the majority of these only predict static risk, the accuracy of which is questionable in a dynamic MMH environment. Therefore, in order to ensure accuracy of assessment, it is essential to measure both spinal loading (forces on the L_5/S_1) as well as dynamic trunk/spinal motion. In addition to these biomechanical measurements, working heart rate responses and body discomfort measures will provide a more holistic understanding of the task than any single measure.

TASK COMPARISON

Three palletising tasks of varying mechanical advancement were measured, in order to more fully understand the demands of performing the task. The three tasks ranged from: an entirely manual task, clay dry brick (CDB), taking dry 2.8kg bricks off a multi-layered manually-stacked kiln outdoors and placing the bricks on a pallet, to two semi-mechanised tasks with conveyor belts. The one task, clay wet brick (CWB), involved moving wet 4.4kg bricks from a conveyor belt on the right of the workers and stacking them onto a pallet on the left.

CLAY DRY BRICK | **CLAY WET BRICK** | **KILN DRY BRICK**

Figure 41: Examples of workers performing the three tasks which were assessed.

The third task, kiln dry brick (KDB), involved moving dry 2.4kg bricks (baked in a tunnel kiln) off a central conveyor belt and placing them on pallets on both the left and right hand sides of the workers. Examples of workers performing the three tasks are shown in Figure 41. The workers' biomechanical, physiological and psychophysical responses to the demands of the three tasks were measured.

BIOMECHANICS

SPINAL KINEMATICS

Spinal kinematics factors are essential in understanding lower back injury risk (Davis and Marras, 2000). In a South African (IDC) workplace, where MMH tasks are common, these measures are particularly important and yet are seldom researched. The body of knowledge surrounding lower back risk has supported the move from static to dynamic assessments (McGill and Norman, 1985; Marras *et* al., 1995; Marras *et al*., 2003; Granata and Marras, 1999). Previous research has shown that static assessments have been shown to under-predict risk (McGill and Norman, 1985; Granata and Marras, 1999) and prediction of job risk is difficult using two-dimensional, static positions alone (Marras *et al*.,1995). In addition, static assessments do not take into account the decrease in the tolerance of the lumbar segment with simultaneous loading in planes (Shirazi-Adl, 1989), or the exponential increase in risk with the presence of more than one risk factor concurrently (Marras, 2003). Although the risk factor thresholds found in Marras *et al*. (1995) can provide an idea of task risk, the multivariate approach has a much greater applicability. The combination of the risk factors which make up the multivariate approach, namely; lift rate, lateral and twisting motion, trunk flexion angle and external moment increase the risk associated with the tasks and therefore are instrumental in distinguishing between high and low risk tasks. Therefore spinal kinematic factors will be discussed individually to determine, a) where specific differences between tasks lie and b) how these factors compare to the risk thresholds put forward by Marras *et al*. (1995) and what the overall risk of the tasks are using the multivariate approach (Marras *et al*., 1993).

Results summary

A summary of the Spinal Kinematic difference between tasks are shown in Table XIX.

Table XIX: The mean (±SD) Spinal Kinematic Range and Speed differences between the Clay Dry Brick (CDB), Clay Wet Brick (CWB) and Kiln Dry Brick (KDB) tasks.

		CDB (Man) mean (±SD)	**CWB (Mech)** mean (±SD)	**KDB (Mech)** mean (±SD)
SAGITTAL	**Max Extension (º)**	10.53 (12.23)	10.71 (5.58)	10.45 (7.87)
	Max Flexion (º)	30.88 (9.02)	24.17 (4.41)	22.26 (8.79)
	Max Sagittal Range (º)	20.36 (12.59)	13.46 (3.68)	11.81 (7.62)
	Ave Sagittal Velocity (º.s^{-1})	6.47 (4.14)	9.54 (3.65)	8.11 (5.39)
	Max Sagittal Velocity (º.s^{-1})	34.65 (20.02)	33.99 (11.42)	30.12 (18.71)
	Max Sagittal Acceleration (º.s^{-2})	212.90 (112.37)	207.42 (68.70)	200.30 (118.20)
LATERAL	**Max Left Bend (º)**	-6.39 (10.39)	-11.81 (5.98)	-3.37 (6.07)
	Max Right Bend (º)	14.75 (8.11)	6.87 (6.54)	10.22 (6.75)
	Max Lateral range (º)	21.14 (8.47)	18.68 (8.86)	13.59 (9.13)
	Ave Lateral Velocity (º.s^{-1})	7.91 (3.15)	12.45 (4.81)	9.31 (6.13)
	Max Lateral Velocity (º.s^{-1})	37.30 (16.42)	38.66 (12.26)	30.45 (15.68)
	Max Lateral Acceleration (º.s^{-2})	245.74 (25.26)	234.89 (68.67)	199.81 (90.91)
TWISTING	**Max Left Twist (º)**	-9.23 (6.97)	0.05 (4.29)	-8.18 (6.09)
	Max Right Twist (º)	8.98 (9.49)	18.22 (5.63)	5.68 (4.35)
	Max Twist Range (º)	18.21 (10.67)	18.18 (5.10)	13.86 (6.91)
	Ave Twist Velocity (º.s^{-1})	6.53 (3.62)	12.53 (4.02)	10.84 (5.28)
	Max Twist Velocity (º.s^{-1})	41.14 (23.91)	49.99 (13.23)	39.10 (17.91)
	Max Twist Acceleration (º.s^{-2})	283.25 (162.98)	321.39 (78.21)	260.52 (120.73)

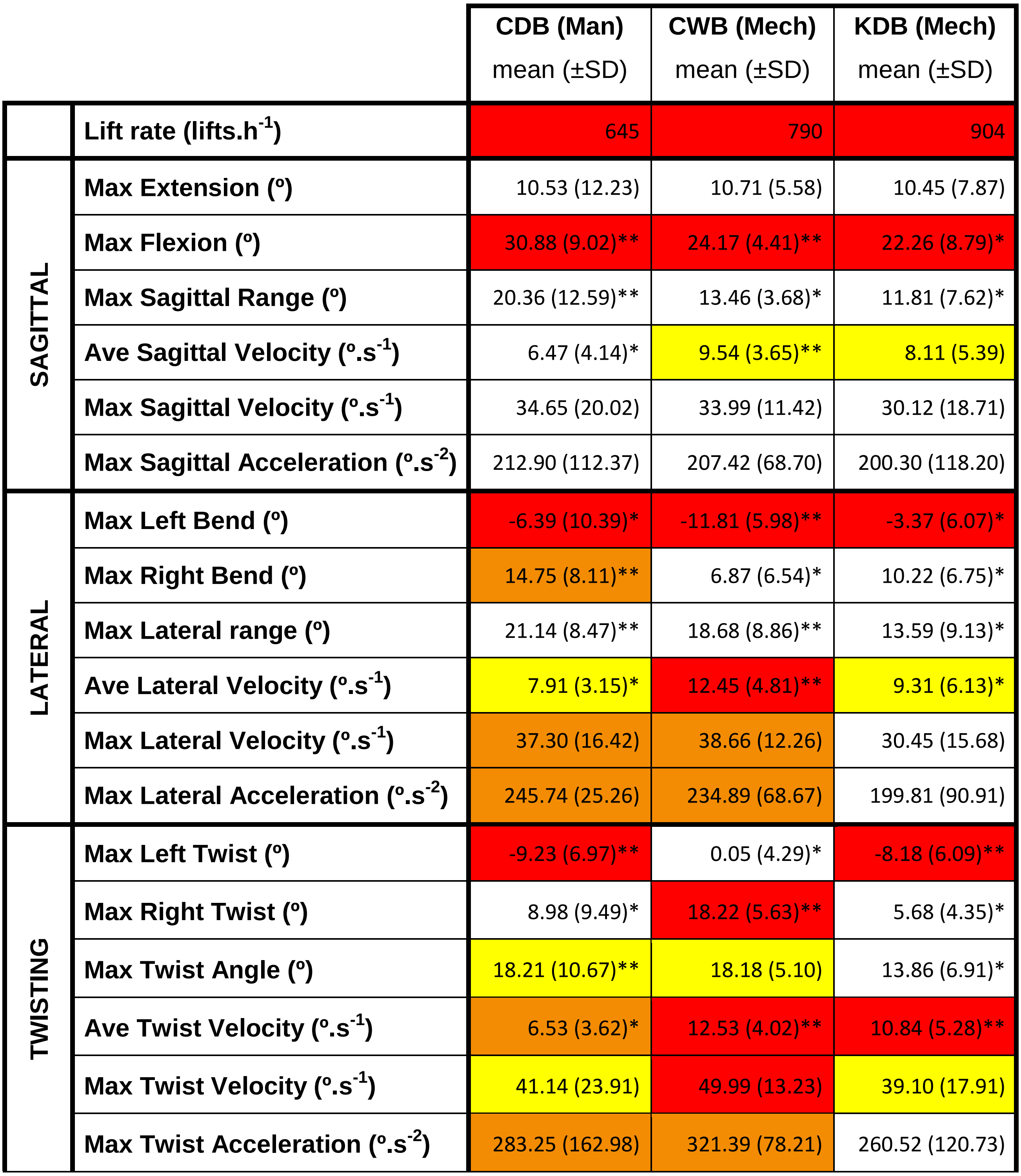
└--┘ Denotes a significant difference

The CDB task was associated with a significantly higher maximum sagittal range and maximum right bend than both other tasks. In addition to this it had a significantly greater maximum flexion, lateral range and twisting range than the KDB task, and a greater maximum left twist than the CWB task. The CWB task showed significantly higher maximum left bend, right twist and average lateral velocity angles than both other tasks. In addition to this, the CWB task had a significantly greater average sagittal and twist velocities than the CDB task and significantly greater maximum flexion and lateral range than the KDB task. Lastly, the KDB task had significantly greater maximum lateral twist than the CWB task and significantly higher average twist velocity than the CDB task. Despite these significant differences, the associated levels of risk were not seen in all areas. A summary of the risks involved are shown in Table XX. For all tasks, movement was occurring simultaneously in the three planes for all three tasks, therefore exacerbating the associated risk.

Associated risk

Table XX shows the risk of developing a LBD with each task assessed, using threshold guidelines for spinal movement angles, velocities and accelerations from Marras *et al*. (1995). Due to the manual nature of the CDB task, it was thought that this task would have greater ranges than the other two tasks. This was the case for the sagittal ranges, but both the CWB and CDB lateral ranges were greater than the KDB range and the CDB twist range was only significantly greater than the KDB task. As the CDB task is entirely manual task, it was expected that this task would present with the greatest risk for LBDs in terms of movements angles. Despite the CDB task having the highest ranges in all three planes, there was only low-medium risk associated with the twisting values of this task, this risk level was also found for the CWB task. Maximum ranges, however, will not show accurately enough where a potential risk lies (Marras *et al*., 1993) and can be deceptive, as a small range in a more exaggerated bend or twist would be higher risk than a large range in posture closure to neutral. It is therefore important to look more closely at the risks associated with both sides of each of the three planes, see (Figure 35) which more fully shows the risk.

Table XX: The LBD risk association of the mean (±SD) Spinal Kinematic Ranges and Speeds for the three tasks, according to Marras *et al*., (1995).



		CDB (Man) mean (±SD)	**CWB (Mech)** mean (±SD)	**KDB (Mech)** mean (±SD)
	Lift rate (lifts.h^{-1})	645	790	904
SAGITTAL	**Max Extension (°)**	10.53 (12.23)	10.71 (5.58)	10.45 (7.87)
	Max Flexion (°)	30.88 (9.02)**	24.17 (4.41)**	22.26 (8.79)*
	Max Sagittal Range (°)	20.36 (12.59)**	13.46 (3.68)*	11.81 (7.62)*
	Ave Sagittal Velocity (°.s^{-1})	6.47 (4.14)*	9.54 (3.65)**	8.11 (5.39)
	Max Sagittal Velocity (°.s^{-1})	34.65 (20.02)	33.99 (11.42)	30.12 (18.71)
	Max Sagittal Acceleration (°.s^{-2})	212.90 (112.37)	207.42 (68.70)	200.30 (118.20)
LATERAL	**Max Left Bend (°)**	-6.39 (10.39)*	-11.81 (5.98)**	-3.37 (6.07)*
	Max Right Bend (°)	14.75 (8.11)**	6.87 (6.54)*	10.22 (6.75)*
	Max Lateral range (°)	21.14 (8.47)**	18.68 (8.86)**	13.59 (9.13)*
	Ave Lateral Velocity (°.s^{-1})	7.91 (3.15)*	12.45 (4.81)**	9.31 (6.13)*
	Max Lateral Velocity (°.s^{-1})	37.30 (16.42)	38.66 (12.26)	30.45 (15.68)
	Max Lateral Acceleration (°.s^{-2})	245.74 (25.26)	234.89 (68.67)	199.81 (90.91)
TWISTING	**Max Left Twist (°)**	-9.23 (6.97)**	0.05 (4.29)*	-8.18 (6.09)**
	Max Right Twist (°)	8.98 (9.49)*	18.22 (5.63)**	5.68 (4.35)*
	Max Twist Angle (°)	18.21 (10.67)**	18.18 (5.10)	13.86 (6.91)*
	Ave Twist Velocity (°.s^{-1})	6.53 (3.62)*	12.53 (4.02)**	10.84 (5.28)**
	Max Twist Velocity (°.s^{-1})	41.14 (23.91)	49.99 (13.23)	39.10 (17.91)
	Max Twist Acceleration (°.s^{-2})	283.25 (162.98)	321.39 (78.21)	260.52 (120.73)

🟥 High risk 🟧 Medium-high risk 🟨 Low-medium risk ⬜ Low risk

** Significantly greater, * Significantly lower

When considering specific directional movement, the higher flexion of the CDB task was due to the workers being required to often lower bricks to floor level. Despite the palletising of the CWB and KDB tasks both being done off conveyor belts onto pallets, the flexion of these tasks were not expected to be significantly different. Although the flexion of the CDB and CWB tasks were significantly greater than the KDB task, all of the tasks were associated with a high risk according to Marras *et al*. (1995). Increasing the height of the base of the pallets or lifting the pallets would result in a decreased maximum sagittal angle of the CWB and KDB tasks. Although this would decrease the sagittal flexion of the CDB workers when they are placing bricks, they are still required to pick bricks up from or below the level of their feet, so the maximum sagittal flexion would not be greatly affected. Maximum flexion was reported by Norman *et al*. (1998), to have the highest odds ratio for lower back pain. Low sagittal angles during a lift result in a decreased risk of LBD, but as the angle increases, the risk increases (Marras *et al*., 1995).

