A FIELD INVESTIGATION INTO THE IMPACT OF TASK DEMANDS ON WORKER RESPONSES IN THE SOUTH AFRICAN FORESTRY SILVICULTURE SECTOR

BY

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THESIS

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ABSTRACT

Background: In South Africa, limited research has focused on the task demands and workers responses associated with forestry silviculture work, particularly pitting and planting. The methods currently in use are manual, but despite our lack of understanding of the existing demands, advances in forestry engineering have resulted in an introduction of semi-mechanised versions of these tasks. This project aimed to compare the task demands of silviculture tasks using the current manual techniques and the more modern, semi-mechanised techniques. **Methods:** A holistic investigation focused on the worker characteristics of a sample of black male pitters and black female planters from the Kwa-Zulu Natal forestry industry, as well as biomechanical (spinal kinematics and L5/S1 forces), physiological (heart rate, oxygen consumption and energy expenditure) and psychophysical (ratings of perceived exertion and body discomfort) responses associated with manual and semi-mechanised pitting and planting. **Results:** The pitting task saw significant improvements in the spinal kinematic measures as a result of the increased mechanisation, with eight of the 16 recorded variables decreasing to a lower level of risk classification. Physiologically, the manual task was associated with a mean heart rate of 157 $bt.min^{-1}$ and absolute energy expenditure of 11.27 $kcal.min^{-1}$, which were not found to be significantly different to the values of 143 $bt.min^{-1}$ and 9.8 $kcal.min^{-1}$ recorded during the semi-mechanised technique. Psychophysical responses indicated that the workers perceived manual pitting to be more physically demanding than the semi-mechanised method. The manual and semi-mechanised planting tasks were, in general, found to be acceptable from a spinal kinematics perspective, with the majority of variables classified as low risk. However, the maximum sagittal angle was reduced by more than 20 degrees as a result of the new equipment. The physiological and psychophysical demands associated with manual planting were found to be within acceptable limits. **Conclusion:** In terms of pitting, it can tentatively be concluded that the semi-mechanised technique is better than the manual one, based on the biomechanical and psychophysical findings, however physiological demands require further investigation. When considering the planting techniques, the semi-mechanised method showed a slight improvement from the biomechanical perspective, but further physiological and psychophysical investigations are needed.

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CHAPTER I
INTRODUCTION

BACKGROUND TO THE STUDY

Manual materials handling tasks have long been acknowledged as extremely physically demanding in nature, and remain integral to industrial processes (Denis *et al*., 2007). Associated physical stressors have the potential to exceed the capacities of the biomechanical and physiological systems of the body, resulting in strains which may lead to fatigue, discomfort and injury (Dempsey, 1998). Extensive research, using the principles of biomechanics, physiology and psychophysics, has been conducted worldwide in an attempt to understand the capabilities and limitations of workers performing these tasks (Dempsey, 1998). Despite this growing expanse of knowledge, as well as increases in mechanisation and automation, manual materials handling (MMH) remains widespread in industrially advanced countries (IACs), and dominates in industrially developing countries (IDCs) such as South Africa (Scott and Christie, 2004).

The forestry industry shows no exception in terms of the demanding nature of related jobs, and has been identified as one of the most hazardous industries in which to be employed (Bentley *et al*., 2002; Lilley *et al*., 2002 and Slappendel *et al.*, 1993). Slappendel and colleagues (1993) acknowledged that research focusing on ergonomics in forestry has primarily been conducted in IACs, and has centred on tasks associated with harvesting, although it has been inadequate in relieving the burdens associated with the challenges of forestry work. Despite the disparity in IDC-based research, three factors related to forestry work are universally recognised as contributory in terms of the high-risk status of the industry. These include harsh and unyielding environmental conditions, awkward working postures, and the physiologically taxing nature of the tasks (Christie, 2006; Lilley *et al*., 2002 and Driscoll *et al*., 1995).

When taking into consideration the persistence of issues within forestry in the advanced world, Woolf (2008) suggested that these are most likely compounded in developing countries for a variety of reasons. The manifestation of ergonomics issues in IDCs can, in essence, be attributed to the fact that these countries simply skipped years of development that were synonymous with the growth of the advanced world (Scott and Charteris, 2004 and Jafry and O'Neill, 2000). Lifestyles transitioned from rural and agriculturally-based, to urban and industrialised, with workers facing increased work stressors, the use of incompatible equipment as a result of technological transfer, and inappropriate training in the operation of such equipment (Scott and Charteris, 2004; Jafry and O'Neill, 2000 and O'Neill, 2000). Beyond the irregularities directly associated with task performance and the work environment in IDCs, several authors (Scott and Charteris, 2004; Christie, 2001 and Scott, 1993) have argued that external burdens experienced by workers should also be taken into consideration. These factors, collectively represented by the economic cycle of disease, include low incomes, inadequate living conditions and poor health, which lead to low working capacity and thus low productivity (O'Neill, 2000). Poor levels of education and high rates of unemployment and violence exacerbate an already precarious situation faced by South African workers, and those in other IDCs, on a regular basis (O'Neill, 2000).

Since IACs, the forerunners of ergonomic development, acknowledge the difficulties associated with matching task demands to worker capacities, it can be reasoned that these difficulties extend to the developing world (Helander, 1997). As such, the applicability of ergonomics standards, developed in IACs, to developing country populations is brought into question (Christie, 2012 and Scott, 2009). When focusing on South Africa, research centred on manual materials handling tasks and the capabilities of associated workers, including those within the forestry industry, is very limited. When research is population specific, it can be argued that results will have a more direct and pertinent relevance to forestry workers, potentially contributing to a more controlled set of work demands, an improvement in productivity and therefore a reduction in the impact of the economic cycle of disease (Christie, 2012).

Commercial Forestry plays a significant role in the South African economy, both in terms of the annual turnover, as well as the significant number of employees directly connected to the industry (Shackleton *et al*., 2007 and Tewari, 2001). A total of 1.4% of formal employment in South Africa is a product of the forestry industry, with up to

260 000 individuals employed in various facets including paper manufacturing and sawmilling (Biggs, 2008). The primarily rural setting of commercial forestry plantations, means that close to 5% of rural South Africans are dependent on this industry as a source of income (DWAF, 2005). In terms of the country's Gross Domestic Product (GDP), the industry contributed 12.2 billion rand in 2003 and 14 billion rand in 2006, which is analogous with the contribution of the mining sector at that time (Biggs, 2008).

Silviculture, harvesting and processing are the three main stages associated with commercial forestry. Both internationally and in South Africa, forestry-related research focussing on the task demands and worker responses, has primarily concentrated on tasks related to harvesting (Slappendel *et al*., 1993). The primary tasks of felling, cross-cutting and stacking are commonly associated with awkward working postures and high energy demands, which place heavy strain on workers (Christie, 2006). Given these characteristics of harvesting, the workforce is considered unstable. In South Africa, on a monthly basis, the average labour turnover is 4%, and on a daily basis, absenteeism is reported as 6% (Manyuchi and Pulkki, 2002). Silviculture, which involves the preparation of land, and the planting of seedlings, has comparatively less research focusing on work demands and the risk of injury (Slappendel *et al*., 1993).

Given the limited availability of research focusing on South African forestry, particularly within silviculture, the present study aimed to assess the task demands and worker responses within this sector, specifically those associated with the pitting and planting tasks. The existing methods are highly manual in nature, but despite our lack of understanding of current pitting and planting demands, advances in forestry engineering have resulted in an introduction of mechanised versions of these tasks, however. Due to the fact that the incoming technology has not been designed specifically for a South African population, compatibility is not yet known. A comparison of these manual and mechanised methods will therefore provide important insight into firstly, the demands of silviculture work in South Africa, and secondly the potential benefits or hazards that may be associated with the introduction of new technology.

Due to the complexity of the South African population, and the predicted reduction in worker capacities, this research aims to adopt a holistic approach in the assessment of task demands and worker responses. Factors from the domains of physiology, biomechanics and psychophysics were therefore incorporated into the assessment of worker performance. Furthermore, despite the difficulties associated with field-based research, several authors have acknowledged that ergonomics cannot succeed primarily through laboratory-based investigations, predominantly because work demands are influenced by several, interlinked factors including task characteristics, worker capabilities and environmental conditions (Scott and Charteris, 2004; O'Neill, 2000 and Dempsey, 1998). Additionally, the simulation of forestry tasks with their associated demands in a laboratory setting is nearly impossible, with worker experience crucial to safe task performance. Due to the difficulties relating to the simulations in a laboratory, performed by inexperienced participants, generally students, it is essential for field-based research to be conducted. For this reason, this study will attempt to produce 'realistic' data which can be applied more effectively in developing valid interventions.

STATEMENT OF THE PROBLEM

Regardless of the physically demanding nature of forestry, it is evident that the commercial forestry industry in South Africa is an extremely important contributor towards the GDP, and rural employment. Limited silviculture-relevant research, focussing on the task demands and worker responses associated with current pitting and planting methods exists. Furthermore, there is an impending introduction of mechanisation to the current manual methods of task performance, the demands of which within the South African context also remain unknown. For this reason, and taking into consideration the fundamental characteristics of the rural workforce, this project aimed to assess physiological, biomechanical and psychophysical responses of workers to imposed task demands, for both the manual and mechanised versions of pitting and planting. Therefore the purpose of this study was twofold in nature. Firstly, it aimed to investigate the demands imposed on the unique sector of the South African workforce within silviculture, specifically black workers involved in the forestry industry of Kwa-Zulu Natal, and secondly, to compare and contrast the existing manual methods of task performance, with the new, semi-mechanised methods. Given the importance of acknowledging the challenges associated with workers in developing regions, assessment of workers will be field-based in nature, in order to improve the applicability of results to ‘real-world’ settings.

RESEARCH HYPOTHESIS

The twofold nature of this research aims to demonstrate the demands of silviculture work within a South African population, and secondly to compare the two techniques associated with planting and pitting. When considering the pitting task, it was hypothesised that the biomechanical, physiological and psychophysical demands placed on workers would be considered excessive for the current method, and that these demands would differ according to the method of task performance when comparing manual to semi-mechanised pitting. Similarly for planting, it was hypothesised that manual performance would be excessive from a biomechanical, physiological and psychophysical perspective. Furthermore, it was proposed that the biomechanical responses would differ between manual and semi-mechanised planting.

STATISTICAL HYPOTHESES

1. Pitting

a) The biomechanical responses will remain the same for manual and semi-mechanised pitting:

Ho: $\mu BR_{(manual)} = \mu BR_{(mechanised)}$

Ha: $\mu BR_{(manual)} \neq \mu BR_{(mechanised)}$

b) The physiological responses will remain the same for manual and semi-mechanised pitting:

Ho: $\mu PR_{(manual)} = \mu PR_{(mechanised)}$

Ha: $\mu PR_{(manual)} \neq \mu PR_{(mechanised)}$

c) The psychophysical responses will remain the same for manual and semi-mechanised pitting:

Ho: $\mu PSY_{(manual)} = \mu PSY_{(mechanised)}$

Ha: $\mu PSY_{(manual)} \neq \mu PSY_{(mechanised)}$

2. Planting

a) The biomechanical responses (spinal kinematics) will remain the same for manual and semi-mechanised planting:

$$Ho: \mu BR_{(manual)} = \mu BR_{(mechanised)}$$

$$Ha: \mu BR_{(manual)} \neq \mu BR_{(mechanised)}$$

Where:

- (manual) = current manual method of task performance
- (mechanised) = incoming mechanising method of task performance
- BR = Biomechanical responses including spinal kinematics and loading responses
- PR = Physiological responses including heart rate, oxygen consumption and energy expenditure
- PSY = Psychophysical responses including Central Ratings of Perceived Exertion and Body Discomfort ratings

DELIMITATIONS

The selected sample for this study was delimited to 56 South African forestry workers from the Kwazulu-Natal province of South Africa. Participants, aged between 18 and 60, were recruited through the forestry company Sappi, and were involved specifically in the pitting and planting tasks of the silviculture sector. After consultation with company management, current manual, and incoming mechanised versions of the pitting and planting tasks were selected for further investigation. For the pitting and planting tasks, 27 males and 29 females respectively, were assessed.

The study was divided into two distinct phases, the first of which involved the assessment of characteristics inherent to the sample population. Individuals were given details of the research in a laboratory set-up located near their place of residence. If they agreed to participate, basic measures were obtained including anthropometric (stature and body mass), morphological (body mass index, body fat percentage and waist-to-hip ratio), cardiovascular (heart rate and blood pressure) and strength (grip, back, pushing and pulling) measures. At this stage, a questionnaire pertaining to their health status and incidence of musculoskeletal disorders was administered in Zulu, their first language, with the assistance of a translator.

The second phase was conducted during each participants work shift, and focussed on their biomechanical, physiological and psychophysical responses to the tasks performed, both manually and mechanically. Dependent variables included spinal kinematics and applied forces (biomechanics), heart rate, energy expenditure and oxygen consumption (physiology), and Ratings of Perceived Exertion and Body Discomfort (psychophysics). The performance of manual and mechanised methods of each task was permutated between participants.

LIMITATIONS

The stringent control of extraneous variables, as would take place in a laboratory setting, was limited in the current research due to the field-based nature of the data collection. Despite this, the need for *in situ* research, focussing on the realistic demands in a natural work setting, is highlighted by the fact that the simulation of these forestry tasks in a laboratory setting would not be feasible or accurately representative of work demands. This however does not remove the need for the generation of ergonomics information pertaining to these jobs; therefore the current research is justified in terms of its relevance and the need for intervention applications in the forestry industry. Initially, measures of ambient temperatures and humidity were conducted, however, due to equipment failure in the early stages of data collection, these measures could not be completed fully. In order to maintain a certain degree of control, task assessments were only conducted on days where temperatures did not vary by more than 20 degrees.

Another aspect which potentially impacted the findings was associated with the language barrier and education level. All participants were Zulu-speaking, with little or no understanding of English, and, despite the assistance of a translator, certain aspects may have been hindered as a result of misunderstanding. Included in this were the results generated by the questionnaires, as well as the Ratings of Perceived Exertion. The RPE scale, given its conceptual nature, was difficult to explain sufficiently, owing primarily to the level of education of the participants. As the assessments were conducted at a time where possible reductions in the workforce size were unknown (both to the researcher and employees) it is unlikely that workers reported lower levels of discomfort and exertion as a result of job loss fear.

CHAPTER II
REVIEW OF LITERATURE

INTRODUCTION

The forestry industry has been acknowledged worldwide as one of the most dangerous in which to be employed (Lilley *et al.*, 2002). In developing countries, the predominantly manual nature of forestry work contributes to its high risk status. Despite this, forests collectively provide several benefits to the surrounding communities as well as society as a whole (Shackelton *et al.,* 2007). Poverty in South Africa is widespread, with some 70% of the country's poor found living in rural areas. As a result, forestry contributes significantly to the well-being and, in many cases the survival, of thousands of rural South Africans (Shackelton *et al.,* 2007). In fact, it was reported that 66 000 people are employed directly through commercial forestry, with a further 300 000 dependent on it. This sector currently covers 1.1% of the South African total land area, which equates to approximately 1.35 million hectares (Shackelton *et al*., 2007 and Tewari, 2001). In 2002, the forest products industry, as a result of primary processing, had a value of just under R14 billion, accounting for 7.3% of the GDP at that time.

Commercial forestry can be subdivided into three distinct sectors, specifically silviculture, harvesting and processing. Harvesting, which includes the felling, debarking and stacking of trees, is the domain most closely correlated with reported accidents and injuries in the industry and accounts for between 38% and 90% of the total, and therefore has been the primary research focus in the field (Christie, 2006 and Hagen *et al.,* 1998). Despite the obvious contribution of physical hazards such as falling trees and hand-operated equipment to these statistics, several authors have purported the significance of biomechanical and physiological overload, to fatigue and injury development (Scott and Charteris, 2004). Although a variety of research has been conducted on these excessive work demands in industrialised countries such as New Zealand and Sweden, little improvements have been noted (Slappendel *et al*., 1993).

In developing countries including South Africa, statistics representative of fatalities and injuries, as well as research focusing on task demands imposed on workers, is inadequate. When considering the potential role of ergonomics in these regions, it has been suggested that focus should be placed on alleviating the extreme manual nature of tasks, and smoothing the transition from manual to mechanised task performance. In South Africa, research has focused on the demands associated with harvesting, however limited, if any, ergonomics-based research has investigated task demands within the silviculture sector, as is the case in the international forestry community (Slappendel, 1993).

THE SOUTH AFRICAN CONTEXT

In order to gain an understanding of the demands placed on workers in the South African silviculture sector, it is necessary to acknowledge the extent of the issues faced by a developing country of this nature (Ferreira, 2004). Besides existing epidemics such as HIV/AIDS, places like South Africa are overwhelmed by a broad range of political, economic and social problems including devastating poverty, severe levels of unemployment, poor infrastructure and underdevelopment, high levels of violence and limited food and livelihood security (Ferreira, 2004). Although the extent of severity of these issues across South Africa itself is highly varied, many of these aspects still prevail, particularly in rural areas (Shackelton, 2007).

By acknowledging the holistic approach inherent to ergonomics, the numerous factors that define a South African worker must be understood before appropriate ergonomics can be implemented. The interlinked factors ascribed to have an impact on individuals, their work capacity, and performance, include education level, employment opportunities, income level and health status (O'Neill, 2000). These factors are connected within the economic cycle of disease, as highlighted in Figure 1, which is a representation of events typically found in developing countries (O'Neill, 2000). The state in which the majority of individuals are living and working in these rural forestry environments can be considered one of poverty (Christie, 2001), which, according to May (1999), is the "inability of individuals, households or entire communities to command sufficient resources to satisfy a socially acceptable minimum standard of living." For this reason, a large proportion of forestry employees does not receive adequate daily nutrition, and are therefore in a state of poor health (Christie, 2001).

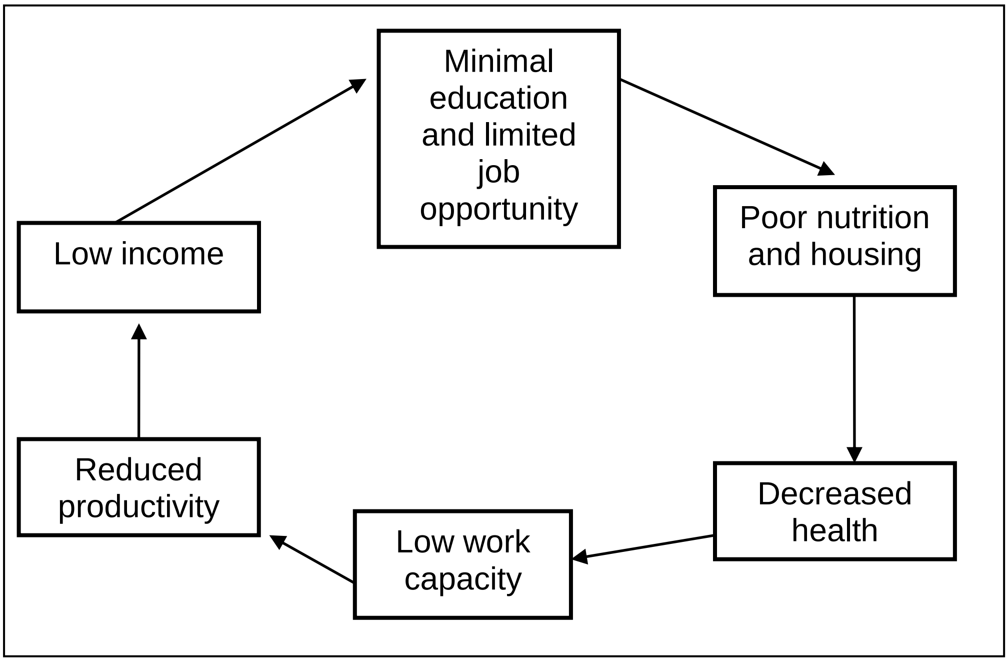


Figure 1: Economic cycle of disease (Adapted from O'Neill, 2000).

The white paper published by the Department of Water Affairs and Forestry (DWAF) in 1996, highlighted the need for a broader definition of sustainability in the South African commercial forestry industry. Taking into account religious, cultural, social and environmental needs, the paper stated that: "the new forestry policy of South Africa is defined as one that deals with the scope of relationships between people and forestry resources" (DWAF, 1996). Considering this, along with Manyuchi and Pulkki's (2002) opinion that the most valuable asset in the forestry industry is the employees, the need for appropriate ergonomics in this industry is further justified. Another compounding factor, that affects the performance and wellbeing of forestry workers in South Africa, and requires further consideration, is that of contracting or outsourcing in the industry (McLean, 1996).

CONTRACTING

In South Africa, the greatest portion of commercial forestry is controlled by large corporations commonly referred to as grower-processors (GPs) (Clarke and Isaacs, 2005). From about the mid 1990's however, the majority of forestry operations, ranging from silviculture to harvesting practices, were outsourced to smaller contracting companies (Louw, 2004). This outsourcing, meant that GPs were no longer responsible for dealing with labour issues, unions, capital equipment and various others aspects relating to management techniques and production (Clarke and Isaacs, 2005). This has resulted in forestry contracting forming a complex subsector of the South African forestry industry (Khosa, 2000). In terms of cost savings and production efficiency, contractual work proved to be a positive change for the GPs, however, it has been well acknowledged that this came at the expense of the forestry workers employed in the industry (Clarke and Isaacs, 2005; Crickmay *et al*., 2004 and Louw, 2004). This crossover resulted in a loss of several employee benefits, including pensions, disability provisions, medical aid and labour feeding schemes (Crickmay *et al*., 2004). Ultimately, the loss of formal policies resulted in poor labour practices, inadequate training and lower wages (Crickmay *et al*., 2004 and Louw, 2004). To sum up, the reduced costs associated with contracting were disadvantageous to the worker, resulting in the deterioration of the social situation in forestry, and in all likelihood, lowered levels of worker productivity (Crickmay *et al*., 2004). In short, these issues serve to exacerbate an already dire situation in developing countries, were job demands are already physically excessive.

SILVICULTURE

Silviculture is a word used to describe the cultivation and tending of forests for human use, and broadly includes processes such as ground preparation, planting of seedlings, and maintenance of tree health through fertilizing and clearing of alien vegetation (Johnson *et al*., 2009). In terms of worker health and safety, according to the 2007 ILO guidelines, the silviculture sector falls under the umbrella of the larger forestry industry, which includes harvesting. Although limited studies worldwide have assessed the physical demands imposed on workers within the silviculture sector, the ILO acknowledges plantation work as extremely demanding, hazardous and psychologically taxing (Hodges and Kennedy, 2011; ILO, 2007 and Banister *et* al., 1990). As is the case in harvesting, workers are exposed to harsh environmental conditions including temperature extremes and ultraviolet (UV) radiation, which can potentially cause dehydration or sunstroke, as well as uneven terrain and layers of organic material and debris on the ground, which can cause slip and trip accidents

(Hodges and Kennedy, 2011; Slot, 2010; ILO, 2007; Bentley *et* al., 2002 and Trites, 1992). In New Zealand, The Forest Industry Accident Reporting Scheme (ARS) is used to cover both the harvesting and silviculture sectors to inform their injury prevention research (Bentley *et al*., 2002). A review conducted by Slappendel and colleagues in 1993, aimed to examine potential contributing factors to work-related injuries in the forestry industry of New Zealand. While acknowledging the fact that the majority of research worldwide, has focused on those tasks associated with chainsaw operation and felling, and little on silviculture work, these authors constructed a general model to explain injury causation within forestry (Slappendel, 1993).

This model (Figure 2) suggests that any potential injury within forestry can be initiated by three distinct means, specifically operator errors, design or system errors and finally natural hazards. Firstly, operator errors are those arising from cognitive failure, and are a result of an interaction between the components of the work system, namely worker characteristics, equipment and work organisation (Slappendel *et al*., 1993). For example, in the case of forestry harvesting, a chainsaw operator may decide to leave a ‘hang-up’ and carry on working, which is a well-known safety risk. This interactive model of a work system and its subsections is commonly utilised in the holistic approach of ergonomics, which will be discussed during the methods used for the assessment of worker responses. The second domain of risk arises from errors associated with the system or design. These usually result from a mismatch in tool or equipment design, or inadequate organizational structures, policies and administration (Slappendel *et al*, 2003). Issues associated with this domain are indirectly connected to the development of an injury, due to their differing stages within the causal process. Finally, natural factors are those that are considered uncontrollable, such as steep and uneven terrain, or unfavourable climatic conditions (Slappendel *et al*., 2003). Based on this model, the current research project is focused on the issues associated with the second domain of risk, in particular the potential mismatch between the silviculture workers and the equipment used.

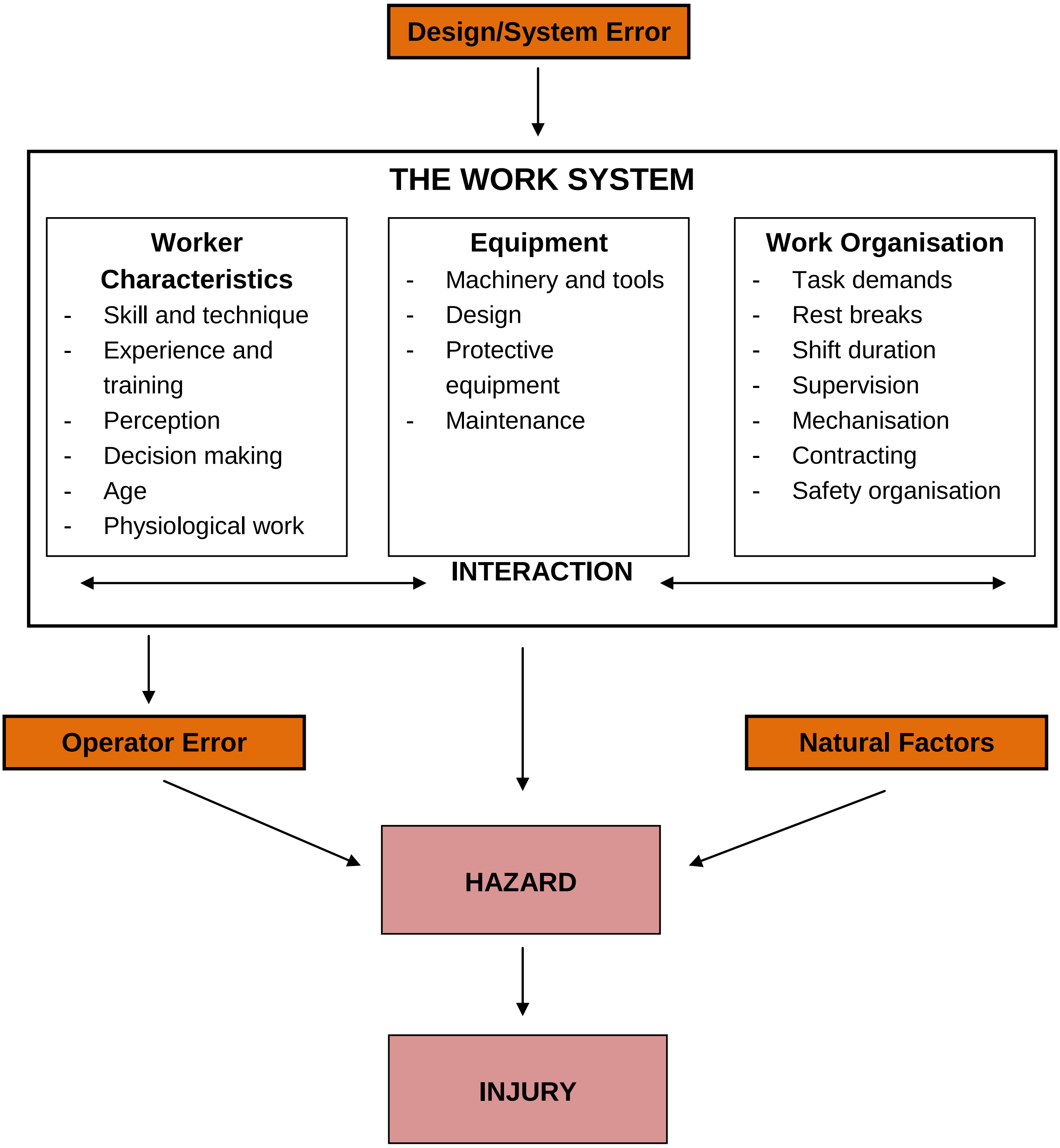


Figure 2: Framework for potential injuries in forestry work (Adapted from Slappendel *et al*., 2003).

Given the limited international understanding of this model in relation to silviculture-based tasks, it can be expected that a similar situation would be found in the South African forestry industry. In order to establish a starting foundation for the assessment of silvicultural work demands and the stressors imposed on workers, it is necessary to develop an understanding of the characteristics of this sector, which can primarily be subdivided into the stages of site preparation and planting.

SITE PREPARATION: PITTING

The establishment of young seedlings at a plantation site usually requires some form of ground preparation, be it mechanically, chemically, through burning, or a combination of the three methods (Dickens, 2012). The oldest and cheapest preparation technique is that of burning which uncovers the mineral soils required for seedling growth, and is used to control other competitive plant species (Dickens, 2012; Evans, 1992 and Florence, 2004). Chemical site preparation has become increasingly popular since the 1980's, and makes use of herbicides to remove or control grass and plant growth (Evans, 1992 and Dickens, 2012). Finally, mechanical site preparation involves the physical clearing of unwanted vegetation and usually some kind of soil tilling in order to aerate the soil and improve topsoil and organic matter distribution (Dickens, 2012 and Evans, 1992). Typically in South Africa, the burning of a plantation site is followed by mechanical soil preparation.

In terms of mechanical cultivation, the minimum requirement is the opening of a single hole in the soil, followed by the placement of the seedling roots (Evans, 1992). It has been suggested previously, that any improvement to this method will enhance tree growth, as was highlighted by Haig (1970), who investigated the growth quality of two tree species in Zululand, South Africa. However, the selection of the appropriate mechanical preparation technique is based on the balance between producing the best growth results, and the cost of the technique used (Evans, 1992). For this reason, methods range from entirely manual soil preparation, to a variety of mechanical methods. Disking, ploughing, bedding and ripping are processes associated with mechanical ground preparation and are performed using specialised heavy machinery (Dickens, 2012 and Du Toit *et al*., 2010). On the other hand, the manual approach involves the digging, referred to as pitting, of single pits, approximately 30 centimetres wide and 30 centimetres deep, using a crowbar or pick (Evans, 1992). It has been acknowledged that mechanical cultivation is associated with more limitations than manual performance, such as steep gradients, tractor inaccessibility, restrictions associated with logging and material debris and terrain conditions such as rockiness (Evans, 1992). Furthermore, purchasing and maintaining the required equipment, as well as skill training for the machine operators, can prove costly (Evans, 1992). A final factor which favours manual methods, especially in developing countries like South Africa, is the low wage associated with this type of work and the large potential workforce living in rural forestry areas.

In South Africa, research on silviculture techniques (du Toit *et al*., 2010), particularly those relating to ground preparation, has focused on the survival and growth of seedlings, and the impact of different ground preparation methods on soil structure and therefore nutrient availability. Although this research is not directly related to the performance of workers in this sector, the associated outcomes are important in understanding the method of ground preparation – manual pitting – currently being used. Over three decades ago, intensive land preparation techniques, such as ploughing, ripping, sub-soiling and ridging, were vital components in forestry management in order to maximise early seedling growth and to ensure stand survival (Du Toit *et al*., 2010). This was based on early research, such as that conducted by Schönau in 1984, which suggested that soil tilling was beneficial for plantation growth. However, Smith and colleagues, in 2001, reviewed a series of trials that investigated the efficacy of several land preparation techniques compared to customary pitting techniques, and concluded that intensive site preparations did not necessarily result in growth improvements. This was further supported by mixed results produced by similar studies worldwide (Du Toit *et al*., 2010 and Smith *et al.*, 2001). In South Africa, these results were attributed to the good conditions of soil during the summer-rainfall months, implying that basic cultivation methods such as pitting are sufficient to ensure suitable growth within plantations (Smith *et al*., 2001).

In summary, it is likely that the single-pit method of ground preparation in South Africa has perpetuated as a result of the culmination of these factors, the majority of which are based on the promotion of rapid plantation growth and greater output, with limited consideration of the impact on the workforce. Additionally, access to the rural population, who can fill minimum wage positions associated with manual work, and the prevalence of work sites which are usually inaccessible to large pieces of machinery such as tractors and ploughs, further substantiates the existing method of pitting.

PLANTING

After a site has been suitably prepared, the cultivation of a new plantation is possible, and can take place immediately, or some months following the stages of site preparation (Evans, 1992). Worldwide, the planting of seedlings remains predominantly manual in nature (as seen in Stjernberg, 2006 and Hodges *et al*., 2005), although the methods of task performance may vary in terms of the tools used, the transportation of seedlings, and the addition of fertilisers and water supplements at the initial planting stage. The manual nature is of significant importance due to the fact that the quality with which the task is performed, determines the growth of that tree for the following 20 to 30 years, and therefore it's resultant economic value (Sullman and Byers, 2000). For this reason, it would be expected that the work demands of tree planters would be closely investigated, however, even in advanced countries, research remains insufficient (Stjernberg, 2006 and Sullman and Byers, 2000). Despite the limited availability of data representative of worker responses associated with planting, several authors have acknowledged the psychologically and physically demanding nature of the job (Hodges and Kennedy, 2011; Slot, 2010; Toupin *et al*., 2007 and Trites, 1992). This is based on various characteristics, including the lifting and carrying of heavy loads, large distances covered on foot each day, and harsh environmental conditions which may include steep terrains, rocky ground, thick vegetation cover and adverse climatic conditions which may include temperature extremes, strong winds and precipitation (Hodges and Kennedy, 2011 and Slot, 2010).