A higher angle of sagittal flexion results in the flattening out of the lumbar spine causing ‘stiffer’ functional spinal units, therefore the intervertebral disks have to bear the majority of the load (Marras *et al*., 1995). When this occurs the shear forces can increase up to 60% (Berkson *et al*., 1979) resulting in an increased risk of lower back pain and injury. Maximum sagittal flexion is the only spinal kinematic factor included in the risk model, in which the CDB probability of high risk grouping is greater than the other two tasks (Figure 42). Despite this, sagittal flexion is an area of concern for all three tasks, as they are all greater than 85% probability of high risk grouping. The odds ratio of the Marras *et al*., (1993) multivariate approach is greater, however, and will therefore be the focus of over-all risk determination.

The significantly higher left bend of the CWB task was because the workers in this task only had access to the left side of the conveyor belt, whereas the CDB and KDB tasks allow movement on both sides, as shown in Figure 41. Despite this, the left bend of all tasks were associated with high risk according to Marras *et al*., (1995). Therefore the left bends of all tasks, especially the CWB task, are too high and need to be decreased in order to reduce the risk of injury.

As all the workers were right hand dominant and the CDB workers were able to freely decide which side they bend to move bricks (because they are not limited by a conveyor belt), they mainly chose to lift from the left and move to the right, increasing the right bend of these tasks. The CDB workers did not have any lifting space limits as seen in the other two tasks (due to the limited space between the conveyor belt and the pallets), which could explain the significantly greater right bend of this task and the associated medium-high risk of this task. Therefore all tasks displayed asymmetry, with the large left lateral bend of the CWB task and the large right bend of the CDB and KDB tasks. Shirazi-Adl *et al*., (1984) showed that disc damage is more likely to occur when there is load asymmetry. Asymmetry results in unevenly loaded musculature, therefore increasing the stresses places on the musculoskeletal system (Drury *et al*., 1989). Asymmetry will cause the centre of gravity to move towards the perimeters or outside of the base of support, forcing workers to adopt awkward working postures to complete tasks. A greater deviation of the centre of gravity from the mid-sagittal plane results in a lower the maximum acceptable weight (Waters *et al*., 1993) and a greater energy cost (Drury *et al*., 1989). Therefore, reducing the asymmetrical nature of the tasks would decrease the risk of lower back pain/injury, which is necessary due to the high risks associated with the left bend of all tasks and the right bend of the CDB task. This, however, is difficult in the CWB and KDB tasks, as the workers are; a) under immediate time pressures, due to the speed of the conveyor belts and b) either working two people to one pallet (CWB task) or more than one pallet per person (KDB task), therefore making it challenging to implement changes. An alternative plan would need to be made to reduce the risks of the workers, such as job rotation or shorter work hours.

The CWB workers need to focus on accurately packing the bricks on one pallet in the required manner without breaking the delicate wet bricks. The workers performing this task, therefore, tend to stand with their hips facing the pallet (with a left twist close to 0º), so they can comfortably pack the pallet. This stance, however, requires a significantly larger right twist to collect the bricks than the other tasks. Workers from the other tasks work on more than one pallet at once, so their stance requires constant readjustment. The significantly greater left bends of the CDB and KDB tasks were associated with high risk of LBDs and the significantly higher right twist of the CWB task was also associated with high risk according to Marras *et al*. (1995).

Due to the increased time pressures of working on a conveyor belt line, the more mechanised CWB and KDB tasks had greater risk in terms of spinal movement velocity and acceleration. This increases the risk of the CWB and KDB even further as all the tasks measured involve asymmetrical lifting which has been identified as a significant risk factor for lower back pain (Dolan *et al*., 2007). In the lateral and twisting planes, the average and maximum velocities as well as the acceleration were all associated with risks in CDB and CWB tasks, with only the average lateral and twist velocities and maximum twist velocity showing risk in the KDB task. The only risks in the sagittal plane were low-medium risk from the average sagittal velocities of the CWB and KDB tasks. Therefore the lateral and twist movement speeds need to be reduced. Interestingly, velocities/accelerations of the KDB task, which has a conveyor belt, were lower than the manual CDB task in six of the nine speed measures. Therefore, there must be other factors influencing the speed of palletising other than the time pressures of the conveyor belt. Future studies would need to be done in order to research what these factors might be.

In summary, as shown in Table XX from the 19 spinal kinematic factors assessed, the CDB task had 12 areas of risk (3 low-medium, 5 medium-high and 4 high), the CWB task also had 12 (2 low-medium risk, 3 medium-high and 7 high) and lastly the KDB task 8 areas of risk (3 low-medium and 4 high). However, looking at these factors as single entities is often not accurate, so when assessing overall risk, the low back disorder risk model developed by Marras *et al*. (1993) is highly applicable due to the multifactorial nature of the model. This model looks at two task (maximum load moment and lift rate) and three spinal motion factors (maximum lateral velocity, maximum sagittal flexion and average twist velocity) in order to determine the probability that a task will be associated with high LDB risk (Marras *et al*., 1993). Together these factors result in the predictive power of this assessment tool being 10.7 times better than chance (Marras *et al*., 1993).

Using this risk model, shown in Figure 42, it was determined that the overall risk of the CWB was the greatest out of the three tasks with 92.40% of probability of being high risk. This was followed by the KDB task with a 72.29% chance of high risk probability. Lastly the overall risk of the CDB had the lowest probability of high risk, with 64.03%. Therefore the more mechanised tasks showed a higher risk than the manual CDB task and the CWB task with the highest brick weight, left lateral bend, right twist and the highest average velocity in all three planes, had the highest probability of being high risk. Therefore although there was an introduction of technology in the more mechanised CWB and KDB tasks, these tasks were at a greater overall risk. This shows that an increase in mechanisation does not necessarily relate to a decrease in risk. In this case, the automation of the conveyor belt has increased the time pressures on the workers, forcing them to palletise bricks more quickly, therefore increasing the velocities and accelerations of the tasks. As the overall risk shows that all tasks have more than a 60% probability of being high risk tasks, it would be necessary to implement interventions to reduce these risks for the CWB and KDB tasks. Another area worth discussing is the asymmetry of the three tasks.

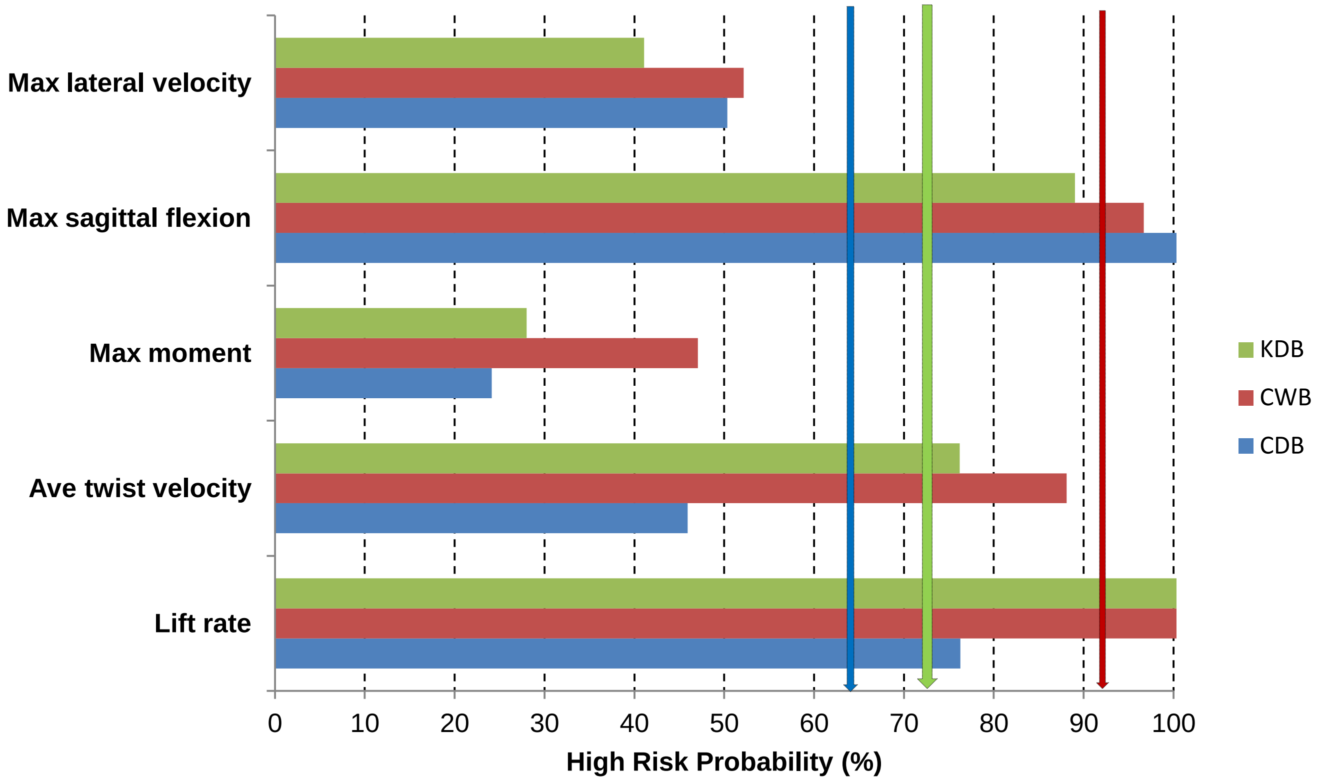


Figure 42: The overall risk of the three tasks using the multivariate approach (Marras *et al*., 1993).

In particular, maximum sagittal flexion and lift rate were the highest contributing risk factors for all tasks and average twisting velocity was a substantial contributing factor. The findings of the current study clearly indicate the high risks for the development of musculoskeletal disorders amongst the brick manufacturing cohort within the South African context. Regardless of the degree of mechanisation along the production lines palletising of bricks was associated with high risks and there is a clear need for ergonomics interventions to be implemented to reduce the physical demands of these tasks.

Asymmetry in brick manufacturing has been seen previously in Korean research (Chung and Kee, 2000). In this example it was suggested that pallets placed behind the workers should be moved to the side of the worker in order to reduce the asymmetry angle (Chung and Kee, 2000). Reducing the angle of lateral bend and twist by moving the pallet closer would result in a decreased lateral and twist velocity, as the workers would have to move the bricks a lesser distance in the same amount of time. This, however, would not be possible for the more mechanised CWB and KDB tasks, as vehicles need to reach the back of the pallets in order to remove them. There is also minimal opportunity for change in the CDB task as pallets need to be placed on the edge of the kiln, so the fork-lifts can remove them, but this task is more flexible than the more mechanized tasks.

In addition to this, similar to the research by Chung and Kee (2000), the employees of the CDB task were given a certain number of pallets to complete daily, which most worker finished in 5-6 hours, therefore increasing the lifting frequencies. Chung and Kee recommended that lifting frequency should be kept below 0.5 lifts/min (30 lifts per hour), which is much lower than the current lift rate of all three tasks in the current study. The other two tasks, CWB and KDB, required the employees to work for the entire eight hour work shift, and these two tasks had the greatest overall risk, using the multivariate approach (Marras *et al*., 1993).In addition to this, because the movements are happening simultaneously in all three planes, the risk is exponentially increased

L_5/S_1 JOINT LOADING

Occupational spinal loads have been associated with an increased risk of lower back disorders (Marras *et al*., 1995). Although the compressive forces are more often researched, the spinal tolerance to shear force is much lower than tolerance to compressive forces (McGill, 2004) and is therefore an essential factor to consider. Although static prediction models are not entirely accurate when assessing a dynamic task, its use as a representative measure of a static point in the work task can be useful in conjunction with spinal kinematics (Rodrick and Karwowski, 2006). Photographs were uploaded to the University of Michigan’s Three Dimensional Static Strength Prediction Program, which was used to acquire estimates of compression and sagittal shear forces at the point of brick placement onto the pallet. This allowed a prediction of the forces acting on the spine when workers were in the most extreme position, with the greatest sagittal flexion and the largest load moment, due to the increased distance of the hands away from the body and trunk angle. As a result of the similarities between the tasks, the positions of placement are very similar between tasks, although differences can be seen in: the CWB only moving bricks from right to left, whereas the CDB and KDB task workers moved bricks from and to both sides; the CDB workers occasionally placing bricks below foot height, whereas workers from the other task always place bricks above floor height; and the differences in brick weights.