When considering the planting process, Trites (1992) described the procedure used by workers in British Columbian forestry in his Masters research, which focused on the ergonomics of tree planting. In this case, 300 to 400 seedlings were carried in three hip-bags, weighing between 10 and 20 kilograms, which evenly distributed the weight on the hips, with additional supporting straps attached over the shoulders. The workers also made use of a shovel weighing between one and three kilograms. Trites acknowledged the repetitive nature of the task, with each cycle lasting between five and 60 seconds. Based on this, the workers investigated planted between 300 and 3000 seedlings per day. In terms of the physiological responses reported in this research, the mean heart rate of workers measured for the duration of an eight hour work shift was found to be 117 $bt.min^{-1}$ (Trites, 1992). A more recent study conducted in Canada reported similar findings, with a mean heart rate of 115 $bt.min^{-1}$ and working heart rate of 128 $bt.min^{-1}$ (Hodges and Kennedy, 2011). In New Zealand, an ergonomic assessment of manual planting conducted by Sullman and Byers (2000), reported working heart rates ranging between 133 and 135 beats per minute according to work sites.

Biomechanically, stress imposed on these workers is a result of highly repetitive movements, awkward working postures and heavy loads, which is therefore frequently responsible for the development of musculoskeletal disorders in tree planters (Stjernberg, 2006 and Slot, 2010). In Canadian silviculture operations, 62% of lost time resulting from injuries was attributed to tears, sprains and strains (Slot, 2010). Although data relating to the biomechanical responses of workers proved to be further limited when compared to cardiovascular responses, research conducted by Slot (2010) reported that deep trunk flexion took place over 2600 times a day, with half of the total shift duration spent maintaining a flexion angle of more than 45 degrees. Similar results were reported by the Forest Engineering Research Institute of Canada, who measured trunk flexion of greater than 45 degrees for 39% of the time (Stjernberg, 2006).

Based on the above research, it can be seen that the demands of pitting are critically under-researched, not only in developing countries like South Africa, but worldwide, and the ergonomics of planting is almost exclusively based on Canadian workforces. A holistic understanding of the work demands imposed on South African forestry workers for each task is therefore vital in order to implement appropriate interventions and improve safety and productivity in the investigated forestry industry.

ASSESSMENT OF WORK DEMANDS

SYSTEMS APPROACH

The fundamental basis of ergonomics as a profession focuses on the interaction between an individual and their work environment (Wilson, 2000). The systems approach adopted by ergonomists to understand this interaction is therefore multifaceted in nature, drawing on different disciplines in order to understand overall human performance (Wilson, 2000). With particular reference to manual materials handling tasks (MMH) which are extremely physically demanding in nature, workers are frequently predisposed to strains of the cardiovascular and musculoskeletal systems (Dempsey, 1998). Therefore, in order to prevent the overexertion of a human operator, it is necessary to maintain the demands of a task within acceptable limits (Ayoub and Woldstad, 1999). Provided the relationship between the task demands and worker capacity is kept at a sustainable level, issues that are responsible for compromised productivity can be controlled. However, potential discomfort, fatigue and injury are likely to result if a worker is unable to cope with the task demands imposed upon them (Dempsey, 1998). It must also be kept in mind that, while this research focused on the primary tasks associated with the pitting and planting, understanding the demands of the overall job (such as the walking phases, which may cover large distances), is also necessary to ensure the system is sustainable.

The interacting factors of task demands and worker capacity characteristics associated with the systems approach are highlighted in Figure 3. In terms of task demands, related aspects include attributes of the materials used, task performed, place of work and environmental and organisational aspects (Dempsey, 1998). Worker capacity is then defined by characteristics inherent to the worker, specifically their personal attributes, and their biomechanical, physiological and psychophysical capacity (Dempsey, 1998). Based on these principles associated with worker capacity, as well as epidemiological evidence, various criteria have been developed in order to define acceptable limits for task demands (Dempsey, 1998). Once these criteria are measured for a given task, they can be compared to predefined standards in order to determine the overall compatibility of a task to a worker’s capacity. Given the fact that these approaches are fundamentally in conflict, a holistic understanding of each is crucial, before appropriate and applicable recommendations can be made (Dempsey and Ayoub, 1999). A brief summary of each approach and their basic aims, criteria and limitations is highlighted to inform the assessment of work demands in silviculture.

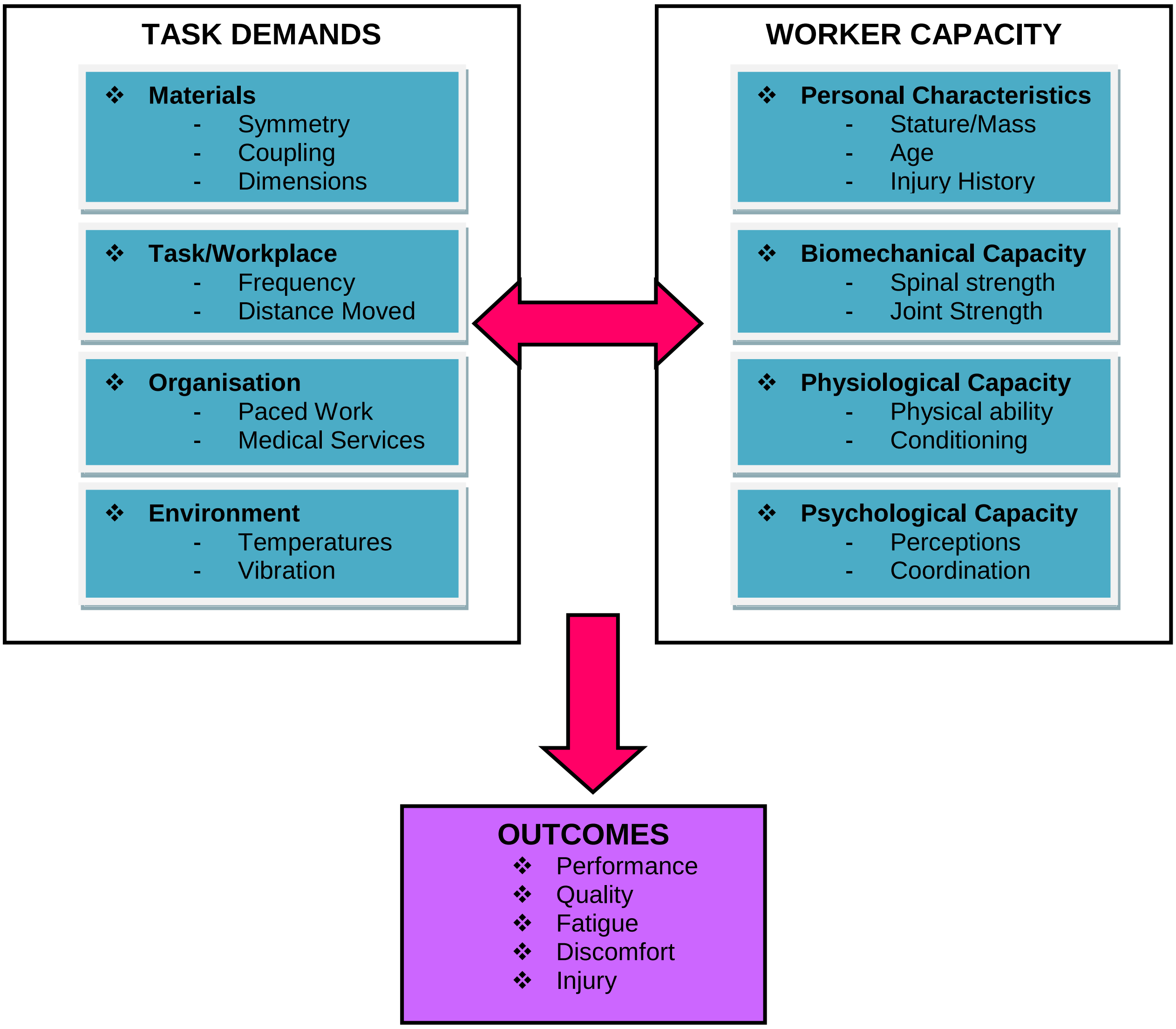


Figure 3: System interactions based on task demands and worker capacity (adapted from Dempsey, 1998).

BIOMECHANICAL APPROACH

The aim of this approach is to estimate the mechanical stress placed on the body, relative to the tissue tolerances of the muscles, bones and connective tissues, thereby ensuring that the capacity of the musculoskeletal system is not exceeded (Dempsey, 1998). Of the three primary principles, biomechanics is the only approach that has a defined hypothesis relating to the mechanism of injury. Static and dynamic biomechanical models are used to estimate the stresses imposed on the spine by the external forces associated with the work task, as well as the internal forces generated by muscle contractions (Dempsey, 1998 and 1999). The main criteria assessed in this approach are the compression limits at the L5/S1 joint and maximum joint torques (Dempsey and Hashemi, 1999 and Dempsey, 1998).

Injury mechanism

Lower back disorders (LBDs) continue to prevail in industries associated with manual work, and as such, are coupled with high compensation costs (Marras 2000 and Dempsey and Hashemi, 1999). Marras and colleagues (1995) have suggested that LBDs account for almost 20% of work-related injuries and as much as 40% of the total compensation costs (Marras, 2003). Despite the extensive research focusing on lower back biomechanics, and the mechanisms responsible for disorder progression, a definitive cause has not yet been identified (Pheasant and Haslegrave, 2006). The variety of risk factors linked to lower back injury originate from both personal and work-related domains, and the complex interactions of these factors further complicates the situation (Marras 1992 and 1995).

According to several authors, compression forces associated with spinal loading at the level of the L5/S1 joint have been the focus of scientific research (Gallagher and Marras, 2012, Adams *et al.,* 2006 and Bogduk, 1997). However, the loading components of shear and torsional forces are also accepted as contributory factors to the progression of LBDs (Granata and Marras, 1999). An understanding of these forces is crucial to the principle of biomechanics, which suggests that an injury is likely to occur if these loading forces exceed the tolerance limits of the spine (Marras, 2000 and McGill, 1997). The load-tolerance relationship, a model which suggests the mechanical nature of injury progression, acknowledges the potential impact of acute and cumulative loading of the spine (Figure 4) (Marras, 2003). Provided the application of a load is maintained below the tolerance limit of the spine, within the safety margin, work is considered safe. The load-tolerance relationship proposes two mechanisms for injury, either through the application of excessively high forces, or through low repetitive loading (McGill, 1997). The application of high forces through acute traumatic events, or excessive variable loading, will result in the tissue tolerance being exceeded. On the other hand, low repetitive loading may cause recurring micro failures and eventually reduce tissue tolerance to a point where previously acceptable loadings become excessive (Marras 2000 and McGill, 1997).

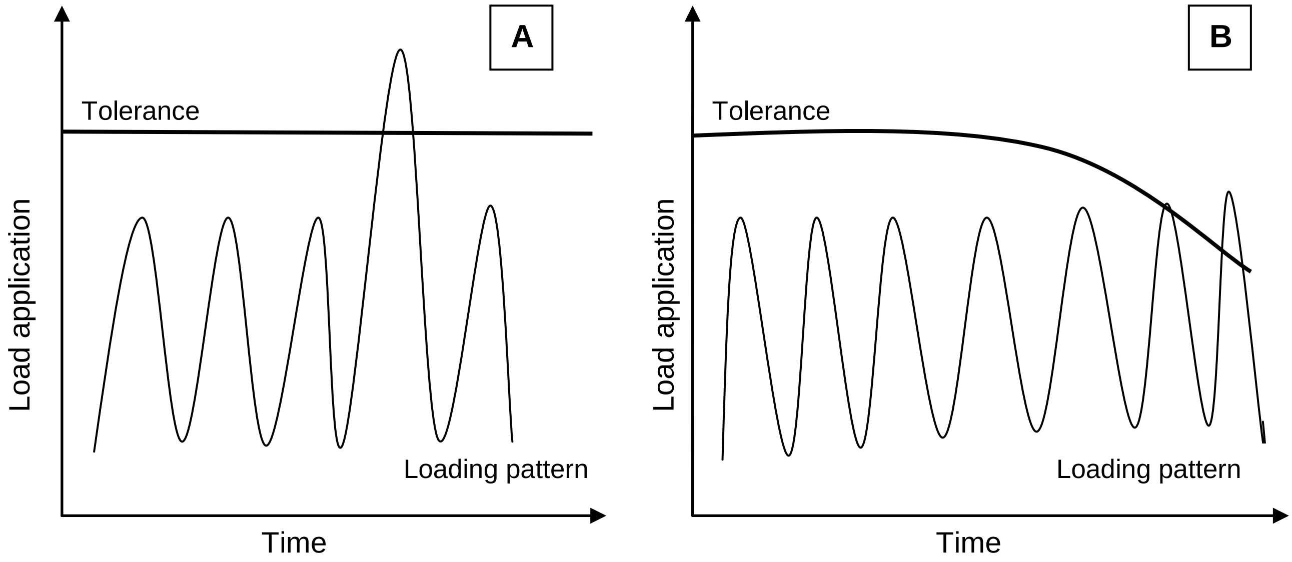


Figure 4: The load-tolerance relationship showing high force variable loading (A) and load tolerance reduction (B). (Adapted from Marras, 2000 and McGill, 1997).

Assessment techniques

A variety of biomechanical models have been developed in order to determine task acceptability in MMH. Traditionally, static tools, for example the 1981 NIOSH lifting guide (Waters *et al*., 1993) and static strength prediction programs, were the primary techniques used for the assessment of spinal loading. However, the likelihood of these to underestimate dynamic spinal compression was reported by several authors, including Granata and Marras (1999). According to Marras *et al*. (2003b), these models overlooked the contribution of dynamic motion to LBD causation. Since the 1970's, the models used have progressed from predominantly static assessments, to those which are more dynamic in nature (Davis and Marras, 2000). This can be attributed to increases in mechanisation and improved work methods, resulting in greater work output, and therefore an increasingly dynamic component associated with manual task performance (David, 2005). Resultant increases in frequency and velocity of movements, repetitive activities, and frequent bending and twisting, would thus suggest that trunk motion requires important consideration in the proliferation of LBDs. Indeed, the fact that the spine undergoes complex movements in a three-dimensional plane would imply the importance of trunk motion characteristics as risk factors (Marras *et al*., 1992).

Of the dynamic assessment techniques that have been developed in more recent years, the biologically assisted models, which involve the direct measurement of active muscles, are considered the most accurate (Marras, 2006 and Marras, 2005). However, these models require significant instrumentation and time (Marras, 2000), which often renders their use impractical in real work settings. In consideration of this, the Industrial Lumbar Motion Monitor (iLMM), which mimics the motion of the spine and can provide information based on position, velocity and acceleration in the three cardinal planes, is easily utilised *in situ* (Marras and Allread, 2005). These trunk kinematic measures have been purported as excellent determinants of risk (Ferguson *et al*., 2004), and as such, Marras and colleagues (1993; 1995) were able to develop the Multivariate Approach, which employs a combination of trunk motion factors and task characteristics to classify tasks that are high risk for LBD. These five variables in combination, specifically maximum moment, frequency, maximum sagittal flexion, maximum lateral velocity and average twisting velocity, contribute to the models predictive power, which is said to be 10.7 times better than chance (Marras *et al*, 1993).

PHYSIOLOGICAL APPROACH

In order to prevent overexertion of the physiological capacity, this approach aims to limit whole-body fatigue, and to a lesser degree, localised muscle fatigue, primarily associated with the performance of continuous, repetitive tasks (Ayoub and Woldstad, 1999 and Dempsey, 1998). Metabolic energy demands are increased during repetitive task performance, resulting in a need for higher levels of oxygen and nutrient delivery (Ayoub and Woldstad, 1999). As the capacity of the oxygen-transport system is a primary limiting factor in worker endurance, oxygen consumption and heart rate responses, and therefore energy expenditure, are frequently used to define the limits of the physiological system (Christie, 2006). These variables, while valuable in the assessment of task workloads and fatigue development, have not yet been shown to aptly identify the level of risk for the development of LBDs in different tasks (Dempsey, 1998). The concept of specificity is important in determining the physiological demands of a given activity, due to the fact that the optimal measures are obtained when participants are performing a task in which they are well trained (McArdle, 2001). Therefore, for the assessment of manual work, the testing procedure should closely correlate to a workers regular manner of task performance (Christie and Scott, 2005).

Heart rate responses

Despite the limited substantiation for the use of physiological criteria in defining suitable work limits (Dempsey, 1998), certain research does provide low, moderate and heavy cardiovascular strain ranges according to measured heart rates. For example, Kilbom (1995) suggested that strain could be conveyed as light for average heart rates below 90 $bt.min^{-1}$, moderate between 90 and 110 $bt.min^{-1}$ and extremely heavy between 150 and 170 $bt.min^{-1}$. More recently however, Kumar and colleagues (2000) suggested an acceptable range of between 104 and 114 $bt.min^{-1}$ (Christie, 2006).

Oxygen consumption and energy expenditure

Acceptable energy expenditure is either expressed in $kcal.min^{-1}$, or more frequently, as a percentage of oxygen consumption (VO_2) to aerobic capacity (Singh, 2011 and Dempsey, 1998). For individuals involved in extended work hours, a value of 33% of aerobic capacity, according to Christie and Scott (2005), has been widely acknowledged as the limit for oxygen consumption, or a work rate of 5 $kcal.min^{-1}$. These values however, may not be accurately related to the performance of MMH tasks, due to the fact they are based on treadmill or cycle ergometer performance, once again relating to the importance of specificity in assessment (Christie and Scott, 2005 and Hagen *et al*., 1993). If a worker's task is significantly different to the standard means of physiological assessment, recommendations may lead to overexertion in normal task performance (Christie, 2006). In 2001, McArdle and colleagues proposed an energy expenditure classification system for manual work, according to effort intensity (Table I).

Table I: Classification levels for manual work intensity (Adapted from McArdle, 2001).

	ENERGY EXPENDITURE	
	Men	
WORK LEVEL	EE ($kcal.min^{-1}$)	$V0_2$ ($L.min^{-1}$)
Light	2.0 – 4.9	0.40 – 0.99
Moderate	5.0 – 7.4	1.00 – 1.49
Heavy	7.5 – 9.9	1.50 – 1.99
Very heavy	10.0 – 12.4	2.00 – 2.49
Unduly heavy	> 12.5	> 2.5
	Women	
Light	1.5 – 3.4	0.30 – 0.69
Moderate	3.5 – 5.4	0.70 – 1.09
Heavy	5.5 – 7.4	1.10 – 1.49
Very heavy	7.5 – 9.4	1.50 – 1.89
Unduly heavy	> 9.5	> 1.9

Where: EE = Energy expenditure
$V0_2$ = Oxygen consumption
kcal = kilocalories

PSYCHOPHYSICAL APPROACH

As a branch of psychology, appropriate task design is based on what the majority of a work population deems acceptable (Ayoub and Dempsey, 1999 and Ayoub and Woldstad, 1999). The motivation behind this approach is based on the principle that individuals are able to accurately perceive and evaluate the sensations and stimuli generated by the biomechanical and physiological systems, in order to rate task demands (Ayoub and Dempsey, 1999). The value of these perceptual responses has been substantiated by the fact they correlate closely with work performance and intensities. It can be said that assessing an individual's capacity from this perspective, in addition to more objective measures, allows an indication of what a worker is prepared to do, and not only what they are physically capable of doing (Borg). With the aim of measuring these perceptions in a quantitative manner, and practically applying them in work situations, rating scales were developed, such as the Ratings of Perceived Exertion (RPE) scale designed by Borg in the 1960s, and the Body Discomfort scale of Corlett and Bishops (1976).

Ratings of Perceived Exertion (RPE)

Borg's RPE scale introduced the concept that subjective ratings of effort could be closely correlated to objective measures of physiological performance, with significant reliability (Kumar, 1999). He proposed that the overall perception of exertion was based on an integration of information received from the central nervous system, cardiovascular and respiratory functions, as well as the peripheral muscles and joints utilised in task performance (Kumar, 1999). This collective configuration was termed "Gestalt" perception. This scale can be used from both a "central" and "local" perspective, depending on the perception of strain to be investigated. Central ratings are based on an individual's perceptions of their fundamental cardio-respiratory strain, whereas localised ratings are focused the effort required by specific, selected regions, such as the muscles of the legs. As most psychophysical studies have focused on continuous aerobic performance, the applicability of the concept of RPE to manual materials handling tasks, which are predominantly intermittent, was questioned by various authors, including Kilbom and colleagues in 1986 (Kumar, 1999). However, Gamberale (1972) found that activities as diverse as ergometer cycling, weight lifting and pushing a wheelbarrow, showed linear relationships between heart rate responses and RPE ratings (Kumar, 1999).

Body Discomfort Scale

This scale is used as a means to identify and quantify uncomfortable sensations experienced during task performance, and therefore potentially sites at risk of developing MSDs. The experience of discomfort would therefore be an indication of incompatibility between a worker and their job demands. The body is represented in two maps, consisting of an anterior and posterior view, each divided into 28 sites for discomfort identification. An intensity scale, ranging from one to ten, with one being minor discomfort, and 10 being highly uncomfortable, is then used to rate the level of discomfort experienced the site identified.

CHAPTER III
METHODOLOGY

INTRODUCTION

Despite associated difficulties, the research design for the current project was field-based in nature for two important reasons. Firstly, although the ability to control extraneous variables is reduced, field research allows access to workers performing tasks in their real work settings, and the measurement of their genuine responses to the task demands (Zalk, 2001). The validity of using students during simulated task performance would be questionable due to their lack of experience and training within forestry work. Secondly, field-based research in developing countries allows a direct link between the knowledge generated, and the environments in which its' application is most urgently needed. For these reasons, this type of research has been supported by several authors in recent years (Christie, 2006; Scott and Christie, 2004 and Zalk, 2001). When considering forestry work specifically, laboratory simulation of the tasks performed is near impossible due to the demands imposed on workers, but also external factors associated with the harsh environment in which work is carried out.

Our knowledge of the basic characteristics of South African manual workers is inadequate within most work contexts, including forestry. From an ergonomics perspective, an understanding of the task demands and worker responses associated with manual work within the South African context therefore also remains limited. If the goal of ergonomics is to effect change within these situations, it is therefore crucial to conduct research that is directly applicable to the workforce affected by the research knowledge produced. It was upon this foundation that the current research project was designed, with the goal of gaining a better understanding of the South African manual worker, as well as the demands of work performed. Within the framework of manual labour, forestry-related work was selected for the focus of the research based on two factors. Firstly, the forestry industry is an important contributor to the South African economy, providing employment to a large portion of the rural population, and secondly forestry work is well acknowledged as being extremely hazardous to the work force. Upon approaching Sappi, a large stakeholder in South African forestry, it was identified that tasks within the silviculture sector were undergoing a shift from manual to semi-mechanised. Given that the majority of forestry-related research has focused on harvesting, rather than the demands of silviculture, an investigation into this sector was deemed crucial in order to produce appropriate ergonomic recommendations relating to the shift from manual to semi-mechanised task performance.

FIELD OBSERVATIONS AND PILOT STUDIES

With the help of forestry management and supervisors, a series of trips was made into Sappi plantations in Kwa-Zulu Natal between August and October of 2012. These allowed the researcher to gain familiarity with the two primary tasks in silviculture in South Africa, namely pitting and planting, the workers involved and the work-shift set-up. The pitting and planting teams assessed were all employed by a contracting company affiliated to Sappi, and worked on a piece-rate payment system. Photographs and video footage allowed a more focused assessment of postures adopted, as well as time-motion investigations into the frequency of task performance. The initial in-field and video analyses led to the development of the most appropriate methodology that would permit the least interference with task execution but still produce data relevant to the task demands investigated. Basic pilot testing was conducted to allow for a sound understanding of the equipment to be used, as well as the feasibility of measurement procedures, in relation to the methods of manual and semi-mechanised task performance for pitting and planting.

TASK DESCRIPTIONS

In order to provide a framework for the methodological approach used within this research project, detailed descriptions of the tasks performed, as well as the manual and semi-mechanised methods of each, are presented.

Manual Pitting

Pitting, or manual tilling, performed almost exclusively by males, is a section associated with soil preparation in the silviculture process. The existing method of task performance involved the use of a handheld hoe or pick, to loosen the soil at two metre intervals across several hectares of land a day (Figure 5A). This therefore consisted of numerous kilometres of walking, combined with highly repetitive motions and awkward or extreme postures. According to the video analyses, each pit takes approximately 30 seconds to prepare. Workers operated as a team (Figure 1Bii), with two individuals moving a knotted rope to mark the designated pit sites at each two metre interval (Figure 5Bi). Occasionally workers would rotate between the task of pitting and that of holding the marking rope. This rotational work was, however, not well defined or structured.

Figure 5: Pit preparation (5A), Marking rope operator (5Bi) and Pitting team working along marking rope (5Bii).

Figure 6: Mechanised pitting using a Stihl auger

Semi-mechanised Pitting

The semi-mechanised method of pitting that has been introduced to this sector, involves the use of a soil auger, which operates in a drill-like manner (Figure 6). The rotating blade burrows into the ground through a downward pressure applied by the operator. Once the pit has been suitably prepared, the operator then lifts the machine and blade out of the soil and moves on to the next site to be pitted. The auger, manufactured by Stihl, was the first design to be introduced with the initial shift from manual to semi-mechanised pitting, weighing approximately 18 kilograms with a full tank of fuel. This auger, used for all assessments in the current research was designed to be operated by a single individual, although variations do exist where a machine can be operated by two workers.

Manual Planting

In the current manual method of planting, predominantly performed by females, a worker is required to dig a hole within the loosened soil of the pit with a hand-held, short handled spade called a trowel, place the seedling, and then add a cup of hydrogel before refilling the hole (Figure 7A). The hydrogel, which is a jellylike, water-based substance, serves to function as an initial water source for the young seedling. Each seedling is planted at two metre intervals, in accordance with the previously prepared pits (Figure 7Biii). A planting worker is required to carry a tray of seedlings (Figure 7Bi), weighing between three and four kilograms, in one hand, and a 20 litre container of hydrogel (Figure 7Bii) in the other, which, at three-quarter capacity weighs approximately 16 kilograms. The three-quarter capacity of the hydrogel container is seen as acceptable by the workers in terms of carrying the weight in-field. The time required to plant each seedling was recorded as approximately 35 seconds, therefore the task can be deemed highly repetitive in nature. As each individual's hydrogel and seedling supply becomes depleted, another worker is beckoned to replace the stock, therefore work is continuous, with limited variety in task demands.

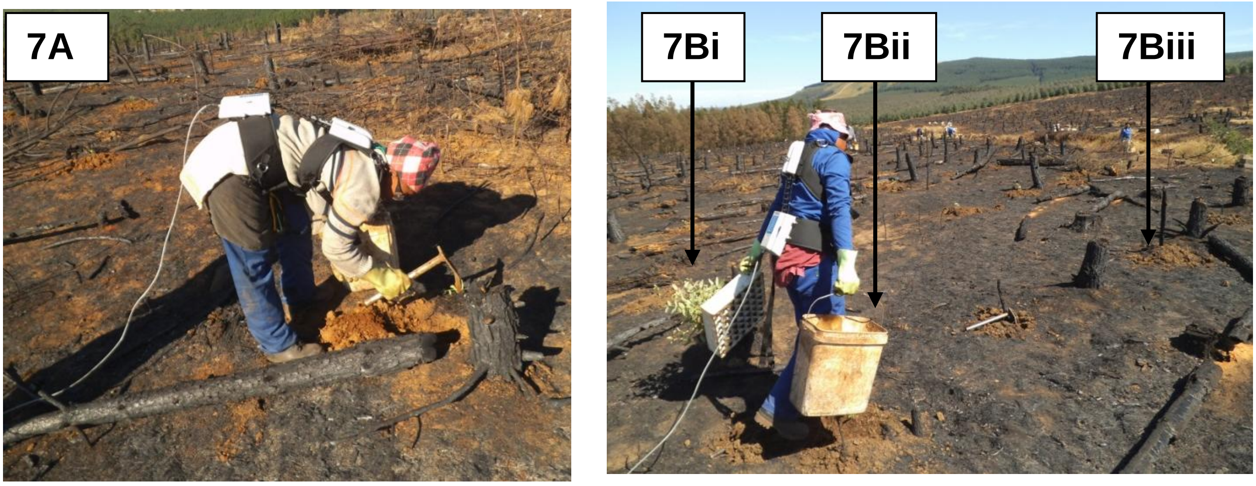


Figure 7: Planting procedure (7A), Seedling tray (7Bi), Hydrogel (7Bii) and Prepared pit (7Biii).

Figure 8: Semi-mechanised planting (8A), Handles used to operate the planting tube (8Ai), Opening of tube for seedling and hydrogel (8Aii) and Proposed container for hydrogel transport (8B).

Semi-mechanised Planting

The semi-mechanised method of planting currently being introduced has been designed in an attempt to reduce the extreme postures associated with the task, as well as the awkward style of seedling and hydrogel transport. The new piece of equipment is a hand-held, tube-like structure, commonly referred to as a Krups Planter (Figure 8A). The operator is required to drive the pointed lower tip into the soft pit, insert the seedling at the top of the tube (Figure 8Aii) followed by the cup of hydrogel, and then close the handles (Figure 8Ai) to drop the contents into the ground. Combining the use of this tool, with an appropriate method of seedling and hydrogel transport, remains in the planning phase, however, Figure 8B displays the proposed design. Each worker will be required to carry the liquid on their backs in the visible yellow container, with the seedlings hanging in a bag over the shoulder. The container is connected to the planting tube via a pipe, which releases water every time the handles of the tool are closed. Since the exact transport method of the seedlings and hydrogel has not been confirmed, the current methodology aimed only to assess the biomechanical responses associated with the use of the planting tube.

Table II: Summary of field observations for manual and semi-mechanised pitting and planting, including basic procedures, equipment, weights and cycle times.

	PITTING		**PLANTING**	
	Manual 	**Semi-Mech** 	**Manual** 	**Semi-Mech** 
Basic Procedure	Pit preparation through repetitive pick swinging	Pit preparation through "drilling" auger into soil	Opening of soil using trowel, placing of seedling and hydrogel	Insertion of planting tube mouth, placing of seedling and hydrogel
Equipment used	Hoe/Pick	Stihl Auger	▪ Trowel ▪ Seedling tray ▪ Hydrogel container	▪ *Planting tube ▪ Hydrogel container ▪ Seedling bags
Maximum weight held	7-10 kgs	18 kgs	22 kgs	*Unknown
Cycle time (continuous work)	35 seconds	12 seconds	35 seconds	12 seconds
Team size	±25 male workers	±10 male workers	±25 female workers	*Unknown
Work rate (pits/plants per shift)	Up to 556 pits	Up to 556 seedlings	Between 300 and 500 seedlings	*Unknown

***** Semi-mechanised planting procedure not yet finalised

EXPERIMENTAL DESIGN

The South African forestry industry is in the process of re-evaluating the methods used in the silviculture sector in order to provide improved productivity, and worker health and safety. As such, the use of ergonomics in the evaluation of altered task characteristics, and how these relate to the capabilities of the workers, is essential. This has allowed for the development of the current research project, which aims to firstly, assess the existing nature of silviculture work, and secondly, to analyse the effects of altered task demands, based on increasing mechanisation, on worker responses.

SELECTION OF INDEPENDENT VARIABLES

As highlighted in the field observations section, the critical components of silviculture, which require ergonomic evaluation, are task type – pitting and planting – and method of performance – manual and semi-mechanised (See Figure 5). These factors therefore form the basis of the experimental design for the current study as independent variables of interest. The selection of participants according to sex was based on the existing situation within each task in the industry, where pitting is performed by males and planting by females, with little if any overlap between the two tasks. Female workers will therefore be used in the assessment of manual and mechanised planting, and male workers will be used when assessing both pitting methods.

Males

	Pitting
Manual	
Mechanised	

Females

	Planting
Manual	
Mechanised	

Figure 9: Research design highlighting the focus on two tasks, and two methods of performance

SELECTION OF PARTICIPANTS

Manual materials handling tasks, including those occurring in the forestry industry, are extremely physically demanding, and to perform tasks safely, workers are required to be well trained and experienced. The validity of student participation as subjects within human factors related research is therefore brought into question. It cannot be said that the application of task demands associated with a particular job, will elicit the same responses within student participants, who are most likely inexperienced in the task performance, when compared to individuals who are experienced and work-hardened. For this reason, and the fact that forestry task simulations within a laboratory are near impossible, the responses of actual workers who perform these jobs on a daily basis were assessed. As a result of the transition from manual to semi-mechanised task performance for pitting, the number of participants was reduced from 25 workers to 10. The selection procedure adopted by the employer was unfortunately not investigated. However, the fact that productivity was always based on team, rather than individual performance, it is unlikely that selections were based on individual productivity assessments, therefore the comparison of results of the manual and semi-mechanised techniques was deemed acceptable.

Participant characteristics

In order to understand the relationship between task demands and the resultant worker responses, a sound understanding of the personal characteristics of these workers is crucial. Furthermore, the socio-economic status of workers, as well as factors associated with the negative cycle of disease, can potentially have a harmful impact on their productivity in the workplace (O'Neill, 2000). For this reason, various anthropometric (stature and body mass), demographic (age and sex), morphological (body mass index, body fat percentage and waist-to-hip ratio), physiological (heart rate and blood pressure) and strength (grip, back, pushing and pulling) characteristics were measured, and a basic health questionnaire was administered.

SELECTION OF TESTING PROCEDURE

Due to the complexities of field-based research, the testing procedure was devised to incorporate three phases. The first phase procedure was designed to provide detailed explanations of the research to the participants, as well as to provide equipment demonstrations and measure basic worker characteristics. This phase therefore aimed to suitably prepare participants for phases two and three, which were conducted in-field.

In terms of the phase two and three *in situ* measures, the foundation upon which the most suitable testing procedure was designed was based on two important aspects. Firstly, consideration was given to the fact that disruption of productivity needed to be limited within the planting and pitting teams, and secondly, each worker needed to perform their task using normal, unrestricted movements and pacing techniques. Furthermore, environmental factors had to be taken into consideration, such as site location, slope gradient and organic debris underfoot, due to the potential impact on physiological workloads (Trewin and Kirk, 1992). For this reason, it was determined that a designated testing area, located in-field was allocated at each work site. With the expertise of management and team supervisors, each testing area consisted of flat terrain, and limited underfoot debris. Within this area, each participant was able to perform their pitting or planting task in the same manner as they would under normal circumstances, limiting the disruption of the team, and allowing each individual to maintain their productivity by completing pits or planted seedlings at a normal pace. The elimination of as many extraneous variables as possible is crucial from a study design perspective, therefore control and standardisation of the in-field work site contributes to the scientific rigidity of the current research.