The maximum flexion of the CDB and CWB tasks and the sagittal range of the CDB task were found to be the greatest. It was therefore predicted that these tasks would have the greatest compression forces at L_5/S_1. Although the compression force of the CWB task, the task with the heaviest bricks (4.4kg compared to 2.8kg for the CDB and 2.4kg for the KDB tasks), was the greatest, it was not significantly higher than the forces of the other two tasks, as seen in Table XXI. Compression at the L_4/L_5 joint was in the CWB task, which was significantly greater than compression forces of the CDB and KDB tasks, with no significant difference observed between the L4/L5 compression forces of the CDB and KDB tasks. Despite these differences, the compression values of all tasks were below the 3400N limit put forward by NIOSH. In conclusion, although the L_5/S_1 joint compression was highest in the CWB task, this was not a significant difference and all values remained in acceptable ranges.

Due to the lower spinal tolerance to shear forces when compared to compression forces, the tasks with a higher shear force can be expected to result in a higher risk of LBDs. The L_5/S_1 sagittal shear force of the CDB task was significantly greater than that of the KDB task by 12.17%; whereas the force of the CWB, 11.19% lower than the CDB task, was not significantly different to either task. Again the L4/L5 shear forces showed a different trend, with the CDB task showing the highest force, significantly greater than the CWB and KDB tasks as shown in Table XXI. In addition to this, the shear force of the KDB task was significantly greater than that of the CWB task. These values are all lower than previously recorded tolerance limits of 1000N (McGill, 1997), 1735N (Farfan *et al*., 1970) and 2500N (Yingling *et al*., 1999). Therefore, although the CDB task showed the highest shear force and hence the highest LBD risk, none of the tasks exceeded the shear limits currently available.

Table XXI: The mean compression and shear forces (N) at the L4/L5 and lumbosacral joints of workers from the three tasks.

		CDB	**CWB**	**KDB**
Compression (N)	**L_4/L_5**	2057.81 ⌞------	2623.50 ------⌟ ⌞------	2200.58 ------⌟
	L_5/S_1	2125.10	2380.75	2226.83
Shear (N)	**L_4/L_5**	291.86 ⌞------ ⌞------	75.67 ------⌟⌞------ --------------	188.25 ------⌟ ------⌟
	L_5/S_1	340.33 ⌞------	302.25 --------------	298.92 ------⌟

⌞--⌟ Denotes a significant difference

According to Sanders and McCormick (1993), the horizontal distance of the load in relation to the worker is the most significant factor affecting compression and shear forces at the lumbosacral joint. In the current study, workers often have to balance on one foot in order to place the bricks at the back of the pallet, indicating a large horizontal distance. A far reach will result in an increased sagittal flexion and an anterior shift in the centre of gravity of the workers. As a result of this, the torque of the erector spinae muscles would need to increase in order to prevent the worker from falling over (Knapik *et al*., 1996). It would therefore be beneficial if the horizontal reach required of the workers could be reduced, possibly by introducing pallets which could easily rotate, to allow workers to reach all sides of the pallet without significant reaching.

The accuracy of the compression and shear force limits, however, is unknown due to the impact of cumulative stress on the workers. NIOSH (1981) and Nordin and Frankel (1989) state that, the exact magnitude of loading which can be sustained by the spine before spinal damage occurs, is not known. It is likely that workers who perform highly repetitive lifting and lowering tasks for full eight hour work days, even with low weight loads, will experience a degree of lower back discomfort or injury over a number of years (Karwowski *et al*., 1992).

PHYSIOLOGICAL PARAMETERS

HEART RATE

The heart rates of workers from all tasks were not significantly different at the start of the protocol. Heart rate was significantly higher for the workers of the CDB and CWB operations than the KDB operations at both the middle and end of the lifting protocol. Therefore the exertion of the CDB and CWB workers was significantly greater than the KBD workers, suggesting that the KDB task requires the least amount of energy to perform. In addition to this, halfway through the protocol, the heart rates for both the CDB and CWB tasks were between 110 and 130bt.min^{-1}, putting them into the 'heavy work' category according to Ismaila *et al*. (2012). At the end of the protocol, the CDB task had increased to the 'very heavy work' category (Ismaila *et al*., 2012), whereas the CWB task was still in the heavy work category. Hence, from a physiological perspective, the CWB and more importantly the CDB tasks would need to be amended, or an intervention would need to be implemented to reduce the exertion of the workers of these tasks.

Heart rate has been shown to be an indicator of cardiac output (Vogt and Metz, 1977). An increase in heart rate during work can be attributed to both metabolic and thermal increases (Vogt and Metz, 1977). Metabolic increases are more difficult to alter, as they are a direct result of the task itself, but the thermal increases can be reduced. According to Nunneley (1989), heat stress is caused by three main factors; work, clothing and environment. From these factors, the increased CDB and CWB heart rates could be as a result of the increased workload of the CDB and CWB tasks; lifting two 2.8kg bricks 250 times per hour (1400kg.hr^{-1}) and two 4.4kg bricks 583 times per hour (5134kg.hr^{-1}) respectively compared to two 2.4kg bricks 417 times per hour (2000kg.hr^{-1}) for the KDB task. If this was the case, however, it would be expected that the CWB and KDB tasks would have a higher heart rates than the CDB task, due to the increased workload. Therefore other factors such as environmental conditions and safety clothing are likely to increase the heart rate of the CDB workers. The CDB workers palletise the brick outside and are therefore exposed to the sun, whereas the CWB task is indoors. In addition, although all workers wear the same protective overalls, the CDB and KDB workers wear protective gloves to ensure their hands do not get injured on the coarse, hard bricks, whereas the CWB workers do not wear gloves due to the softer nature of the wet bricks. Protective clothing or gloves in this case, will decrease the thermoregulation of the covered areas by decreasing the evaporation of perspiration (Nunneley, 1989); elevating the overall body temperature hence increasing heart rate.

PERCEPTUAL

BODY DISCOMFORT

According to Kroemer and Grandjean (1997), the origin of musculoskeletal disorders lies with body discomfort. A raised body discomfort rating can affect productivity and may increase the risk of injury (Axelsson and Eklund, 2001). Although there were few reported work-related injuries, workers still experienced discomfort throughout the work-day. In many cases, body discomfort is an indicator of a mismatch between the worker and the task performed (Corlett and Bishop, 1976) and it is therefore an important measure to consider.

Workers from the CDB task had perceived discomfort in the greatest number of body areas at the start, middle and end of the work day. At the start of the day, the CDB task had the highest percentage of reports, this was in the lower back area, whereas the KDB task had the highest perceived level of pain, from the forearm area, but discomfort in the forearm was only reported by one worker. Measures at the start of the day are either not work related, or are signs of chronic work-related pain or delayed onset muscle soreness present in the less experienced workers. At the middle and end of the day, the highest percentage of discomfort reported were from the KDB workers in the lower-back area.

The highest reported discomfort was reported in the forearm area by the KDB workers at both the middle and end of the work shift. The lower back area was the area with the highest reports of discomfort for all tasks at all times of the day. According the Figure 43, the lower back had the highest percentage of discomfort reports in the CDB and KDB tasks, not included in the figure, 100 percent of reported discomfort in the CWB task was in the lower back area. With regards to psychophysical factors, the highest amount of discomfort was reported in the KDB task; however, this measure was from a single individual and is therefore likely not representative of the task. Workers from the CDB task reported discomfort in the most number of body areas and would therefore require measures to reduce the perceived discomfort in the reported areas.

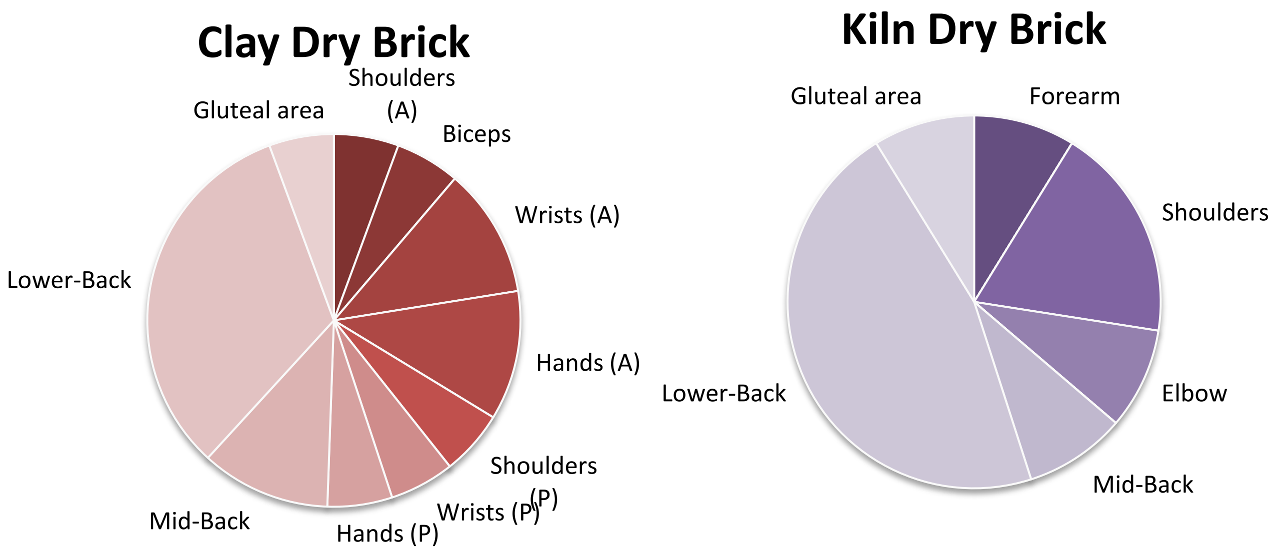


Figure 43: Percentage total incidence of the Body Discomfort ratings at the end of the work shift.

GENERAL DISCUSSION

Overall, a holistic approach was taken to determine the workers' responses to task demands, a summary of which is shown in Table XXII. Dempsey (1998) shows that these three criteria are different and by their nature conflicting. The current research shows a similar trend.

The CWB was linked to the highest biomechanical risk of LBDs both in terms of risk shown in individual factors and in the overall low back disorder model assessment. Although the CDB task had more spinal kinematics factors associated with risk than the KDB task, the KDB task was associated with a greater overall risk in terms of the Marras *et al*. (1993) low back disorder risk model. The five key factors for lower back disorder risk determination are; lift rate, maximum sagittal flexion, maximum lateral velocity, average twisting velocity and maximum lift moment (Marras *et al*., 1993). These factors together increase the predictive power of determining risk and are therefore more accurate than looking at any individual spinal kinematics factor. The CWB task also had the greatest lumbosacral compression, whereas the CDB had the highest lumbosacral shear force. As shown in Table XXII.

Physiologically, heart rate values of the CDB task had the highest risk of strain and the KDB task had the lowest. Conversely the psychophysical body discomfort measures were associated with the highest chance of risk in the KDB task followed by the CDB task.

It is therefore shown that the finding by Dempsey (1998) was supported in this study, in that the different tasks were associated with higher risk in different areas, as shown in Table XXII.

Table XXII: An overview of the standings, in terms of the biomechanical, physiological and perceptual criteria, of the three tasks.

		CDB	**CWB**	**KDB**
Biomechanical	Spinal Kinematics	🟩	🟥	🟨
	Compression (L_5/S_1)	🟩	🟥	🟨
	Shear (L_5/S_1)	🟥	🟨	🟩
Physiological	Heart Rate	🟥	🟨	🟩
Psychophysical	Lower Back BD	🟨	🟩	🟥

🟥 Highest 🟨 Middle 🟩 Lowest

In terms of biomechanics, the CWB task was associated with the greatest risk (Table XXII). This same task had the lowest risk for the psychophysical factors and a medium risk compared to the other two tasks for the physiological approach. The CDB task had the highest risk of strain in the physiological criteria, the lowest risk in two of the biomechanical factors and was the intermediate task for psychophysical measures. Lastly, the KDB task showed the greatest values for the psychophysical measures, the lowest physiological strain and medium levels for two of the biomechanical factors. Therefore, no task is conclusively at a greater or worse risk, but rather each task is at a higher and lower risk for different criteria. It would therefore be important to further research the three tasks in the areas in which they are most affected (as shown in Table XXII). Although each industry is unique, the current South African brick manufacturing industry showed an increase in mechanisation, with one task being entirely manual (CDB) and the other two being partly-mechanised due to the presence of a conveyor belt (CWB and KDB).