DEPENDENT VARIABLES

In order to assess the impact of pitting and planting stressors on silviculture workers *in situ*, the testing procedure was designed according to two important principles, the first being the holistic approach of ergonomics, and the second, the dynamic nature of manual work. The holistic approach of ergonomics, as detailed in Chapter 2, focuses on a human-centred design of work systems (Dempsey, 1998), taking into consideration applicable factors including organisational, environmental, physical, cognitive and social aspects (Karwowski, 2005; Karwowski, 2006 and Wilson, 2013). Whether the domain of ergonomics centres on cognitive, organisational or physical work, the objective is to optimise performance and wellbeing by understanding the interactions between an individual, and everything that surrounds them (Karwowski, 2006). Manual materials handling is predominantly associated with physical ergonomics, a domain concerned with physiological, biomechanical, anthropometric and anatomical characteristics of a human (Karwowski, 2006 and Genaidy *et al*, 2007).

The second concern, with regards to valid assessment of workplace demands, is the nature of task performance. Various authors, including Dempsey (1998) and Marras (2000), have highlighted the fact that understanding injury risk in manual work, specifically from a biomechanical perspective, has historically been one dimensional and static in nature. The emerging criticism for this is primarily based on the highly dynamic nature of manual work due to mechanisation increases, and, in order to accommodate these changes, the frequency and velocity of work movements have been amplified (Davis and Marras, 2000). As a result three-dimensional trunk movements, intra-abdominal pressure and muscle activity and co-activation have increased (Marras *et al*, 1995). It can therefore be said that two essential components of research within physical ergonomics, are the need for holistic assessment techniques, as well as sound consideration of the dynamics within various tasks. As such, variables from the physiological, biomechanical and psychophysical domains are investigated in the context of silviculture work.

Biomechanics

Bearing in mind the increasingly dynamic nature of manual work, it can be acknowledged that biomechanical assessment models have evolved accordingly. Historically, these models focused on the use of pre-defined criteria associated with compression forces of the L5/S1 joint, largely ignoring factors such as spinal kinematics and forces produced by the inertia of body segments and load (Dempsey, 1999 and Marras, 2000). Over the past 20 years, significant evidence produced regarding the importance of the dynamic, three-dimensional nature of work tasks, as highlighted by Marras and colleagues in 1992, has seen a shift in the methods used for risk assessment, specifically from 2D and 3D static models, to a variety of dynamic models (Marras *et al*., 1995; David, 2005 and Chaffin, 2009).

Of the dynamic models, the biologically assisted models have proven most accurate (Christie, 2006), however these have primarily been used in laboratory simulations of manual tasks, and are difficult to use in field-based research due to the complexities of equipment set-up and data collection (Garg and Kappelusch, 2009). Marras (2000) emphasised the importance of understanding the three-dimensional nature of spinal movement in realistic situations, saying that biomechanical studies that are not validated in-field are merely unverified hypotheses. While accepting the fact that there is a critical need for biomechanical assessments within realistic workplaces, and acknowledging that biologically assisted models, although the most accurate, are not feasible for in-field research, the current project design incorporated both dynamic and static methods of assessment. The specific tools selected, and variables assessed, were based on the risk factors observed in-field, specifically awkward working postures, repetitive movements and rapid cycle times. For the purposes of this study, spinal kinematic responses, compression and shear force estimates, and strength measures were selected for further investigation.

In terms of spinal kinematics, asymmetrical movements and increases in velocity and acceleration of the trunk have been correlated with decreases in strength, as well as increases in muscle activation and spinal loading (Marras *et al*., 1992). Dynamic motion characteristics are therefore critical measures in determining risk of injury within various tasks. For this reason, measures of trunk position, velocity and acceleration were recorded during manual and semi-mechanised pitting and planting. A Lumbar Motion Monitor – LMM (see experimental set-up and equipment) was selected as the most suitable means to record these characteristics. In order to obtain sufficient data from this device, workers were required to perform five repetitions of the manual task, and five repetitions of the semi-mechanised task. According to Marras *et al*. (1992), who investigated the accuracy of the LMM, three repetitions of each movement allows for adequate measurement of trunk position, velocity and acceleration, with recordings taken at a frequency of 60 Hz.

While dynamic movements are important contributors to injury risk in manual work, different combinations of biomechanical stresses are imposed on workers performing these jobs, therefore no criterion in isolation can be used to accurately predict task demands (Waters *et al*., 1998). As such, measures of the compression and shear forces imposed on the spine, using the 3D Static Strength Prediction (3DSSPP) Model, were deemed important factors to consider within silviculture work. Although this programme provides static estimates, these values can be compared to predefined baseline measures to further assist in determining risk (Waters *et al*., 1998).

Physiology

The importance of biomechanical criteria in determining risk of injury is well documented, and is supported by the load-tolerance theory of injury development (see Chapter 2). However, from a physiological perspective, highly repetitive tasks performed continuously for longer than 15 minutes, are associated with increased metabolic energy demands (Ayoub and Wolstad, 1999 and Dempsey, 1999) as is the case during pitting and planting. The need for higher levels of oxygen and nutrient delivery during these tasks (Ayoub, 1999), means that the capacity of the oxygen-transport system is a primary limiting factor in worker endurance. For this reason, the assessment of physiological criteria, with the goal of preventing whole body or local muscle fatigue (Waters *et al*, 1998) is an important consideration during silviculture work.

Detailed information pertaining to the physiological demands of such jobs can be obtained through heart rate, oxygen consumption and energy expenditure measurements (Waters *et al*., 1998), and these variables were therefore selected for assessment in the current study. Field-based limitations of physiological assessments were highlighted by Christie (2006), who stated that recording techniques can be a hindrance in task performance, and potential equipment damage is a concern. However, the set-up of the designated testing area within the workplace, allowed for measures to be obtained without disrupting productivity. An understanding of whole-body fatigue and energy expenditure is of particular importance in the case of South African manual workers, due to their potentially suboptimum nutritional statuses. In fact, Christie (2006) assessed the energy demands of forestry harvesting in South Africa, noting that daily energy deficits exceeded 8000 kilojoules. Therefore, in order to ensure that the physical capabilities of workers are not being over-taxed, it is crucial to understand the physiological demands imposed upon them during task performance (Scott and Christie, 2004). Due to the field-based nature of the research, determining the aerobic capacity of the workers proved difficult. However, as the aim was to generate a basic understanding of the differences in the physiological demands of the two techniques, comparisons of generated oxygen consumptions and energy expenditure was deemed acceptable. Furthermore, the commonly used techniques for determining aerobic capacity in laboratory settings, such as treadmill running, would likely not have yielded accurate measures, due to the differing demands imposed on the workers physiological systems.

Psychophysics

The importance of worker perception in understanding the demands of manual work originated in the 1950s (Kumar *et al*, 1999). This field of research centres on the fact that there the strength of a sensation experienced by an individual, is closely correlated to the intensity of the imposed physical stimulus, as acknowledged by several authors including Ayoub, Dempsey, Kumar, Snook and Ciriello. Psychophysical assessments have an important role to play in field applications of ergonomics, potentially contributing to the design of task and workplace set-ups, and allowing for modifications which are perceived as more acceptable by the affected workforce (Ayoub and Dempsey, 1999). Consequently, two psychophysical techniques were selected for the assessment of worker perceptions during pitting and planting. The Rating of Perceived Exertion (RPE) scale proposed by Borg, and the Body Discomfort Map are both easily administered within a field investigation. Furthermore, the perceptual ratings produced by the RPE scale are closely correlated to physiological responses, specifically heart rate (Kumar *et al*., 1999).

EXPERIMENTAL SET-UP AND EQUIPMENT

PERSONAL CHARACTERISTICS

This phase of data collection was conducted in a laboratory type set-up at the hall of the workers residence. Characteristics measured were those associated with anthropometry, morphology, physiology and strength.

Stature

A tape measured fixed to the wall in the residence hall was used to obtain each participants stature. They were required to stand with their backs against the wall, barefooted, heels touching the wall and head in an upright position looking straight forward. Stature was recorded as the distance from the floor to the highest point in the mid-sagittal plane.

Mass

Body mass was measured to the nearest 0.1 kilograms using a digital scale. Participants were required to complete the recording barefooted, with all heavy clothing removed.

Body Composition

Measurements from four skinfold sites, specifically the triceps, biceps, subscapular and suprailliac, were obtained using Holtain skinfold callipers in order to calculate body fat percentage. The callipers were placed perpendicular to the skinfold site, at a distance of one centimetre from the thumb and forefinger. Where necessary, the appropriate calliper placement was determined by calculating the midpoint of the anatomical site. To ensure accuracy of readings, three measures were taken at each site and if these were not within two millimetres of each other, further readings were taken. The Durnin-Womersley (1974) skinfold method was used to calculate body density, following which the Siri formula was applied to obtain body fat percentage. This method was selected over the Jackson and Pollock technique as only four sites are assessed compared to seven, which reduced the invasive nature of this stage of assessment.

Health Questionnaire

A basic questionnaire was administered, with the assistance of the Zulu interpreter, in order to assess each participant’s health status, currently, and within the previous year (Appendix). Further questions focused on the incidence of musculoskeletal disorders, as well as work experience within the forestry industry.

BIOMECHANICAL RESPONSES

Spinal Kinematics

Previously, examining position, velocity and acceleration of the trunk required the use of video-based motion analysis (VMA), with the need for joint markers, attached to workers, being constantly visible (Marras *et al*., 1992). However the use of these systems is frequently impractical in industrial workplaces due to a variety of factors such as equipment positioning. Consequently, an industrial Lumbar Motion Monitor (LMM) was utilised for the current study. Marras and colleagues (1992) confirmed the accuracy and reliability of the LMM, stating that it is twice as accurate at measuring motion components when compared to VMA. The LMM, as described by Waters *et al*. (1998), serves as an external spine, which mimics the movements of the trunk in three-dimensional space, and is fixed at the level of the thorax and pelvis. The wiring system of the LMM is connected to four potentiometers, which differentially respond to voltages generated by the spinal movements (Marras *et al*., 1992). The differing voltages, measured by the potentiometers at a frequency of 60 Hz, were reported in terms of spinal positioning, velocity and acceleration using Ballet software.

Calibration

Prior to the start of each assessment period, the LMM was placed horizontally in its calibration frame in order for the sensor adjustments to be set to zero degrees. Following this, the device was attached to the participant, and sensor adjustments were once again performed in order to assign the vertical position of the spine as a standardised zero degrees. This procedure was repeated for each participant.

Compression and shear forces

Digital photos were taken during manual and mechanised task performance to be used in the 3D Static Strength Prediction Programme (3DSSPP). This is a three-dimensional model that estimates compression and shear forces exerted on the spine at the level of the L5-S1 joint. Although this model has been purported as an inadequate technique for assessing highly repetitive, dynamic tasks (Rodrick and Karwowski, 2006), it is inexpensive and easy to use. Furthermore, even basic estimates of the external forces acting on the spine allow for a more holistic interpretation of the task demands.

PHYSIOLOGICAL RESPONSES

Assessment of physiological demands was divided between phase two and three of the experimental procedure. In the second phase, the heart rates of each participant were monitored for the duration of a work shift.

Heart Rate

A polar heart rate monitor, consisting of wrist watch and chest strap, was used for the measurement of heart rate responses during shift performance. At the start of the work shift, the participant was fitted with the chest strap at the level of the breastbone, and the watch attached to their wrist.

Oxygen consumption and energy expenditure

A Cortex Metamax unit was used to further assess the physiological demands of manual and semi-mechanised pitting and planting. According to Macfarlane and Wong (2012), this system produced adequately stable and reliable results, however, it may overestimate oxygen and carbon dioxide volumes during moderate and vigorous exercise. Of the range of variables recorded by this unit, heart rate, oxygen consumption and energy expenditure were selected for assessment. The Metamax is a portable, battery powered recording unit which is fitted to the chest of participants via a lightweight harness. An appropriately sized face mask, with an attached bidirectional turbine and gas analysis tube, placed over the participant's nose and mouth, was directly connected to the recording unit. The mask allows the system to assess airflow volume and the gas composition of the participants breath based on the known compositions of ambient air, specifically 20.93% oxygen, 0.03% carbon dioxide and 79.04% nitrogen. These two factors, volume of air inhaled, and composition of air expired, are then used to indirectly calculate energy expenditure. A receiving unit connected to the computer-operated programme, allowed for the transmission of data received by the telemetry system.

Calibration

Prior to the start of testing, the Metamax had to be run through a series of calibration steps. These were conducted in-field, at the start of each testing day, with repeated steps taking place before each participant. The initial calibration was a three-step process and involved the measurement of barometric pressure at the testing site, the assessment of the gas composition of the environmental air as well as known concentrations of gas from a gas cylinder, and finally the volume of air passing through the bidirectional turbine using a three litre syringe. Prior to the testing of each participant, the environmental air was reassessed, and a maximum flow-loop for each individual was obtained.

PERCEPTUAL RESPONSES

Psychophysical rating systems including the Rating of Perceived Exertion (RPE) scale, and the Body Discomfort Map, were incorporated into phase two and three of data collection.

EXPERIMENTAL PROCEDURE

PHASE 1

This stage, conducted in the afternoon prior to the in-field assessments associated with phase two, was designed to obtain anthropometric (stature and mass), demographic (age and sex), strength (grip, back, pushing and pulling strength) and reference cardiovascular responses (heart rate and blood pressure). The purpose of the research, as well as the procedures, questionnaires and scales were explained in English, and translated with the help of a Zulu interpreter. Letters of information were also provided during this stage (see Appendix). Emphasis was placed on the voluntary nature of participation, and once willing participants were identified, informed consent forms (Appendix) were signed.

PHASE 2

The *in-situ* procedures associated with phase two included the assessment of the physiological and perceptual demands of the manual tasks for the duration of a work shift, as well as the biomechanical responses to both the manual and mechanised methods of pitting and planting. At this stage, 26 male and 29 female participants were measured for the pitting and planting tasks respectively.

Upon arrival at the work site, the procedure was explained briefly to participants again, following which they were fitted with a heart rate monitor. They were then required to carry out their tasks as per normal. At half an hour intervals throughout the day, heart rate measures were recorded and participants reported on their level of exertion according to the RPE scale. At hourly intervals, each individual was asked to identify sites, as well as intensity of discomfort experienced in various regions of the body using the Body Discomfort Map.

Once all participants had completed phase one, and had their physiological and perceptual responses measured for a shift duration, biomechanical responses were assessed in the designated testing area at their work site. Within this demarcated zone, individuals were fitted with the LMM, and the procedure was explained again. They were then required to perform five repetitions of the task manually with a pick for pitting, and a trowel for planting, followed by a further five repetitions using the auger and planting tube for pitting and planting respectively, thereby preparing a total of 10 pits or planting 10 seedlings. The order of manual and mechanised task performance was permutated across the participant sample.

PHASE 3

The procedures for phase three were conducted in a similar manner to those of phase two, however this stage focused on more in depth physiological measures. Due to the shift from the manual to semi-mechanised methods of task performance, there was a large degree of disruption within the workforce available for participation.

Pitting

At the time of phase three data collection, in-field pitting was performed using only the semi-mechanised method. Due to the productivity increases, the operating team only consisted of 10 workers, therefore only allowing 10 participants to be measured during this phase. Workers entered the designated testing area and were fitted with the Metamax portable ergospirometry unit. They were then required to perform six continuous minutes of manual pitting using a pick, followed by six continuous minutes of semi-mechanised pitting using the Stihl auger. A six minute rest break was allocated between the performance of each method. The completion of each method was also permutated across the sample group.

Planting

For phase three assessments of planting, the manual method was still the primary method of task performance, and the exact procedure for the semi-mechanised method had not yet been fully established. For this reason, the physiological responses of 10 participants for manual planting only were measured within the designated testing area. Each participant, once fitted with the Metamax unit, was required to perform six continuous minutes of manual planting only.

ETHICAL CONSIDERATIONS

INFORMED CONSENT

The experimental procedures were explained to the participants both verbally and in writing with the assistance of a Zulu Interpreter. In an attempt to ensure that workers were not pressured into participation by management, emphasis was placed on the voluntary nature of the research at several stages throughout the experimental process. In this case, workers were offered monetary compensation for their participation, which, due to their already low income, meant that all willingly agreed. Upon participant agreement, informed consent forms were explained and signed, once again in the presence of an interpreter (Appendix). Ethical approval for this study was obtained from the ethics committee of the Human Kinetics and Ergonomics Department of Rhodes University, before the commencement of any experimentation.

PRIVACY AND ANONYMITY OF RESULTS

Personal names were used for the duration of the testing procedures, in order to ensure the appropriate alignment of results from the three stages of experimentation. Following the completion of data collation, these results were then coded to ensure the anonymity of each participant. Presentation of these results to Sappi was strictly private, with no information directly linked to individual workers.