The CWB had the greatest biomechanical risk compared to the other two tasks. Therefore in order to reduce this risk, task interventions such as lifting the pallets or decreasing the speed of the conveyor belt would decrease the risk. All tasks, however, were associated with a greater than 60% probability of high risk group membership. Therefore these considerations need to be made for all three tasks. Due to the highest risk values of the lift-rate, sagittal flexion and movement velocities, reducing the effect of these factors should be considered in any intervention. These could be changed by decreasing the amount of time performing the task (lift-rate), increasing the height of the pallet (sagittal flexion) or the speed of conveyor belts, for the mechanised tasks and setting a minimum time for CDB workers to stack their required daily pallets.

In the current research, the manual task showed the highest physiological demands, possibly due to the added effect of outside environmental demands. This would therefore need to be assessed in order to determine the exact effect of environmental demands on the worker. Potential environmental interventions for this would include temporary coverings over the manual kilns to reduce the effect of the sun while the bricks are being palletised.

Lastly, the KDB task showed the greatest psychophysical responses to their task. Once again, however, all tasks had reports of lower back discomfort throughout the work day, so an attempt should be made to lower the impact on the lower back in all tasks. Due to the association of LBP with asymmetry, sagittal flexion and speed of movement and the high risks of these factors in the current research, the spinal kinematics factors should be reduced to lower perceived discomfort.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Manual brick manufacturing is a very common MMH industry in industrially developing countries (IDCs), as it introduces unskilled labour and provides cheap building materials to be used in the surrounding areas. In order to fully understand the task demands of palletising in a brick manufacturing industry, the workers responses to the tasks needed to be assessed.

Despite increasing automation and widespread ergonomics research, MMH tasks, lifting tasks in particular, still represent a major health and safety risk in industry (Lin *et al*., 2006; Marras, 2000). This is particularly apparent in industrially developing countries (O’Neill, 2000) and in the case in the current research, where despite the increased mechanisation of CWB and KDB tasks, lifting is still required. Rates of lower back pain are higher in countries with a lower income (e.g. IDCs), due to the hard physical labour in these countries (Volinn, 1997). MMH factors are often exacerbated in industrially developing countries, which have less industrial mechanisation than industrially advanced countries, and often weaker workers due to the enhanced burden of disease. Therefore, workers in South Africa may potentially have a reduced worker capacity due to the increasing average age of the workers and the unique quadruple burden of disease profile, and would have a greater task demands in terms of MMH lifting requirements.

Of the worker capacity factors, age is amongst the most researched as it is non-modifiable and impacts on numerous other worker capacity factors. Age is an important factor as it affects physiological, biomechanical and morphological capacities, which will in turn impact the physical work ability (Kenny *et al, 2008)*. These findings are noteworthy; as research in IACs shows that the workforce is aging. Regardless of this increase, there has not been any subsequent decrease in task demands, despite the physical work capacity decline experienced with aging (Kenny *et al*., 2008).

Ergonomics research has been largely confined to laboratory settings and although this type of assessment is popular, as extraneous variables are more easily controlled, there is a need, particularly in IDCs, to assess workers in their actual working conditions. This would provide a more accurate understanding of the actual requirements of the workers in order to complete the task demands.

SUMMARY OF PROCEDURES

Two separate phases were undertaken in order to more completely understand the manual workers and three examples of the tasks they performed. Prior to each part, the testing protocol was explained to workers, both verbally and written, with a translator present. After this, informed consent was obtained from workers willing to participate.

The first phase assessed worker capacity factors of 101 male workers of four different age groups 20-29 (n=30, 25.10 ± 2.50 years), 30-39 (n=35, 34.34 ± 2.80 years), 40-49 (n=26, 43.92 ± 2.61 years) and 50-59 (n=10, 51.7 ± 3.02 years). Workers' characteristics were assessed on site between 7.30am and 9.30am on normal work days in a laboratory-type setting. After informed consent was signed, participants filled out a health questionnaire and had their resting heart rate and blood pressure measured, while in a seated position. After which, anthropometric measurements of; stature, mass, waist and hip circumferences, and skinfolds of the bicep, tricep, abdomen and subscapular, were measured. All measures were taken on the right hand side where applicable. After these measurements were taken, the participants performed eight isometric strength tests in a permutated order. This test battery included; leg, back, bicep and shoulder strength (measured with a back dynamometer), grip and pinch strength (measured with hand-held dynamometers) and finally push and pull strength tests (measured with a Chattilon dynamometer).

The second part of the research involved assessing the task demands of three palletising tasks of varying mechanisation. After signing informed consent, workers' stature and mass were measured. A heart rate monitor was then attached to the worker, followed by the Chattecx Lumbar Motion Monitor. Workers then performed a protocol of 30 normal lifts, moving 60 bricks from the Manual Kiln (in the CDB task) or the conveyor belt (for the CWB and KDB tasks) to the pallets, with one brick in each hand. During this protocol, spinal kinematic factors were measured from lifts 0-6, 13-

18 and 25-30 and heart rate measures were recorded at the start of the protocol, after 15 lifts and on the 30th lift. In addition to this, Body Discomfort was assessed throughout three times throughout a normal work day; at the start of the work shift, before the lunch break and at the end of the work shift. Photographs of workers were taken when workers were in their most flexed position (when they were placing the bricks onto the pallets). These photographs were used to assess the spinal loading of the tasks using the 3DSSPP software (University of Michigan, 2004).

Therefore this research took a holistic approach in assessing both worker capacity factors, and workers' responses to task demands, by measuring personal, biomechanical, physiological and perceptual measures. All variables were then analysed using descriptive statistics, followed by ANOVAs which were used to determine statistically significant differences between ages (Part I) and between tasks (Part II).

SUMMARY OF RESULTS

PART I: WORKER CAPACITY

Comparisons of workers' morphology with increasing age showed that while BMI did not change significantly with age, the 50-59 age group had significantly greater values than the 20-29 group for WHR, WC and BF%. The oldest group also had greater WHR and WC values than the 30-39 age group. In addition to this, the 40-49 age group had significantly greater WC and BF percentage values than the 20-29 age group. Therefore, in general, body morphology measures increase with aging. The body morphology characteristics are, in general, lower than those previously found in both South African and IACs.

Age did not significantly affect the resting heart rate of workers and all heart rates were within normal ranges. Although no significant differences for age were found in systolic blood pressure, the oldest group was in the 'hypertension category', whereas the other three groups were in the 'pre-hypertension' category. This was different to the diastolic blood pressure, however, where the 50-59 and 40-49 age groups were both significantly greater than the 20-29 age group. The 40-49 and 50-59 age groups were classified as having pre-hypertension diastolic levels, whereas the 20-29 and 30-39 age groups were normal (<80mmHg). In general, the systolic and diastolic blood pressure levels of all age groups were higher than those found in IACs.

In terms of the effect of age on strength, significant differences were: the significantly lower shoulder strength of the 50-59 age group when compared to the 20-29 age group and a significantly greater push strength of the 50-59 group compared to the 30-39 and 40-49 age groups. No significant differences were seen in the other strength tests. This could be due to the 'healthy worker effect' (Kenny *et* al., 2008) influencing the usual decrease seen with age. This effect, in addition to the maintained conditioning of the muscles (as a result of the physical nature of the MMH tasks) will result in a delay in the decrease in muscle mass expected with age. It therefore makes it difficult to determine whether the high burden of disease in South Africa has an impact on the younger workers. The majority of the strengths found in the current study were lower than strength measures found in IACs, leg strength was the only area found to be greater in the current research.

PART II: TASK DEMANDS

Comparisons of workers' responses to three different tasks revealed significant differences in spinal kinematics factors with differing levels of mechanisation. Results showed that the most manual CDB task, which had the highest maximum sagittal flexion, right bend and the highest ranges in all three planes, also had the greatest shear forces at the level of both the L_4/L_5 and L_5/S_1. Due to the lack of immediate time pressures of this task (i.e. no conveyor belt) it also had the lowest average velocities in all three planes. In addition, this task had the greatest heart rate responses in the middle and at the end of the testing protocol and discomfort reports in the greatest number of body areas. Despite these factors, this task was associated with the lowest overall risk according to the multivariate lower back risk model by Marras *et al*., (1993).

The more mechanised CWB and KDB tasks, both involved lifting off a conveyor belt and placing bricks onto pallets. The only differences were the heavier bricks of the CWB task (4.4kg compared to 2.4kg) and the CWB workers only had access to the left hand side of the conveyor belt, whereas the KDB task workers were on both sides. Due to the more mechanised nature of these tasks, it was predicted that they would have a lower risk than the CDB task and similar risk levels to each other.

In terms of spinal kinematics, the CWB task had the greatest average velocities in all three planes, the greatest maximum left bend and right twist. These greater lateral and twist angles are due to the workers only having access to the left side of the conveyor belt and the increased velocities are due to the immediate time pressures of the fast moving bricks on the conveyor belt. The CWB was associated with the greatest overall risk according to the multivariate approach by Marras *et al*. (1993). The CWB task had the second greatest heart rate values at the middle and end of the protocol, both of which were significantly greater than the KDB task. At the middle and end of the work shift, the CWB workers only had perceived discomfort in the lower back. This could be related to the significantly highest compression forces of the L4/L5 joint, although the shear forces at this joint were significantly lower than the CDB and KDB tasks.

Despite the similarities between the CWB and KDB tasks, the KDB task did not have the greatest values in any spinal kinematic areas, but had a maximum left twist significantly greater than the CWB task and an average twist velocity significantly greater than the CDB task. This task had the lowest heart rate values (significantly lower than the other two tasks) which were below the 110bt.min^{-1} threshold proposed by Ismalia *et al*. (2012). It also had the second greatest reported areas of discomfort, and the highest percentage of reports of lower back discomfort. The KDB task had a L4/L5 shear force significantly greater than the CWB task, but a L4/L5 and L5/S1 shear force significantly lower than the CDB task and a L4/L5 compression force significantly lower than the CWB task. Despite the initial expectation that this task would be associated with the lowest risk, when using the Marras *et al*. (1993) multivariate risk model, it was associated with the second greatest overall risk.

It is evident, regardless of the level of mechanisation, that palletising bricks is associated with a high sagittal flexion, a large lift-rate and a high average twist velocity, with all three tasks demonstrating risks according to the multivariate approach. This assessment showed that despite any differences between tasks, all tasks had a strong probability of being high risk (>60%).

STATISTICAL HYPOTHESES

PART I: WORKER CAPACITY

IMPACT OF AGE

HYPOTHESIS 1A:

This hypothesis stated that no significant differences would exist between biomechanical (strength) responses for each age group.

Only two of the eight strength tests showed significant differences, namely shoulder and push strength. Therefore for the shoulder and push strength, the null hypothesis is rejected. The null hypothesis is accepted for the other six strength tests (leg, back, bicep, grip, pinch and pull), in that there were no significant differences in strength between any of the age groups. In general, as the majority of strength test were not affected by age, it can be stated that overall age did not have an effect on the strength capacity of workers.

HYPOTHESIS 1B:

This hypothesis stated that no significant differences would exist between physiological (resting heart rate) and health (blood pressure) responses for each age group.

As there were no significant differences in the resting heart rates of different age groups, the null hypothesis for this is tentatively accepted. For blood pressure responses age was shown to be a factor for diastolic pressure but not for systolic pressure. Due to the significant increase of diastolic blood pressure with age, the null hypothesis is rejected for this factor. In contrast to this, despite the higher category of blood pressure of the 50-59 group when compared to the other three groups, there were no significant differences, and therefore the null hypothesis is tentatively accepted for this factor. Overall, conclusively determining the effect of age on the health factors is challenging and further research would be required.

HYPOTHESIS 1C:

This hypothesis stated that no significant differences would exist between the anthropometric measurements of each age group.

No significant differences were found between the Body Mass Indexes of the various age groups and therefore the null hypothesis is tentatively accepted for this factor. However, due to the significant differences with age for WHR, WC and BF% the null hypothesis is rejected for these variables. It is therefore evident that overall, age was a contributing factors to changing anthropometric characteristics in this study.

PART II: TASK DEMANDS

IMPACT OF TASK

HYPOTHESIS 2A:

This hypothesis stated that no significant differences would exist between the biomechanical responses of each task.

The null hypothesis is rejected for all the spinal kinematic motion angles, the average velocities of all three planes, the compression forces of L4/L5 and shear forces of L4/L5 and L5/S1 due to the significant differences between tasks. For the maximum velocities and accelerations in each plane and the compression forces on the L_5/S_1, the null hypothesis is accepted due to no significant differences between tasks. Overall the task did have an effect on the majority of biomechanical factors.

HYPOTHESIS 2B:

This hypothesis stated that no significant differences would exist between the physiological (working heart rate) responses of each task.

The heart rates of the CDB and CWB tasks were both significantly higher than that of the KDB task at the middle and end of the protocol, therefore the null hypothesis is rejected for task-related heart rate changes. It can be concluded that task does have an effect on the physiological criteria.

HYPOTHESIS 2C:

This hypothesis stated that no significant differences would exist between the perceptual (body discomfort) responses of each task.

Despite differences being observed between incidence and intensity of perceived body discomfort of the three tasks throughout the day, these could not be statistically substantiated, thus the null hypothesis is tentatively accepted.

CONCLUSIONS

PART I: WORKER CAPACITY

Two trends were expected with age; firstly, due to common trends seen in IACs, it was expected that the prevalence towards obesity and hypertension would increase, while strength would decrease with age. Secondly, in a South African-specific context, due to the increased prevalence of disease in the younger age groups (Bradshaw *et al*., 2003), it was expected that a decline in strength would be seen in these age groups.

Comparisons with age revealed that aging had a negative effect on body morphology and health characteristics, with an increased prevalence of obesity and hypertension with age, therefore supporting the first trend expectations. Age, however, did not significantly affect the strength of workers in the current population. This is thought to be due to the ‘healthy worker effect’ highlighted by Kenny *et al*. (2008), as the 50-59 age group had the lowest number of workers (n=10), therefore suggesting that workers with a decreased capacity either moved away from performing the manual palletising job, or retired completely, leaving only healthy older workers performing the manual tasks. These workers should still be physically capable to perform their work tasks, as the manual nature of their work tasks will maintain the muscle conditioning, delaying dynapenia. The health questionnaire reports did not support the findings of Bradshaw *et al*. (2003) that the younger workers had a higher burden of disease. But as the questionnaire was self-reported, its reliability is questionable. This, therefore call for further research into the effect of disease on the capacity of South African workers. In addition to this, obesity prevalence and mean body morphology and strength values of the current population were lower than IACs values. The mean systolic and diastolic blood pressure values, however, were higher in the current research than the values found in IAC research.

PART II: TASK DEMANDS

The horrendous working conditions in many IDCs have been emphasised by Scott and Shanavaz (1997). It was expected that increasing the mechanisation/automation of tasks would reduce the risk workers developing of lower back pain. However, the two tasks with conveyor belts (CWB and KDB) were shown to have a greater probability of being tasks with a high risk of lower back pain and injury, 92.40% and 72.29% respectively, according to the multivariate risk model. The completely manual CDB palletising task therefore had the lowest probability (64.03%) of being a high risk task.

All tasks had a high probability (above 60%) of being high risk tasks, therefore suggesting that all tasks need interventions.

It would be anticipated, that the tasks with the greatest probability of high risk group membership, would produce the greatest percentage of lower back discomfort reports. The CWB task, which was associated with the highest probability of high risk group membership, had the lowest percentage of lower back discomfort reports and the lowest discomfort rating. The CDB task which had the greatest sagittal flexion, but the lowest overall probability of high risk task membership, had the highest percentage of lower back discomfort reports at the start of the day, but the KDB task, which had the second greatest probability of high risk group membership, had higher percentages at the middle and end of the work shift. In addition to this, the KDB task had the highest ratings of lower back discomfort throughout the day.

The CDB had the greatest working heart rate values at the middle and end of the testing protocol, followed by the CWB task. These tasks were both above the recommended 110bt.min^{-1} working heart rate. The KDB task was below this recommended threshold. The heart rate trends were the same as the trend seen in the maximum sagittal flexion and maximum ranges of all three planes, suggesting a link between these factors.

Due to the multifaceted nature of problems found in IDCs, as well as the lower economies of these countries, cost–effective recommendations need to be introduced. In addition to this, the technological advancements of increasing mechanisation increased the probability of risk, rather than reducing it. This is most likely due to the fast moving conveyor belts resulting in increased velocities in all planes and high lift rates throughout the day. It is therefore suggested that either the conveyor belts are slowed down, or workers need to spend less time on the conveyor belt. Reducing conveyor belt speed is unlikely as this would reduce production. Reducing the time that workers spend on the conveyor belt lines could be done by; a) ensuring more workers are employed or b) implementing job rotation between the three tasks, both of which would increase worker-related company costs.

RECOMMENDATIONS

In order for ergonomics to make a meaningful contribution in South Africa, further research should be based on ensuring a greater understanding of the specific worker capacity of specific populations. In order to do this most effectively, workers from a variety of provinces and a wide range of industries should be measured, along with the corresponding task demands, in order to understand the profile of South African industries. The following recommendations could help in this process.

Industrial workers, particularly those in IDCs are known for being required to perform many different types of MMH tasks which are physically demanding. These should be measured within the working environment, using a holistic approach including physiological, biomechanical and perceptual measures (Dempsey, 1998). Studies should include interventions which can be validated in the laboratory before proposing interventions to industries, in order to ensure the interventions are beneficial to the workplaces. The importance of integrating field and laboratory research has been established by Scott and Charteris (2004).

Aerobic capacity has been shown to be a good indicator of the responses of individuals to the task demands imposed on then, and it would therefore be an important measure to consider in future research. Measuring VO_2max in a laboratory or using a step test in the field and VO_2 at work would provide an important understanding of the workers responses to tasks. In addition to this, aerobic fitness has been shown to decrease with age, by 5% per decade in non-sedentary individuals, so it would be an important measure to consider for future research.

Due to the potential effect of health and nutrition on worker capacity factors, these would need to be most thoroughly examined, using medical history reports and obtaining actual blood glucose, cholesterol to more completely understand the worker capacity. In addition to this, measuring the nutritional intake as energy intake compared to energy expenditure is important to understand the manual labour force.

In terms of biomechanical responses, validated tests should be used to assess more areas of strength in a controlled environment, using, for example, an isokinetic dynamometer, in order to get a dynamic strength value, rather than static strength. In addition to this, measures such as leg and arm circumferences would add a new level to understanding potential changes with age, as these measures can be used to ascertain the loss of muscle mass. In addition, attaching EMG electrodes to workers performing the tasks would provide an interesting understanding of the recruitment of muscles during the palletising and would provide insight into the differences in muscle recruitment with asymmetry and extensive reach in tasks.

Lastly, when considering perceptual factors, including assessments of central and local RPE would have provided a more thorough assessment of the perceived effort that workers required in order to complete the tasks. This would result in a more thorough understanding of the discrepancies between the low body discomfort reports of the CWB task, but the high overall risk of this task; as well as the high reporting of discomfort for the KDB task when compared to the low heart rate responses of this task.

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APPENDIX A: GENERAL INFORMATION

1. Letter of Information to the subject

2. Subject Consent Form

1. INFORMATION TO THE PARTICIPANT

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

HUMAN KINETICS AND ERGONOMICS

Cell: 084 5880081 Fax: (046) 603 8934 E-mail: g08b0059@campus.ru.ac.za

Dear participant,

Thank you for agreeing to participate in my Masters study entitled:

Understanding the South African worker capacity and its relationship to the task demands- the effect of age and sex: an industry example

Through the course of this letter the aim of the study, the specific requirements of the study, and the potential risks and benefits will be explained to you.

AIM OF THE STUDY

This study aims to improve the knowledge surrounding the characteristics of South African Workers in relation to the demands they are exposed to within the work environment. The capacity of workers will be compared between male and female workers to compare the strength of different sexed workers, as well as workers of different ages to see the impact that age has on capacity factors. In addition to this, the demands of the tasks will be measured. This understanding will provide automotive industries with information about the strength capabilities of the workers, in particular, the difference between the strength of male and female workers, and, the difference between the strengths of different age groups. This information will help to increase the understanding of the workforce and could help reduce the risk of injuries, and will increase efficiency of the production line to increase overall production of the company.

TESTING PROCEDURE

Prior to testing, all the experimental procedures and testing equipment will be explained to you in person.

You will be required to participate in two sessions of testing, one in a lunch time and one before your work shift the day after your first session.

PART 1

During the first session, you will be given this letter and the experimental procedure will be explained verbally to you. If you are willing to participate after this then you will be required to sign an 'informed consent form, which says that you have been told about the study and you agree to participate. You will then be asked to fill in a Health questionnaire- your individual information collected will be confidential and will not be available to the public or your work place. This will be done to better understand your Health status and home lifestyle in order to better understand how the South African worker differs from workers of other countries. Once this is completed you will be shown how the equipment involved in the testing procedure works and basic body measurements as well as reference measures will be taken. In this session you will also be shown how to do the strength testing for 'Part 2' of the study and you will be allowed to practice to make sure you know how to do it. The Rating of Perceived Exertion (RPE) (how hard you feel you are working) and body discomfort (how sore the different parts of your body are) scales will also be explained to you at this point. Furthermore, any questions or concerns will be answered at this point. During this session you will be required to wear normal work clothing.

The specific measurements that will be taken include;

Height (how tall you are), measured with a measuring tape against a wall.

Weight (how heavy you are), measured on a scale.

Body composition (the amount of muscle, bone and fat in your body), calculated using skinfolds - requires the researcher to measure the amount of fat at four different parts of the body (two measures of the arms, one of the shoulder-blade and one of the stomach). This will require you to reveal these four parts of your body to the researcher.

Blood pressure- a tube will be wrapped around your arm to perform this measure.

Waist and Hip circumference (the size of your hips and waist), using a tape measure

Resting heart rate, using a heart rate monitor, attached around your upper body, underneath your rib-cage.

You will then be required to perform 6 different strength tests (for your back, legs, arms, shoulders and grip and pinch strength) which will be shown to you prior to testing you. For these measures it is essential that you perform the tests as hard as you can to get your highest possible strength measure.

PART 2

The second part of testing will take place during your work shift. When you arrive in the morning the testing will be explained to you again to remind you of the testing procedure. You will then be weighed and fitted with a heart rate monitor. At three times throughout the day you be asked to rate your physical exertion (how hard you feel you are working) and body discomfort (which will show how sore the different parts of your body are) using the RPE and Body Discomfort scales which will be provided. The equipment and the RPE and body discomfort scales will be demonstrated and explained to you during the habituation session. At the end of your work shift the heart rate belt will be taken off and you will be weighed again.

On a separate occasion, you may be asked to wear either a Lumbar motion monitor (a device which attaches to your back and shows how your body moves) and a Heart Rate monitor. You will then be asked to perform your normal work task for 20 minutes, after which the equipment will be removed.

Throughout the day, some photographs may be taken of you but your face will be hidden if these pictures are used in the final report. Your name will also not be used in the report and you will remain anonymous throughout the process.

RISKS

The testing involves maximal strength testing which will put strain on the muscles and could cause injury by damaging the muscles. In order to minimise these risks, you will only perform these tests a maximum of three times. You will be in control of the maximal strength tests and will therefore be able to stop immediately if you feel uncomfortable. Instructions on how to perform the maximal strength tests correctly will be provided to you and you will be shown how to perform the tests in order to minimise any risks.

A level three first aider will be present at all times to reduce any risk of injury. You are also permitted to not take part in the study if you do not want to.

You may also feel slightly embarrassed when the body composition tests are done, but you will be in a separate room with only the researcher present to minimize any feelings of unease.

The rest of the testing will be done during the work that you normally do every day, so you should not feel any different to a normal work day. As this study is voluntary, you can withdraw at any point in the testing process without negative consequences should any discomfort arise from any of the experimental conditions.

BENEFITS

This study aims to provide input into the worker capacity of South African workers, and will provide information on strength differences between males and females and between different age groups. The results will aid in concluding whether all workers are able to perform the same work tasks with the same ease and efficiency. This may improve individual performance, and reduce the risk of injury of workers.

OTHER

Participants will be required to not drink alcohol the day before they are participating in testing and are asked to not do any exercise (beyond what they would do on a normal day) the day before testing. In addition, participants are asked to not do anything that is out of the ordinary the day before testing, to ensure that the results obtained are accurate.

All data collected will be coded and thus your anonymity will be protected. If at any stage during the experimental sessions you wish to withdraw, you may do so without any consequences. If there are any queries involving the testing procedures, or regarding any feedback, please contact me, my details are provided at the end of this letter.

Thank you for agreeing to participate, I hope you this research can help you in some way in the future. Feedback of the results will be given to you in an informal talk, if you are interested an choose to attend. Please feel free to ask any questions.

Yours sincerely,

Samantha Bezuidenhout

Studying towards a Master of Science degree

Department of Human Kinetics and Ergonomics

0845880081

g08b0059@campus.ru.ac.za

2. SUBJECT CONSENT FORM

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

HUMAN KINETICS AND ERGONOMICS

Cell: 084 5880081 Fax: (046) 603 8934 E-mail: g08b0059@campus.ru.ac.za

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

Understanding the South African worker capacity and its compatibility to the task demands- the effect of age and sex: an automotive industry example.

All the procedures have been fully explained to me both verbally and in writing, and the potential risks and benefits have been brought to my attention. By signing this document, I am agreeing to participate in this research, and accept joint responsibility together with the Human Kinetics and Ergonomics Department, in that should an injury occur as a direct result of the protocol being performed during the study, the Human Kinetics and Ergonomics Department will be liable for costs which may ensue and will reimburse the subject to the full amount, i.e. doctors' consultation, medication, rehabilitation etc. The Department will however waive any legal recourse against the researcher and Department of Human Kinetics and Ergonomics of Rhodes University, from any and all injuries sustained in the event that the injury is either self-inflicted due to negligence of the subject, or in any way not directly related to the study itself. This waiver shall be binding upon my heirs and personal representatives. I agree to promptly report any signs of discomfort or symptoms of abnormality or distress to the researchers, should any arise. I have been informed on the ability to withdraw my participation from the research at any time. I am aware that my anonymity will be protected at all times, and that all the data collected may be published for scientific purposes.

I have read the information sheet accompanying this form and understand it. Any questions I may have had have been answered by the researcher to my satisfaction.