STATISTICAL ANALYSES

All recorded data was analysed using version 11.0 of the statistical software programme Statistica. Dependent t-tests were used to compare all results from the biomechanical, physiological and perceptual variables measured for the manual and semi-mechanised methods of the pitting and planting tasks. Alternative hypotheses were accepted, based on a probability value of $p<0.05$, which allowed a 95% confidence interval.

CHAPTER IV
RESULTS

INTRODUCTION

The current study aimed to generate a twofold understanding of forestry, particularly silviculture, in South Africa. Firstly, it investigated the personal characteristics intrinsic to the workers involved in this sector, and secondly, it assessed worker responses to the task demands imposed during manual and semi-mechanised pitting and planting. Manual and semi-mechanised pitting and manual planting were assessed from a biomechanical, physiological and psychophysical perspective. However, as the task design for semi-mechanised planting was not yet fully established, this method was investigated from a biomechanical (spinal kinematics) perspective only. The results in this section are therefore displayed in accordance with the research, with the personal characteristics of the pitting and planting workers presented initially, following which the results are divided into the pitting and planting responses, and then further subdivided according to the biomechanical, physiological and psychophysical variables measured. Statistically significant findings, based on a confidence interval of 95%, are represented graphically.

WORKER CHARACTERISTICS

In order to provide a framework for understanding the worker responses elicited by forestry demands in silviculture, basic participant characteristics were recorded, and are reported on this section. Anthropometric, demographic, morphological and reference physiological measures of the pitting and planting workers are shown in Table III, as well as average work experience within the forestry industry. As the performance of pitting is conducted solely by males, and planting by females, no comparisons have been drawn between the biomechanical, physiological and psychophysical variables. However, as this section aimed to emphasise characteristics inherent to the unique South African workforce, statistical analyses have been conducted on the anthropometric and morphological attributes in order to compare and contrast sex-related differences within this population.

Table III: Basic personal characteristics of the workers investigated. Data expressed as means (standard deviation).

	PITTERS (n=31 males)	PLANTERS (n=29 females)
Age (yr)	27.04 (8.25)	28.69 (11.11)
Stature (mm)	1663.6 (75.4)	1583.1 (61.75)
Body Mass (kg)	60.08 (8.84)	64.07 (10.13)
Body Mass Index ($kg.m^{-2}$)	21.65 (2.43)	25.54 (3.62)
Body Fat Percentage (%)	10.61 (2.36)	29.39 (4.93)
Reference HR ($bt.min^{-1}$)	64.12 (10.16)	79.03 (8.77)
Reference BP: Systolic/diastolic (mmHg)	126/81 (17/12)	122/76 (15/13)
Forestry WE (yr)	2.8 (2.31)	2.16 (2.09)

HR= Heart Rate; BP= Blood Pressure; WE= Work Experience.

PITTERS

All pitting workers assessed during the current research project were male. Worker age averaged 27.04 years, however, the 16.5 year range in ages for this sample of workers proved to be fairly large.

Stature and Mass: In terms of anthropometry and morphology, a recorded stature of 1664 (±75.4) mm and body mass of 60.08 (±8.84) kilograms was observed. A low variability was observed within these characteristics, with a CV of 4.5% for the former, and 14.7% for the latter.

BMI*:* The resultant body mass index (BMI) averaged 21.65 $kg.m^{-2}$ and was maintained within a narrow range from a lowest of 19.22 $kg.m^{-2}$ to a highest of 24.08 $kg.m^{-2}$.

Body Fat Percentage*:* The mean value for body fat percentage was 10.61 (±2.36) for the sample of male silviculture workers. Interestingly, the coefficient of variation for this variable of 22% was double that observed for the body mass index responses (11%), indicating a large variability between the two body composition measures.

Cardiovascular Responses*:* When considering the reference cardiovascular measures, the mean reference (resting) heart rate was found to be 64 $bt.min^{-1}$, while blood pressure (systolic/diastolic) averaged 126/81 mmHg. These responses were associated with a relatively low level of variability.

Work Experience*:* The silviculture-related work experience of the pitters was found to be very low, averaging 2.8 years. Although the range in work experience (4.62 years) was large relative to the mean, none of the workers assessed had more than six years worth of pitting experience.

PLANTERS

Only female workers were included in the assessment of the planting task. The planters were of similar age to the pitters, averaging 28.69 years old, however the range in ages (22.22 years) was found to be even higher within this work group.

Stature and Mass*:* From an anthropometrical and morphological perspective, the measures of stature of 1583 (±61.75) mm and mass of 64.07 (±10.13) kg were relatively consistent between planting individuals, showing fairly low levels of variability. Interestingly however, although both variables produced coefficients of variation below 20%, mass was associated with a variability of 16%, while stature proved more consistent across the planters, with a variation of only 4%.

BMI*:* The BMI, averaging 25.54 $kg.m^{-2}$, was associated with a wide range of 7.24 $kg.m^{-2}$, with a minimum of 18.3 $kg.m^{-2}$ and a maximum of 32.78. The distribution of the planting participants across the different BMI categories is highlighted under the sex-related differences section below.

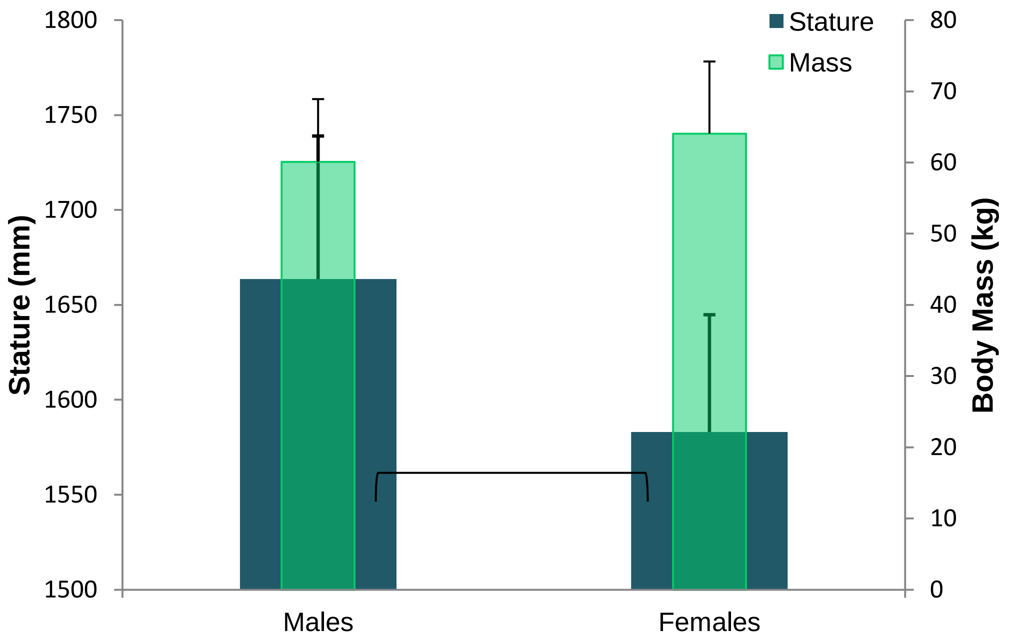
Body Fat Percentage*:* The mean body fat percentage recorded for the female silviculture workers was 29.39%. The distribution of this variable across the cohort of workers was fairly low, with a range of just under 10%.

Cardiovascular Responses*:* In terms of cardiovascular responses, a mean 'resting' heart rate of 79.03 $bt.min^{-1}$ was observed, while the planting workers had an average systolic/diastolic blood pressure of 122/76 mmHg. These findings proved to be very consistent for this sample of workers.

Work Experience*:* The average level of work experience of 2.16 years for the planters was found to be even lower than that of their male counterparts in the pitting section. Although planting experience in general was found to be low (<5 years), the range in was relatively high, with less than a month's worth of experience in some cases, extending up to a maximum of 4.25 years in others.

SEX-RELATED DIFFERENCES

Stature and Mass*:* Figure 10 highlights the differences in stature and mass between the male and female silviculture workers. From an anthropometric perspective, it was seen that, while the male pitters were taller than their female counterparts by an average of 80.5 mm, they weighed just under four kilograms less. Furthermore, for both males and females, stature proved to have a much lower level of variability (<5%), whereas the variability in mass was over 14% in both cases. As a result, the difference in stature proved to be significantly different, whereas that found for body mass remained insignificant (see Figure 10).



Where: ⌐¬ denotes significant difference ($p<0.05$)

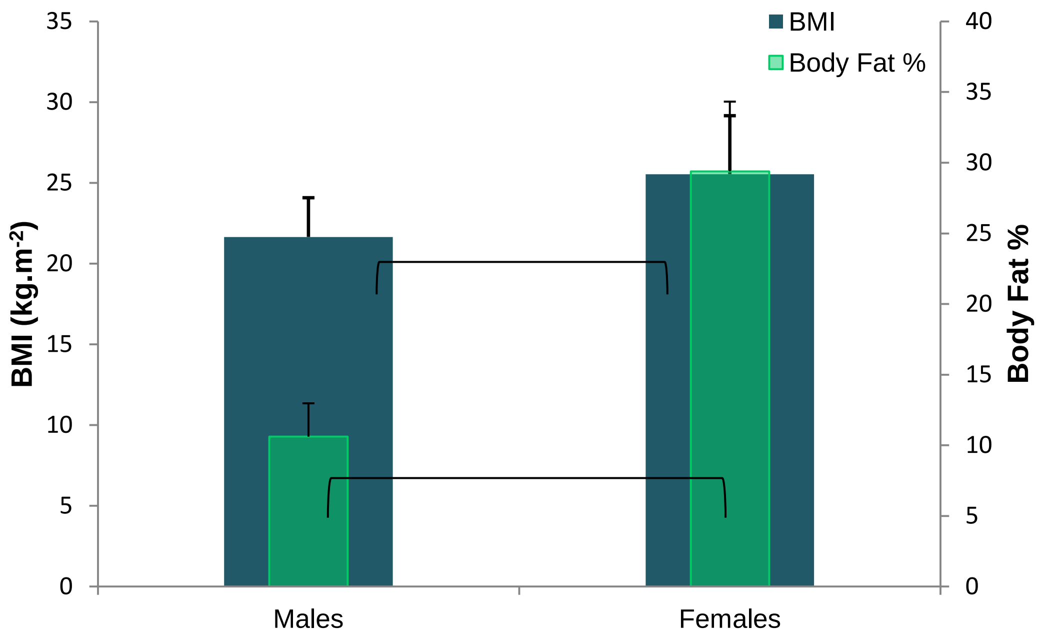
Figure 10: A comparison of stature (mm) and body mass (kg) between male pitters and female planters.

BMI*:* A comparison of BMI and body fat percentage between the males and females is presented in Figure 2. When considering the correlation between stature and mass, it was found that, BMI was higher ($p<0.05$) in the females than the males by 3.89 $kg.m^{-2}$. A noteworthy observation with regards to BMI when comparing males to females is the distribution of individuals across the BMI categories of Underweight, Normal, Overweight and Obese, as highlighted in Table IV. In order for these results to be represented more accurately, the ‘normal’ category has been further divided into Lower Normal and Upper Normal. From Table IV, it can be seen that the majority (90.4%) of male pitters fall into the normal BMI range, with more than half of these falling into the Lower Normal category. On the other hand, the female planters show a trend in distribution towards the upper categories, with over 90% of individuals falling in the Upper Normal category or higher. In fact, over 50% of the planters would be classified as overweight.

Table IV: BMI categorisation of male pitters and female planters according to percentage distribution.

BMI Category	Male Pitters (%)	Female Planters (%)
Underweight (<18.5)	0	0
Lower Normal (18.6 – 21.7)	58.1	6.9
Upper Normal (21.7 – 24.9)	32.3	44.8
Overweight (25 – 29.9)	6.5	37.9
Obese (>30)	3.2	10.3

Body Fat Percentage*:* The statistically higher difference recorded for the BMI of the female planters when compared to the male pitters was also observed in the case of body fat percentage (see Figure 11). In fact, the mean value for this variable was 29.39% in the females, which was almost three times higher than that which was found in the male pitters (10.61%).



Where: ⌐¬ denotes significant difference ($p<0.05$)

Figure 11: A comparison of BMI (kg.m^{-2}) and body fat % between male pitters and female planters.

MUSCULOSKELETAL COMPLAINTS AND HEALTH STATUS

In developing countries, worker productivity is closely affected by various factors associated with the economic cycle of disease (O'Neill, 2000). Included in this cycle is poor worker health, therefore an investigation into the health status of the pitters and planters, is an important contributor to the overall understanding of worker productivity. The results obtained from the musculoskeletal injuries and health status questionnaire are represented in Tables V and VI. These collective responses, both for the musculoskeletal complaints and health status, are based solely on self-reports obtained from each participant and do not include statistics obtained from the company.

The values displayed in Table V, represent the combined reports of musculoskeletal injuries and complaints, currently found in the workforces assessed, and those reported during the 12 months prior to the administration of the questionnaire. Only the injuries that were deemed work-related, both treated and untreated, were included in these results.

Table V: Musculoskeletal complaints recorded for the pitters and planters.

	% PITTERS (n=31 males)	% PLANTERS (n=29 females)
Back Pain	17	17
Shoulder Pain	3	7
Wrist/Hand Pain	0	7
Leg Pain	0	3
Fatigue	10	0

When considering the pitters, 17% of them reported suffering from back pain, accounting for over 80% of musculoskeletal complaints, the remainder being attributed to shoulder pain. An additional work-related complaint, while not directly correlated with any musculoskeletal injuries, was chronic fatigue, and this was reported by 10% of all pitters. Focusing on the planting workers, back pain was once again a major contributor to worker suffering, accounting for 50% of all complaints, and experienced by 17% of individuals. The remaining issues were associated with shoulder pain, and wrist and hand pain, both reported by 7%, as well as leg pain experienced by 3% of planters. Interestingly, there were no complaints of fatigue within the planting workforce.

Health status (Table VI) was quantified according to the prevalence of chronic diseases of lifestyle, common communicable diseases found in South Africa, and the proportion of smokers, and drinkers of alcohol, within the pitting and planting workforces. No cases of diabetes, hypercholesterolemia, heart disease or hypertension were reported among the pitting workers questioned. In terms of communicable diseases, 97% reported suffering from a common cold, while accounts of gastric flu, cholera and tuberculosis (TB) were recorded for 20%, 10% and 7% of individuals respectively. The consumption of alcohol and use of tobacco products was highly prevalent among the pitters, with 80% of individuals drinking and 60% smoking. The results from the planters indicate that 17% of workers suffer from one of the chronic diseases of lifestyle, particularly hypertension, whereas no reports of the remaining three were found. Of the communicable diseases considered, 62%

of individuals had suffered from the common cold, 7% from gastric flu and TB, and 3% from pneumonia. Finally, in contrast to the situation among the pitters, there were no reports of alcohol consumption or tobacco use by the planting workers, which may be indicative of the differing expectations of males and females within the Zulu culture.

Table VI: Health status of pitters and planters.

	% PITTERS (n=31 males)	**%PLANTERS (n=29 females)**
Diabetes	0	0
Hypercholesterolemia	0	0
Heart Disease	0	0
Hypertension	0	17
Common cold/flu	97	62
Tuberculosis	7	7
Pneumonia	0	3
Cholera	10	0
Gastric Flu	20	7
Smokers	60	0
Drinkers (Alcohol)	80	0

PITTING TASK

The following section illustrates the biomechanical, physiological and psychophysical findings associated with manual and semi-mechanised pitting.

BIOMECHANICAL FINDINGS

Spinal Kinematics

All summary data (means and standard deviations) recorded by the LMM during pitting are presented in Tables VII to IX and Figures 12 to 23 and have been divided according to the sagittal, lateral and transverse planes. These results are further subdivided according to the variables measured, specifically maximum extension and flexion, maximum left bend and right bend, maximum left twist and right twist, range of motion, average and maximum velocities and maximum accelerations. In order to facilitate the interpretation of the results, each variable has been analysed independently. Graphical representations and statistical differences are presented where applicable.