SUBJECT:

__________________ __________________ __________________

(Print Name) (Signed) (Date)

RESEARCHER:

__________________ __________________ __________________

(Print Name) (Signed) (Date)

WITNESS:

__________________ __________________ __________________

(Print Name) (Signed) (Date)

APPENDIX B: DATA COLLECTION

1. Body Discomfort Map and Scale

2. Body Morphology Measures

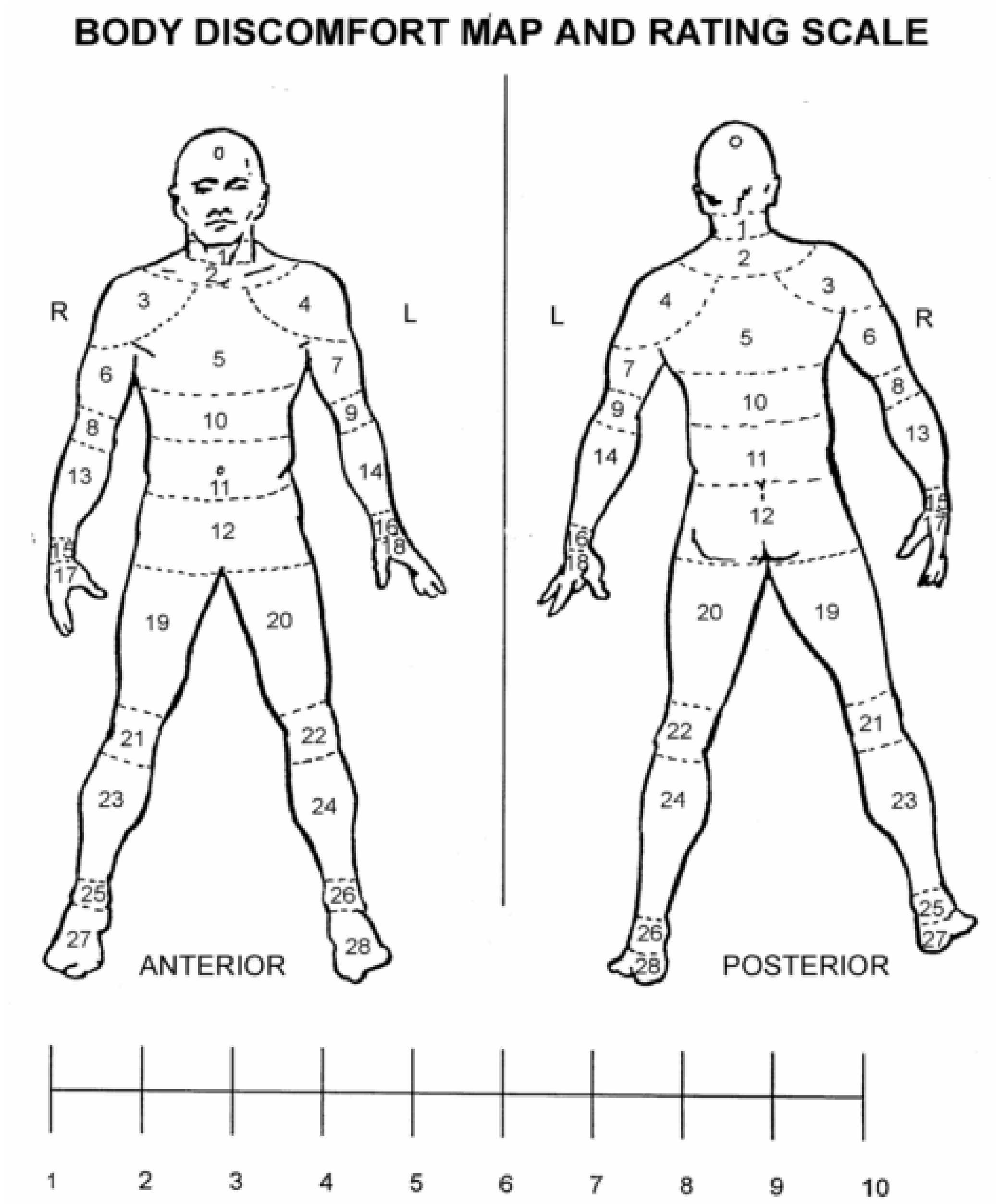
    a. Skinfold sites
    b. Stature

3. Strength Measures

4. Subject Data Sheets

5. Questionnaire Sheet

1. BODY DISCOMFORT



Minimum Intensity Maximum Intensity

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

2. BODY MORPHOLOGY

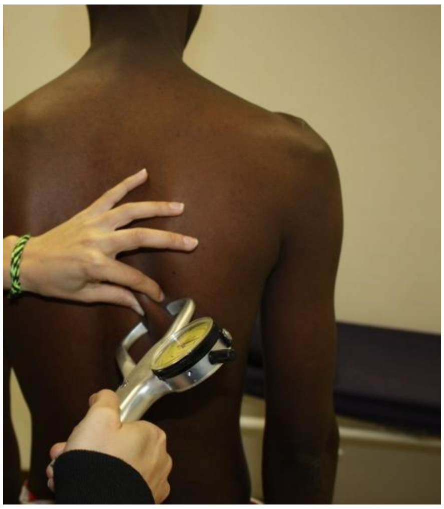
A) SKINFOLD SITES

Tricep

Supra-iliac

Bicep

Sub-scapular



B) Stature

3. STRENGTH MEASURES

Back

Leg

Shoulder

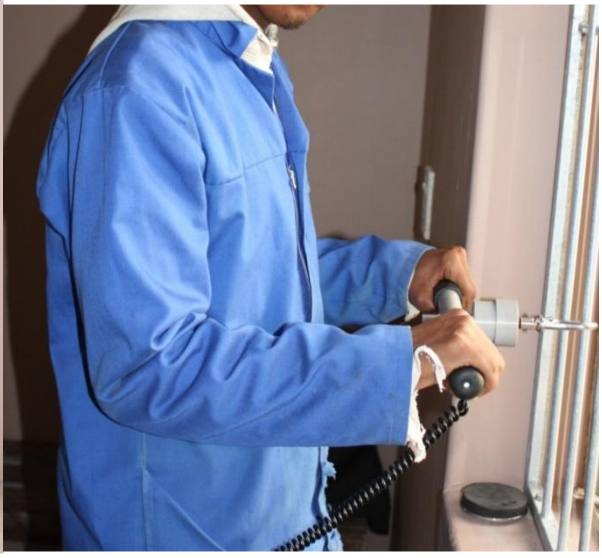
Bicep

Pinch

Grip

Push

Pull



4. SUBJECT DATA SHEET

PART I:

Name:________________________________ Code:__________

Task:________________________________

Age:_________ Sex: (TICK) ☐ Male ☐ Female

Number of years working at Makana:____________years

ANTHROPOMETRIC DATA:

Stature:_________mm Mass:__________kg

Waist circumference:________mm Hip circumference:_________kg

Body Composition:

SITE	1 (mm)	2 (mm)	3 (mm)
Triceps			
Biceps			
Subscapular			
Suprailiac			

RESTING CARDIOVASCULAR RESPONSES:

“Reference” Heart Rate:_________bt.min^{-1}

“Resting” Blood pressure:__________mmHg (Systolic)________mmHg (Diastolic)

STRENGTH:

	1 (kg force)	2 (kg force)	3 (kg force)
Back			
Legs			
Bicep			
Shoulder			
Pinch			
Grip			
Push			
Pull			

PART II:

Name:____

Job:____

Age:___________

Number of years working at Makana:_______________years

ANTHROPOMETRIC DATA:

Stature:___________mm Mass:____________kg

PSYCHOPHYSICAL and PHYSIOLOGICAL:

	Body Discomfort (A-Anterior, P-Posterior)		**Heart Rate**
	Area	**Rating**	
start			
Mid			
End			

5. QUESTIONNAIRE

HEALTH STATUS AND INJURY HISTORY QUESTIONNAIRE

(Adapted from Christie, 2006)

HEALTH STATUS

Non- communicable

DIABETES

- Do you have diabetes? **Yes** ☐ **No** ☐
- Are you on medication for it?

____

____

____

CHOLESTEROL

- Has your cholesterol been measured? **Yes** ☐ **No** ☐
- If so, have you been told you have a high cholesterol? **Yes** ☐ **No** ☐
- Do you remember what it is?

____

HEART DISEASE

- Do you have heart disease (e.g ? ☐ **Yes** ☐

  No

- If so, are you on any medication for it?

____

____

____

____

HYPERTENSION

- Has your blood pressure been measured? ☐ **Yes** ☐ **No**

- If so, have you been told you have a high blood pressure? **Yes** ☐ **No** ☐

- Are you on high blood pressure medication? ☐ ☐

SMOKING

- Do you smoke? **Yes** ☐ **No** ☐

- If so, how many a day?
  - 1 – 14 ☐
  - > 15 ☐

- If you do not smoke now: ☐
  - Are you an ex-smoker (used to)?

- Are you a non-smoker (never smoked)? ☐

ALCOHOL

- Do you drink alcohol? ☐ Yes ☐ No
- What do you usually drink? ____
- How many drinks do you have a day? ________________________________

Communicable

Have you suffered, or are suffering, from any of the following illnesses?

- Tuberculosis ☐
- Pneumonia ☐
- Gastroenteritis ☐
  (Gastric flu: vomiting; diarrhea, cramping)
- Influenza (common flu) ☐
- Meningitis ☐
- Cholera ☐

Do you have any other health problems?

____

____

____

____

MUSCULOSKELETAL INCIDENCE

EXISTING

- Are you currently suffering from a musculoskeletal injury (an injury to a muscle or bone, for example a broken bone or a pulled strained muscle)?

  Yes ☐ **No** ☐

- If so, what part of your body, and what is the injury?

  ____

  ____

- Did your work cause your injury? **Yes** ☐ **No** ☐

- Are you receiving treatment and if so what kind?

____

____

PREVIOUS

- Have you suffered from a musculoskeletal injury in the last 12 months? ☐ ☐

- If so, what part of your body, and what was the injury?

  ____

  ____

- Did your work cause your injury? **Yes** ☐ **No** ☐

- Did you receive treatment and if so what kind?

____

____

____

APPENDIX C: ADDITIONAL RESULTS

1. Significant difference Tables

2. Sex-related Differences in Work Capacity

1. SIGNIFICANT DIFFERENCES

AGE

Blood Pressure-diastolic

Tukey HSD test; variable BP-DIAST (Statistica ALL
Approximate Probabilities for Post Hoc Tests
Error: Between MS = 184.78, df = 96.000

Cell No.	AGE	{1} 74.000	{2} 79.257	{3} 87.462	{4} 89.200
1	1		0.41786	0.00233	0.01554
2	2	0.41786		0.09820	0.18081
3	3	0.00233	0.09820		0.98602
4	4	0.01554	0.18081	0.98602	

Waist to hip ratio

Tukey HSD test; variable W-H (Statistica ALL streng
Approximate Probabilities for Post Hoc Tests
Error: Between MS = .00230, df = 96.000

Cell No.	AGE	{1} .80358	{2} .81002	{3} .83054	{4} .86790
1	1		0.95041	0.16733	0.00243
2	2	0.95041		0.35580	0.00611
3	3	0.16733	0.35580		0.16334
4	4	0.00243	0.00611	0.16334	

Waist circumference

Tukey HSD test; variable WAIST (Statistica ALL stre
Approximate Probabilities for Post Hoc Tests
Error: Between MS = 59.498, df = 96.000

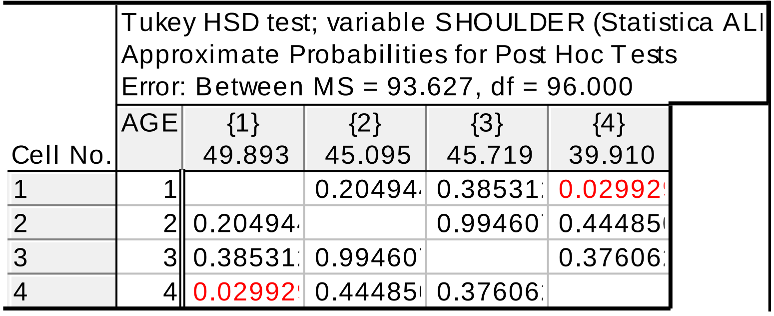
Cell No.	AGE	{1} 72.552	{2} 74.263	{3} 78.250	{4} 82.290
1	1		0.81349	0.03678	0.00476
2	2	0.81349		0.19657	0.02348
3	3	0.03678	0.19657		0.49784
4	4	0.00476	0.02348	0.49784	

Body Fat percentage

Tukey HSD test; variable BF (Statistica ALL strength
Approximate Probabilities for Post Hoc Tests
Error: Between MS = 27.013, df = 96.000

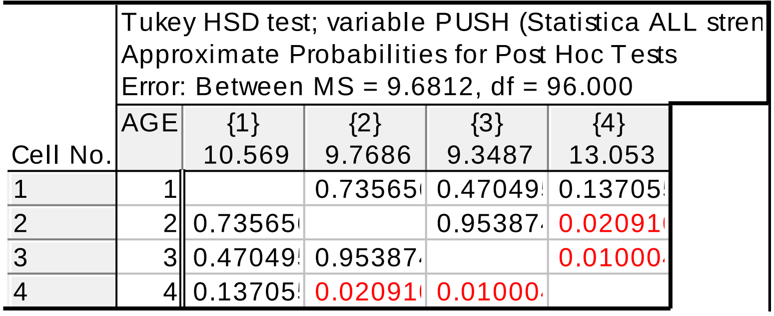
Cell No.	AGE	{1} 11.271	{2} 14.666	{3} 17.344	{4} 20.234
1	1		0.05169	0.00033	0.00018
2	2	0.05169		0.19910	0.01851
3	3	0.00033	0.19910		0.44487
4	4	0.00018	0.01851	0.44487	

Shoulder strength



Cell No.	Tukey HSD test; variable SHOULDER (Statistica AL Approximate Probabilities for Post Hoc Tests Error: Between MS = 93.627, df = 96.000 AGE	{1} 49.893	{2} 45.095	{3} 45.719	{4} 39.910
1	1		0.20494	0.38531	0.02992
2	2	0.20494		0.99460	0.44485
3	3	0.38531	0.99460		0.37606
4	4	0.02992	0.44485	0.37606	

Push strength



Cell No.	Tukey HSD test; variable PUSH (Statistica ALL stren Approximate Probabilities for Post Hoc Tests Error: Between MS = 9.6812, df = 96.000 AGE	{1} 10.569	{2} 9.7686	{3} 9.3487	{4} 13.053
1	1		0.73565	0.47049	0.13705
2	2	0.73565		0.95387	0.02091
3	3	0.47049	0.95387		0.01000
4	4	0.13705	0.02091	0.01000	

TASK

Spinal Kinematics

Tukey HSD test; variable Maximum Left Bend (Summary LMM) Approximate Probabilities for Post Hoc Tests Error: Between MS = 69.763, df = 135.00

	Var1	**{1} - -6.393**	**{2} - -11.81**	**{3} - -3.366**
1	1		0.005313	0.179823
2	2	0.005313		0.000061
3	3	0.179823	0.000061	

Tukey HSD test; variable Maximum Right Bend (Summary LMM) Approximate Probabilities for Post Hoc Tests Error: Between MS = 54.212, df = 135.00

	Var1	**{1} - 14.746**	**{2} - 6.8717**	**{3} - 10.224**
1	1		0.000022	0.007641
2	2	0.000022		0.122816
3	3	0.007641	0.122816	

Tukey HSD test; variable Maximum Lateral Range (Summary LMM) Approximate Probabilities for Post Hoc Tests Error: Between MS = 76.651, df = 135.00

	Var1	**{1} - 21.139**	**{2} - 18.675**	**{3} - 13.590**
1	1		0.367101	0.000094
2	2	0.367101		0.033511
3	3	0.000094	0.033511	

Tukey HSD test; variable Maximum Extension (Summary LMM) Approximate Probabilities for Post Hoc Tests Error: Between MS = 94.806, df = 135.00

	Var1	{1} - 10.525	{2} - 10.712	{3} - 10.448
1	1		0.995339	0.999184
2	2	0.995339		0.992567
3	3	0.999184	0.992567	

Tukey HSD test; variable Maximum Flexion (Summary LMM) Approximate Probabilities for Post Hoc Tests Error: Between MS = 64.191, df = 135.00

	Var1	{1} - 30.881	{2} - 24.173	{3} - 22.259
1	1		0.000190	0.000022
2	2	0.000190		0.559645
3	3	0.000022	0.559645	

Tukey HSD test; variable Maximum Sagittal Range (Summary LMM) Approximate Probabilities for Post Hoc Tests Error: Between MS = 93.442, df = 135.00

	Var1	{1} - 20.355	{2} - 13.460	{3} - 11.810
1	1		0.001796	0.000066
2	2	0.001796		0.743331
3	3	0.000066	0.743331	

Tukey HSD test; variable Maximum Left Twist (Summary LMM) Approximate Probabilities for Post Hoc Tests Error: Between MS = 37.650, df = 135.00

	Var1	{1} - -9.228	{2} - .04583	{3} - -8.176
1	1		0.000022	0.680085
2	2	0.000022		0.000022
3	3	0.680085	0.000022	

Tukey HSD test; variable Maximum Right Twist (Summary LMM) Approximate Probabilities for Post Hoc Tests Error: Between MS = 55.388, df = 135.00

	Var1	{1} - 8.9777	{2} - 18.224	{3} - 5.6842
1	1		0.000022	0.078055
2	2	0.000022		0.000022
3	3	0.078055	0.000022	

Tukey HSD test; variable Maximum Twisting Angle (Summary LMM) Approximate Probabilities for Post Hoc Tests Error: Between MS = 73.007, df = 135.00

	Var1	{1} - 18.206	{2} - 18.179	{3} - 13.860
1	1		0.999871	0.034723
2	2	0.999871		0.075785
3	3	0.034723	0.075785	

Tukey HSD test; variable Average Lateral Velocity (Summary LMM) Approximate Probabilities for Post Hoc Tests Error: Between MS = 20.930, df = 135.00

	Var1	**{1} - 7.9119**	**{2} - 12.450**	**{3} - 9.3082**
1	1		0.000027	0.295559
2	2	0.000027		0.008846
3	3	0.295559	0.008846	

Tukey HSD test; variable Average Sagittal Velocity (Summary LMM) Approximate Probabilities for Post Hoc Tests Error: Between MS = 19.414, df = 135.00

	Var1	**{1} - 6.4672**	**{2} - 9.5358**	**{3} - 8.1126**
1	1		0.002398	0.161886
2	2	0.002398		0.346768
3	3	0.161886	0.346768	

Tukey HSD test; variable Average Twist Velocity (Summary LMM) Approximate Probabilities for Post Hoc Tests Error: Between MS = 17.964, df = 135.00

	Var1	**{1} - 6.5317**	**{2} - 12.533**	**{3} - 10.837**
1	1		0.000022	0.000024
2	2	0.000022		0.197408
3	3	0.000024	0.197408	

Joint Forces

Cell No.	Total L5/S1 Shear (sagittal) (3DSSPP All) Approximate Probabilities for Post Hoc Tests Error: Between MS = 1973.8, df = 42.000			
	Task	{1} 340.33	{2} 302.25	{3} 298.92
1	1		0.057440	0.035653
2	2	0.057440		0.981646
3	3	0.035653	0.981646	

Cell No.	L4/L5 Comp (3DSSPP All) Approximate Probabilities for Post Hoc Tests Error: Between MS = 1435E2, df = 42.000			
	Task	{1} 2057.8	{2} 2623.5	{3} 2200.6
1	1		0.000592	0.555197
2	2	0.000592		0.024304
3	3	0.555197	0.024304	

Cell No.	L4/L5Shear (ant/post) (3DSSPP All) Approximate Probabilities for Post Hoc Tests Error: Between MS = 6498.7, df = 42.000		
	{1} 291.86	{2} 75.667	{3} 188.25
1		0.000119	0.002807
2	0.000119		0.004025
3	0.002807	0.004025	

Heart rate

Cell No.	HEART RATE- Middle Post Hoc Tests Error: Between MS = 263.51, df = 41.000		
	{1} 125.00	{2} 116.82	{3} 98.250
1		0.374180	0.000243
2	0.374180		0.024174
3	0.000243	0.024174	

Cell No.	HEART RATE- End Post Hoc Tests Error: Between MS = 314.32, df = 41.000		
	{1} 131.57	{2} 128.09	{3} 105.92
1		0.858432	0.000848
2	0.858432		0.012671
3	0.000848	0.012671	

2. SEX COMPARISONS

Sex comparisons will show any differences in worker capacity between the male and female workers in this industry. This will aid the understanding of the south african sex differences for comparisons with other industries in south africa and countries. Mean values of 101 males and 11 females of various ages were used. Due to the small female sample size, the results shown cannot be interpreted with statistical confidence, due to the low statistical power of the results. A summary of the trends and observations will be presented in this section to highlight some findings. Males on average had less experience, were younger, taller and lighter than females in the sample groups. There was a large amount of variation in the experience of the male and female workers.

Table XXIII: Summary of the anthropometric and health differences with sex.

	MALES Mean ±SD	FEMALES Mean ±SD
DBP	83.85 (5.95)	90.92 (14.17)
SBP	134.85 (7.13)	127.32 (1.33)
RHR	69.02 (3.20)	79.10 (10.21)
BMI	22.34 (0.75)	26.19 (4.92)**
WHR	0.84 (0.03)	0.82 (0.03)
BF%	17.532 (3.6)	31.82 (5.31)**
**indicates a significantly higher result Acceptable/good, unacceptable/overweight, highly unacceptable/obese		

Males were significantly stronger than females in all strength tests except pull strength, were males were still stronger, but the difference was not significant. The strength data shows a similar strength profile for both males and females; in both sexes leg strength showed the highest produced force, followed by back strength, shoulder strength, grip strength, bicep strength and push strength. The male strength profile continued with pinch strength, and pull strength exhibiting the lowest force, whereas females showed stronger pull strength and the weakest force produced was pinch strength.

Females had a significantly higher BMI and Body fat percentage than males and were within the overweight and ‘too high’ ranges respectively. There was no significant difference in systolic or diastolic heart rate of males and females, but both sexes systolic blood pressure was classified as high. A greater percentage of the male workers smoked when compared to females and the number of cigarettes smoked was greater. Similarly, more male workers drank a greater amount of alcohol than female workers. Males showed higher occurrences of flu, whereas females had a higher occurrence of tuberculosis, pneumonia and gastroenteritis. Females showed a significantly lower strength in all areas except Pull strength. Females managed a higher percentage of the males’ strength with smaller muscles.

ANTHROPOMETRICS

GENERAL

Males on average had less experience, were younger, taller and lighter than females in the sample groups. There was a large amount of variation in the experience of the male and female workers.

Table XXIV: The mean age, experience, stature and mass characteristics of the male and female workers, with standard deviation and coefficient of variation.

	MALES (n = 101)			**FEMALES (n = 11)**		
	Mean	**±SD**	**CoV (%)**	**Mean**	**±SD**	**CoV (%)**
AGE (years)	35.81	9.28	25.90	37.42	7.59	20.27
EXPERIENCE (months)	47.90	48.38	101.01	49.17	52.88	107.54
STATURE (meters)	1.71	0.07	3.90	1.61	0.05	3.29
MASS (kg)	64.24	9.85	15.33	69.04	15.82	22.92

WAIST TO HIP RATIO

There was no significant difference between the Waist to hip ratio of males and females ($p = 0.68$). However, while males’ waist to hip ratio was in the acceptable ranges (good and excellent); the females were in the unacceptable (average) range.

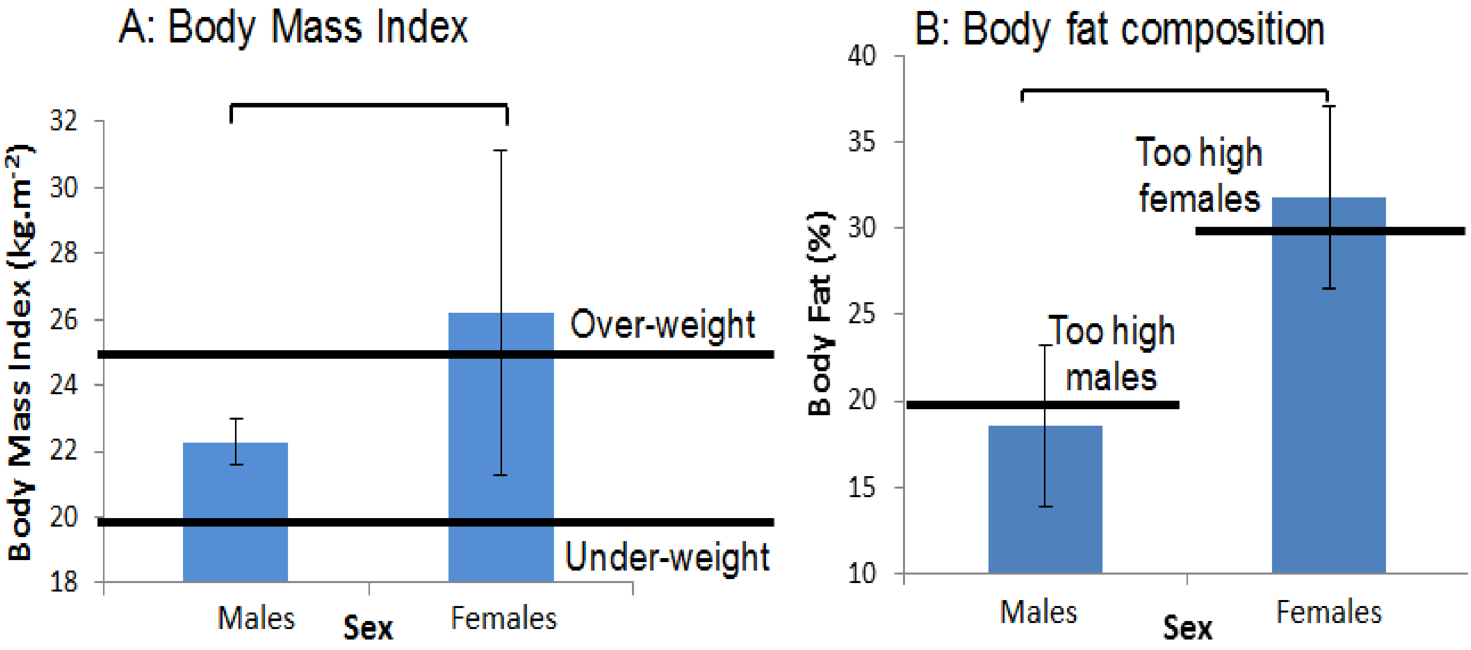


Figure 44: Mean A) body mass index (BMI) and B) body fat percentage of male and female workers.