Sagittal Plane

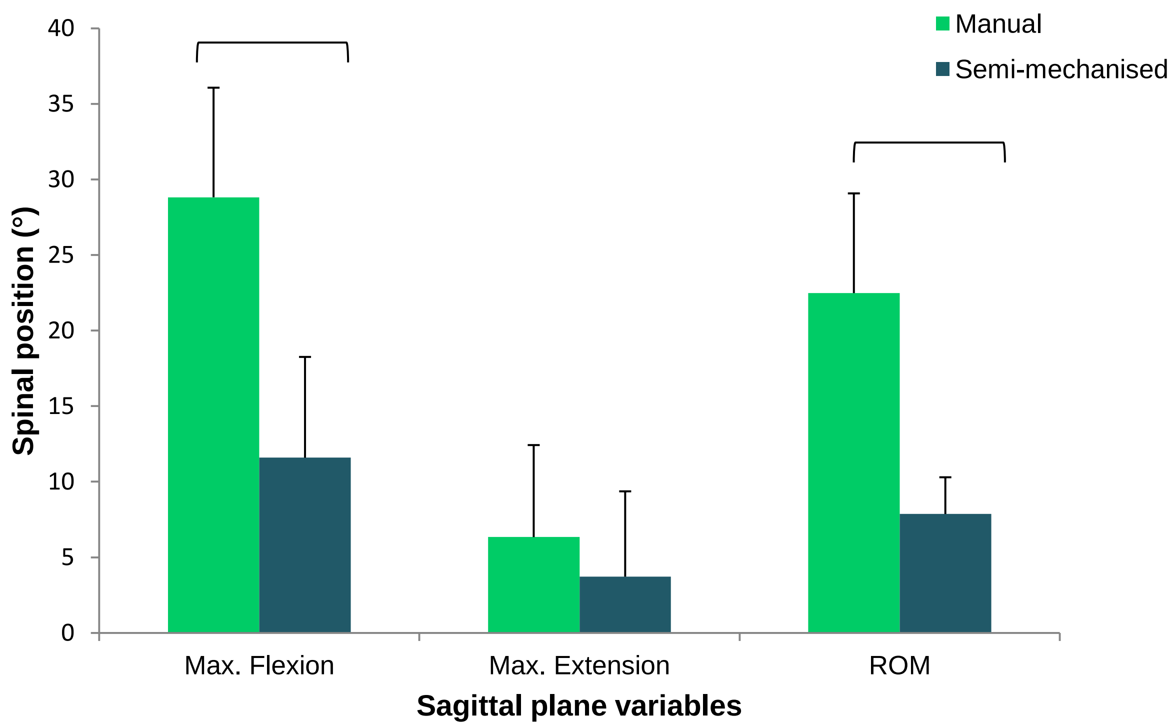
The spinal kinematic responses recorded in the sagittal plane for the pitting phase of manual and semi-mechanised pitting are presented in Table VII.

Table VII: Spinal kinematics of the sagittal plane for manual and semi-mechanised pitting.

	Manual Pitting	Semi-mechanised Pitting
Max. Extension (°)	6.34 (6.09)	3.72 (5.65)
Max. Flexion (°)	28.82 (7.25)	11.59 (6.67)
Sagittal ROM (°)	22.48 (6.6)	7.87 (2.43)
Average Velocity (°.s^{-1})	11.43 (4.02)	2.58 (1.06)
Max. Velocity (°.s^{-1})	76.52 (24.62)	12.92 (3.89)
Max. Acceleration (°.s^{-2})	541.51 (177.28)	94.12 (27.25)

Maximum sagittal extension

During manual pitting, a mean maximum extension of 6.34° was recorded, indicating that the task required a certain degree of spinal flexion to be maintained for the duration of task performance. A similar situation was found during the semi-mechanised pitting, with workers maintaining a maximum extension of 3.72°, which suggests that workers were never fully erect during either method of pitting. Although no significant difference was found between the two methods of pitting for this variable (Figure 12), consideration should be given to the large degree of variability recorded in both cases, as emphasised by the coefficients of variation of 96% and 100% for manual and semi-mechanised pitting respectively. It is evident that, while flexion is maintained during both manual and semi-mechanised task performance, the standard deviations indicate that some workers may reach positions of full extension during manual pitting, and even hyperextension during semi-mechanised pitting.



Where: [bracket] denotes significant difference ($p<0.05$)

Figure 12: Maximum flexion and extension, and sagittal range of motion (°) recorded during manual and semi-mechanised pitting.

Maximum sagittal flexion

Figure 12 highlights the difference in sagittal flexion for the two methods of pitting. The manual method of pitting produced a mean maximum flexion of 28.82°, which was found to be more than double the 11.59° of flexion elicited during semi-mechanised pitting. Consequently, a significant difference of more than 17 degrees of spinal flexion was found between the two methods of task performance.

Maximum sagittal ROM

Despite the fact that the maximum extension values for manual and semi-mechanised pitting were very similar, the substantial difference between the sagittal flexion values considerably impacted the ROMs for each method of pitting. In fact, the ROM of 7.87° associated with semi-mechanised pitting is almost three times ($p<0.05$) lower than the 22.48° ROM generated during the manual technique (Figure 12). Although the variability within the ROMs for each method is fairly high, the coefficients of variation of 29% for manual pitting and 31% for semi-mechanised pitting indicates that the impact of the individual work techniques adopted would be similar for both methods. Figure 13 emphasises the impact of the higher flexion recorded in manual pitting, compared to semi-mechanised, on the total range of motion. It can be seen that the halving of the degree of flexion as a result of the semi-mechanisation, resulted in a significant reduction in range of motion for this method.

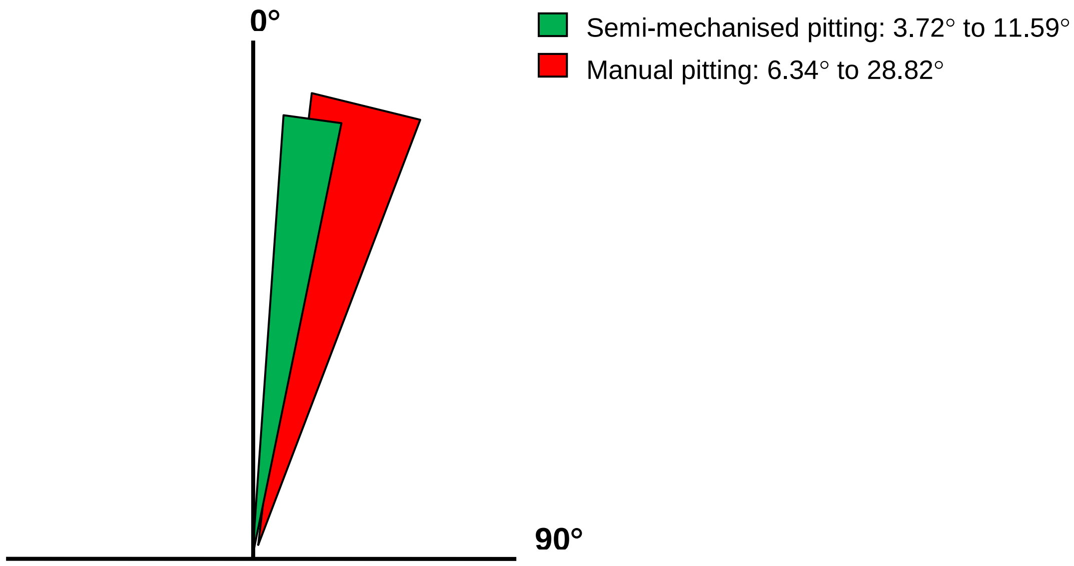
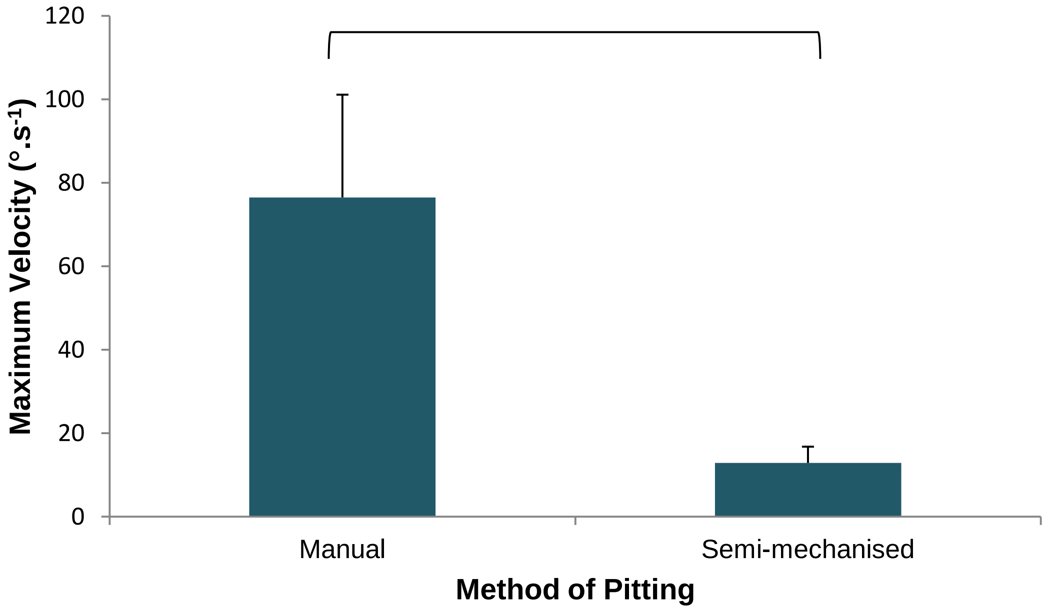


Figure 13: Graphical representation of the sagittal plane ranges of motion during manual and semi-mechanised pitting.

Maximum sagittal velocity

When comparing the maximum velocities produced by the two pitting techniques in the sagittal plane, it was observed that a higher velocity was generated during manual method than the semi-mechanised method. Figure 14 represents the statistically significant difference between the 76.52°.s^{-1} recorded during manual performance, compared to the 12.92°.s^{-1} associated with semi-mechanised pitting. The high standard deviations for both methods, although similar (CVs>30%), indicate the variability in the technique adopted by individual workers to complete each task.

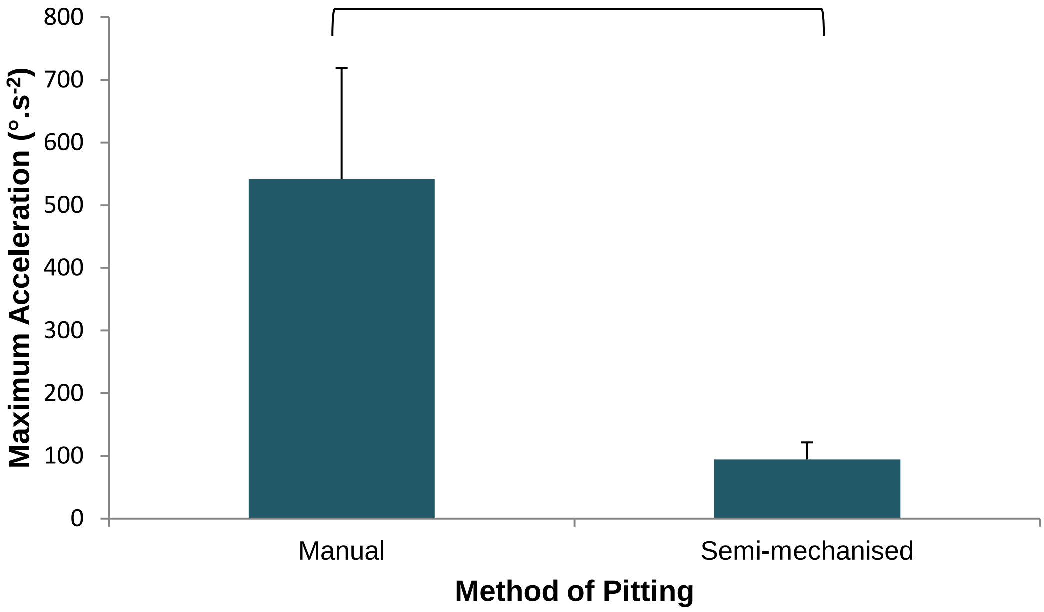


Where: denotes significant difference (p<0.05)

Figure 14: Maximum velocities generated in the sagittal plane during manual and semi-mechanised pitting.

Maximum sagittal acceleration

The acceleration responses recorded in the sagittal plane for manual and semi-mechanised pitting were similar to those found for sagittal velocity. Figure 15 highlights the statistically higher maximum acceleration generated during manual pitting compared to the semi-mechanised method. As was the case for the velocities, the manual pitting acceleration of 541.51°.s^{-2} contrasted greatly from that of only 94.12°.s^{-2} recorded during the semi-mechanised method of task performance.



Where: [bracket] denotes significant difference ($p<0.05$)

Figure 15: Maximum accelerations generated in the sagittal plane during manual and semi-mechanised pitting.

Lateral Plane

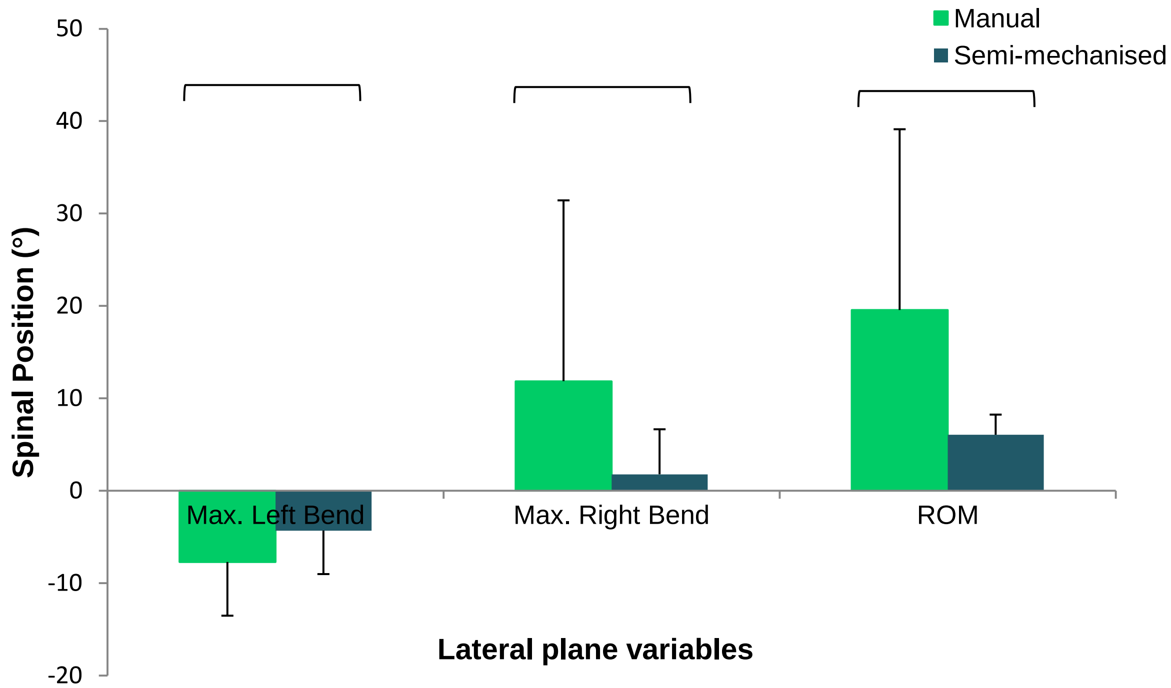
The lateral plane spinal kinematic responses associated with manual and semi-mechanised pitting are presented in Table VIII.

Table VIII: Spinal kinematics of the lateral plane for manual and semi-mechanised pitting.

	Manual Pitting	**Semi-mechanised Pitting**
Max. Left Bend (°)	-7.71 (5.81)	-4.31 (4.71)
Max. Right Bend (°)	11.86 (7.29)	1.78 (4.87)
Lateral ROM (°)	19.56 (5.89)	6.06 (2.18)
Average Velocity (°.s^{-1})	10.61 (3.53)	2.39 (0.93)
Max. Velocity (°.s^{-1})	53.58 (16.67)	11.36 (3.63)
Max. Acceleration (°.s^{-2})	383.11 (132.48)	84.26 (27.13)

Maximum left bend

Referring to Figure 16, manual pitting resulted in a higher mean maximum left bend of -7.71° compared to semi-mechanised pitting, which produced an average of -4.31°. The variability within the left bend data for each method was very high, with the coefficients of variation exceeding 60% in both cases. This would indicate the large impact of individual technique on this variable. However, despite this, a significant difference was observed in maximum left bend between manual and semi-mechanised pitting.



Where: ⌐¬ denotes significant difference ($p<0.05$)

Figure 16: Maximum left bend and right bend, and lateral range of motion for manual and semi-mechanised pitting.

<u>Maximum right bend</u>

The use of the semi-mechanised method of pitting resulted in a reduction in the maximum right bend by almost ten times compared to manual pitting (see Figure 16). The maximum right bend associated with manual pitting averaged 11.86°, whereas the semi-mechanised method generated a value of only 1.78° ($p<0.05$).

<u>Maximum lateral ROM</u>

ROM differences for manual and semi-mechanised pitting are highlighted in Figure 16. The significant reductions in both maximum left bend and right bend associated with semi-mechanised pitting resulted in a large impact on lateral ROM. Initially, ROM associated with manual pitting averaged 19.56° (see Figure 17). When performing the pitting using the semi-mechanised method however, lateral ROM was significantly reduced ($p<0.05$) by almost 70%, to a value of only 6.06°.