BODY FAT COMPOSITION

Males had a significantly lower body fat percentage than females (p = 0.0001). The mean body fat percentage of males was acceptable (<20%), whereas the mean of females was too high (>30%).

BODY MASS INDEX

Body Mass Index (BMI) was significantly higher in female workers when compared to males (p = 0.001). The mean BMI of males was in the 'Average' category, whereas the females' mean BMI was in the 'Overweight' category.

1.1.1 BIOMECHANICS

STRENGTH

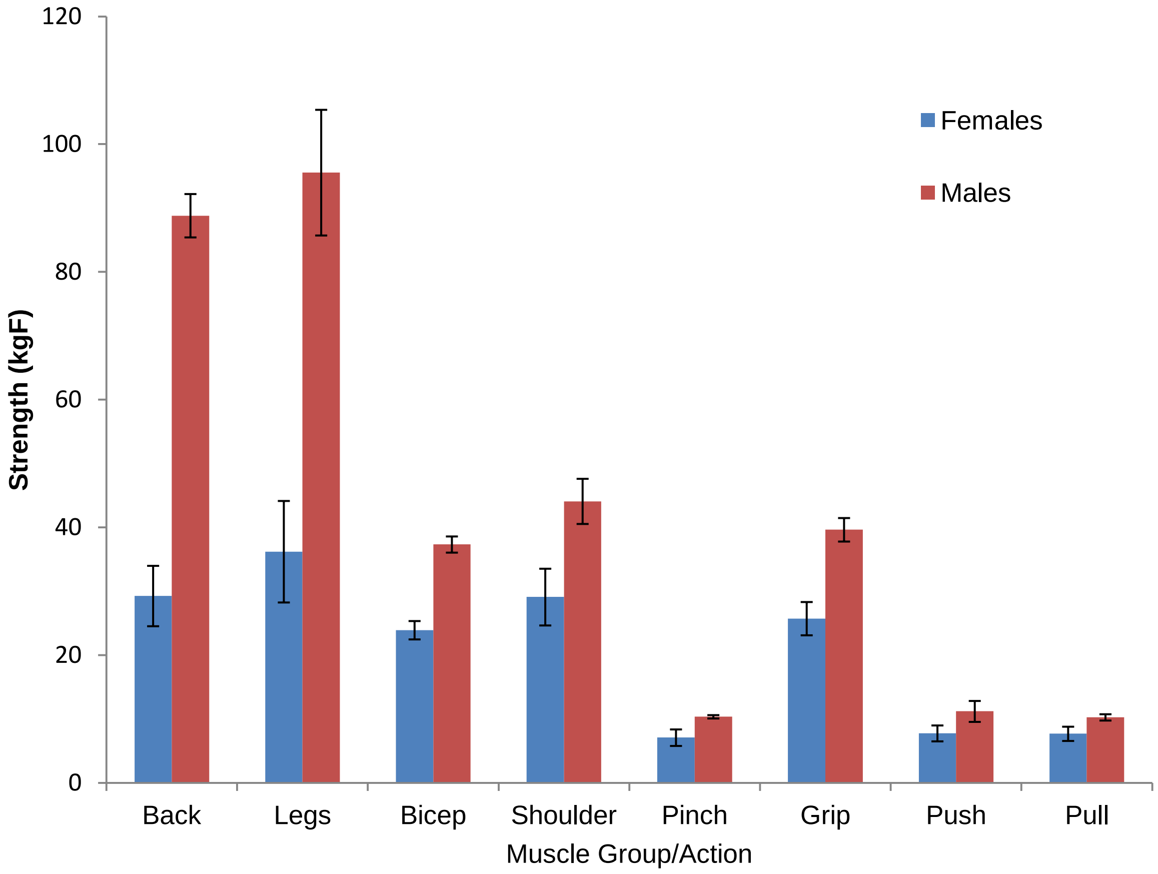


Figure 45: Summary of the strength differences between males and females for all muscle groups/actions measured.

Females had a significantly lower strength in all muscle groups, except those responsible for Pull strength ($p = 0.07$). For the larger muscle groups, females had a lower percentage of the males strength, i.e. Back- 33% ($p = 0.0001$) and Legs- 37% ($p = 0.0014$). For the smaller muscle groups, females had a higher percentage of the males strength, i.e. Bicep- 63% ($p = 0.0001$)), Shoulder- 64% ($p = 0.0001$), Pinch- 68% ($p= 0.0002$) and Grip- 63% ($p = 0.0001$). For the functional strength tests, females had the highest percentage of the males strength, i.e. Push- 74% ($p = 0.043$) and Pull- 76% ($p = 0.07$).

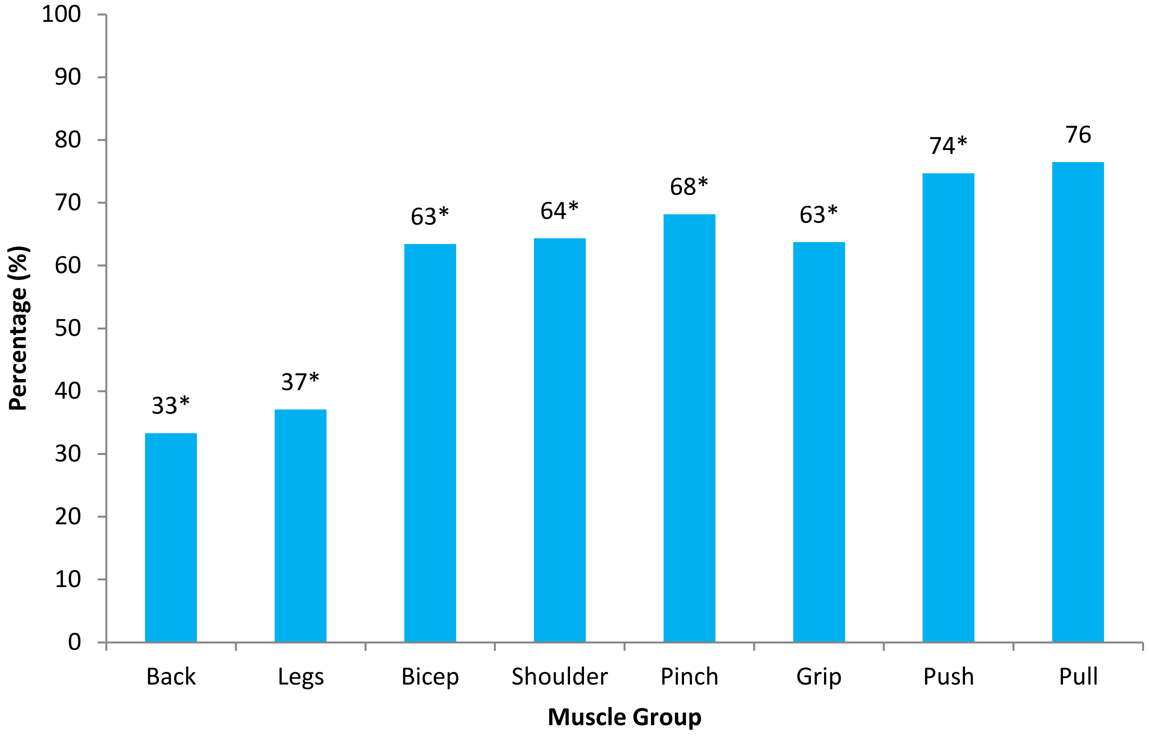


Figure 46: The mean percentage of the males' strength which females achieved. *Indicates a significant difference between the males and females strength.

When considering females strength as a percentage of males strength it is observed that the females could achieve a higher percentage of the male's strength with the smaller muscle groups. Therefore the smallest percentages were from with the biggest muscle groups (i.e. back and leg).

HEALTH

BLOOD PRESSURE

There was no significant difference between both the diastolic ($p = 0.18$) and systolic ($p = 0.39$) blood pressure of males and females, therefore males and females have a similar blood pressure. Both males and females had a systolic blood pressure which is classified as high (above 120mmHg).

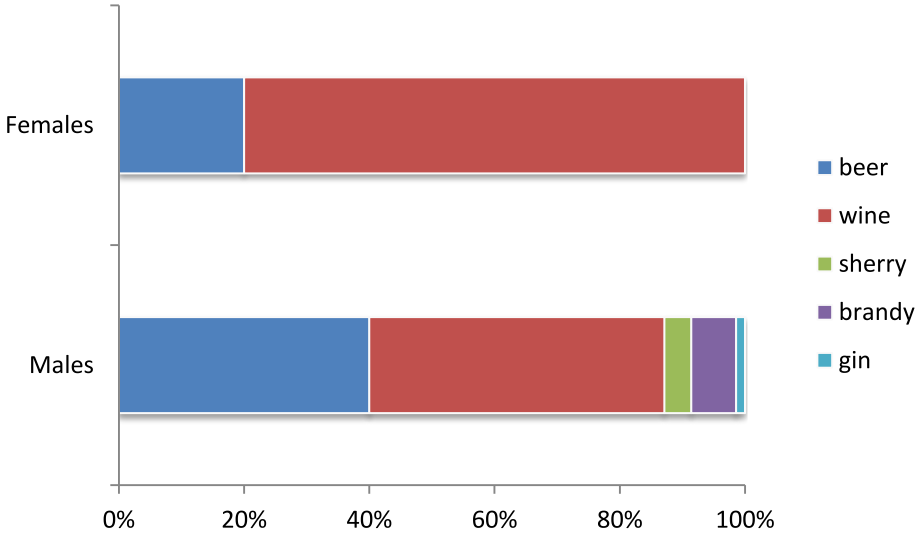
RESTING HEART RATE

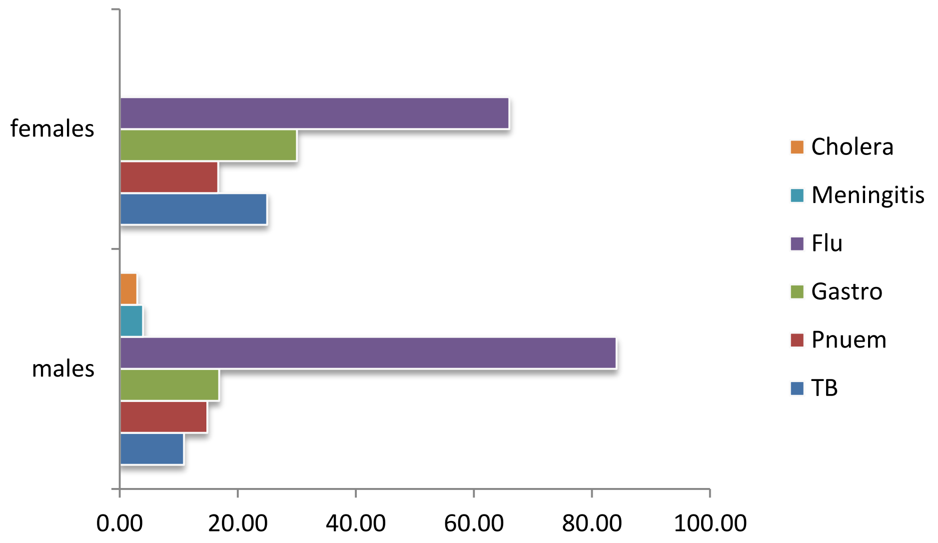
There was no significant difference between the resting heart rates of males and females (p = 0.14). The resting heart rate of male workers was within the ‘normal’ ranges, whereas female workers were in the for males and females.

QUESTIONNAIRE RESULTS

	Diabetes	Cholesterol		Heart disease	Blood pressure	
	# Reports (treatment)	Measured?	High	#Reports	Measured?	High (treatment)
Males (n = 101)	5 (1)	5	60%	1	50	15 (4)
Females (n = 11)	2 (1)	1	0%	0	7	1 (1)

	Cigarettes		Alcohol	
	Smokers (%)	# Cigarettes (±SD)	Drink Alcohol (%)	Amount (L)
Males	69.30	8.83 (4.20)	74.26	2.82 (2.33)
Females	18.18	7.5 (0.71)	63.63	1.64 (0.85)





Females had a significantly higher BMI and Body fat percentage than males and were within the overweight and ‘too high’ ranges respectively. There was no significant difference in systolic or diastolic heart rate of males and females, but both sexes systolic blood pressure was classified as high. A greater percentage of the male workers smoked when compared to females and the number of cigarettes smoked was greater. Similarly, more male workers drank a greater amount of alcohol than female workers. Males showed higher occurrences of flu, whereas females had a higher occurrence of tuberculosis, pneumonia and gastroenteritis. Females showed a significantly lower strength in all areas except Pull strength. Females managed a higher percentage of the males’ strength with smaller muscles.