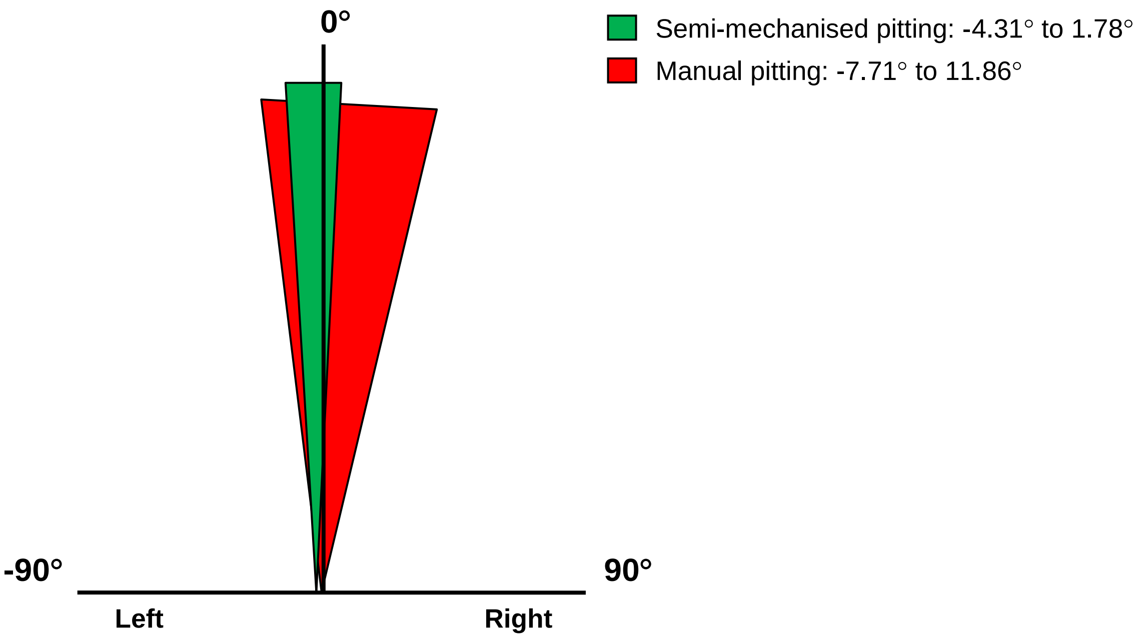
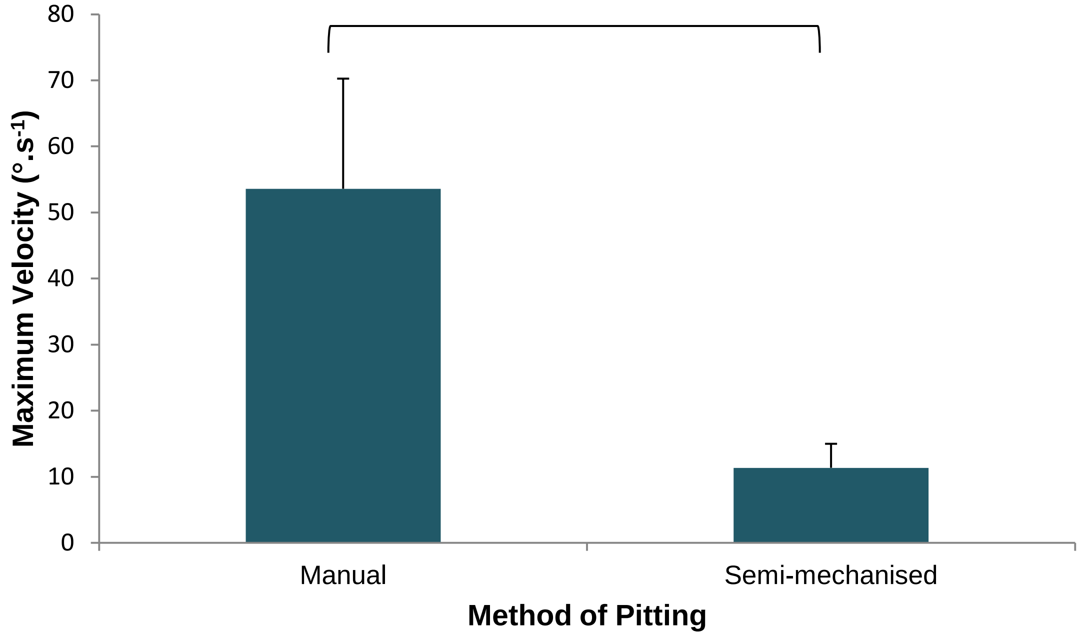


Figure 17: Graphical representation of the lateral plane range of motion during manual and semi-mechanised pitting.

Maximum lateral velocity

When examining the velocities associated with lateral movement, it was found that manual pitting generated a much higher maximum velocity of 53.58°.s^{-1} compared to the 11.36°.s^{-1} produced during semi-mechanised pitting. This difference ($p<0.05$) of 42.22°.s^{-1} is presented graphically in Figure 18. Although a significant difference was found, there was once again a high degree of variability in maximum velocity for both methods of pitting, as indicated by coefficients of variation exceeding 30%.

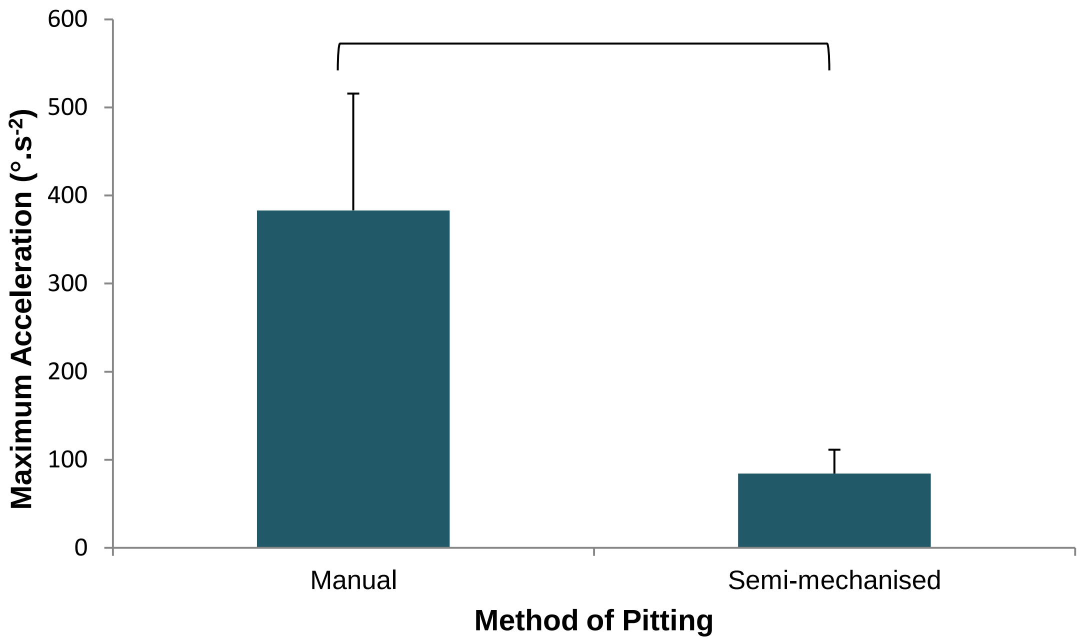


Where: ⌐¬ denotes significant difference ($p<0.05$)

Figure 18: Maximum velocities recorded in the lateral plane during manual and semi-mechanised pitting.

Maximum lateral acceleration

The lateral accelerations associated with manual and semi-mechanised pitting showed a similar trend to the measures of velocity in the lateral plane (Figure 19). In this case, manual maximum acceleration reached 383.11$°.s^{-2}$, although the degree of variability was high (CV=35%). In contrast, semi-mechanised pitting generated a much lower ($p<0.05$) lateral acceleration averaging 84.26$°.s^{-2}$.



Where: ⌐¬ denotes significant difference ($p<0.05$)

Figure 19: Maximum accelerations produced in the lateral plane during manual and semi-mechanised pitting.

Transverse Plane

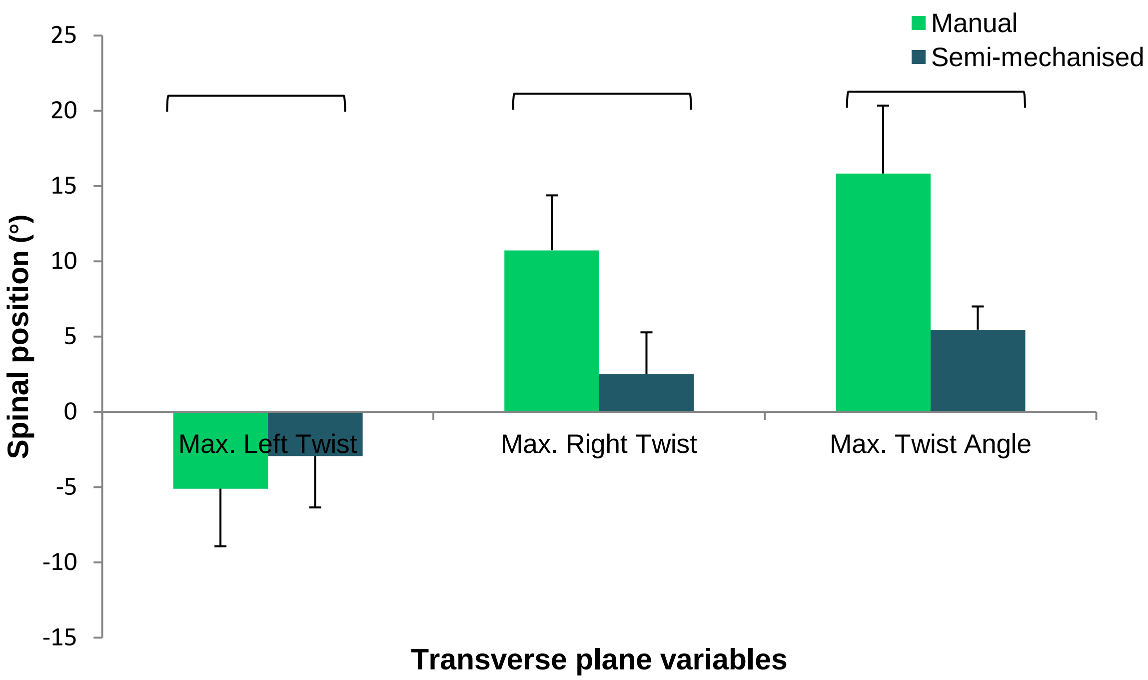
Spinal kinematic responses generated in the transverse plane during manual and semi-mechanised pitting are presented in Table IX.

Table IX: Spinal kinematics of the transverse plane for manual and semi-mechanised pitting.

	Manual Pitting	Semi-mechanised Pitting
Max. Left Twist (°)	-5.11 (3.83)	-2.95 (3.41)
Max. Right Twist (°)	10.72 (3.65)	2.5 (2.77)
Max ROM (°)	15.82 (4.51)	5.45 (1.54)
Average Velocity (°.s^{-1})	8.38 (3.66)	2.4 (2.27)
Max. Velocity (°.s^{-1})	42.53 (15.23)	18.76 (19.48)
Max. Acceleration (°.s^{-2})	304.05 (124.49)	120.84 (25.27)

Maximum left twist

When taking the transverse plane into account (refer to Figure 20), it was observed that manual pitting produced a maximum left twist of -5.11 (±3.83)°. With the introduction of the semi-mechanised method, this variable was reduced by 42% to -2.95 (±3.41)°, denoting a statistical difference for maximum left twist between the two methods. A noteworthy point is the large difference in variability between the performance techniques, with the semi-mechanised method generating a 40% higher degree of variability compared to manual pitting.



Where: ⌐¬ denotes significant difference ($p<0.05$)

Figure 20: Maximum left twist and right twist, and transverse range of motion for manual and semi-mechanised pitting.

Maximum right twist

Figure 20 illustrates the significant difference found between manual and semi-mechanised pitting for maximum right twist. The move from manual to semi-mechanised pitting reduced this variable by four times, from a mean of 10.72° for the former, to only 2.5° for the latter method. Interestingly, the maximum right twist in manual pitting showed a much smaller degree of variability (CV<35%) compared to the left bend, whereas the semi-mechanised method was once again associated with a very large level of variability (CV>100%).

Maximum transverse ROM

Figure 20 highlights the impact of the increased mechanisation associated with pitting performance on the transverse ROM. The large reduction in the maximum right bend from 10.72° for manual pitting, to 2.5° for semi-mechanised pitting, substantially influenced the semi-mechanised transverse ROM. In fact, the ROM of 15.82° associated with the manual method was reduced by 10.37° to that of 5.45° in the semi-mechanised method, a total decrease of 65% ($p<0.05$).

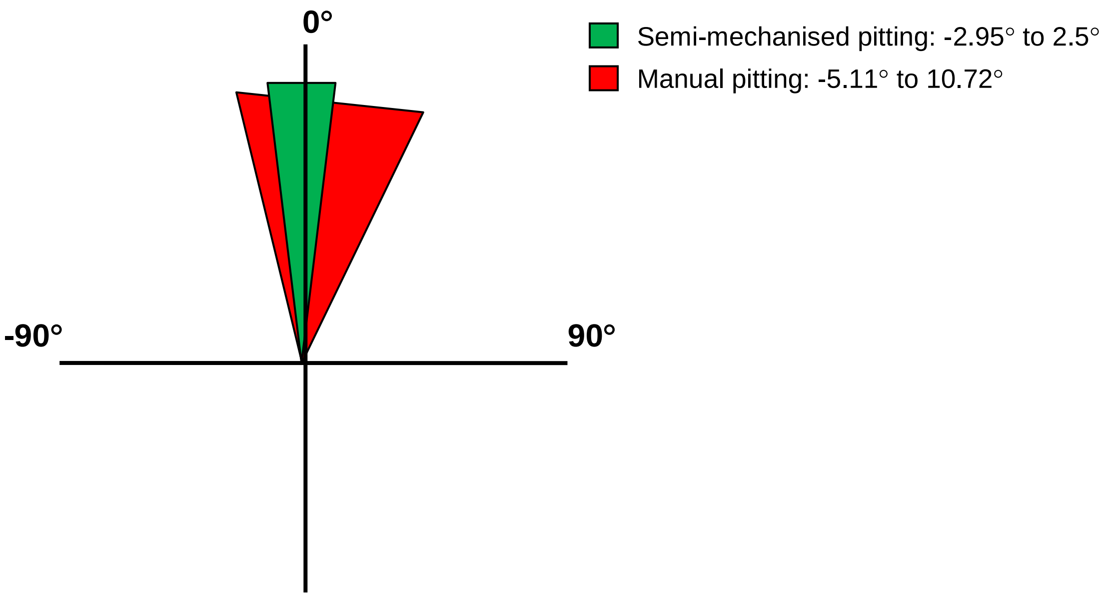
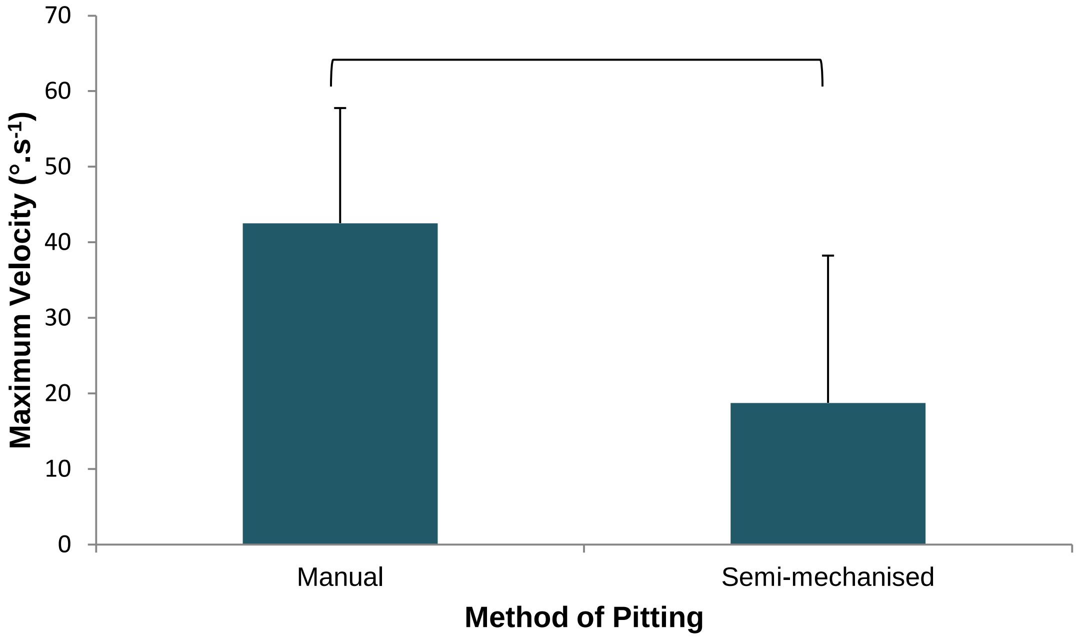


Figure 21: Illustration of the transverse plane range of motion during manual and semi-mechanised pitting.

Maximum transverse velocity

In consideration of the maximum twisting velocities produced by the manual and semi-mechanised pitting techniques, this variable was found to be reduced by more than 50% as a result of the mechanisation (see Figure 22) . The observed decline from 42.53°.s^{-1} to 18.76°.s^{-1} proved to be a statistically significant finding ($p<0.05$). Consideration must be given to the differences in the degree of variability of maximum velocity for manual and semi-mechanised pitting. While variability was high for both techniques in the sagittal and transverse planes, the coefficients of variation were similar. However, in this case the semi-mechanised method was associated with a much higher variability (CV>100%) than the manual method (CV=36%). This indicates the large influence of the auger on the movement pattern within this plane.

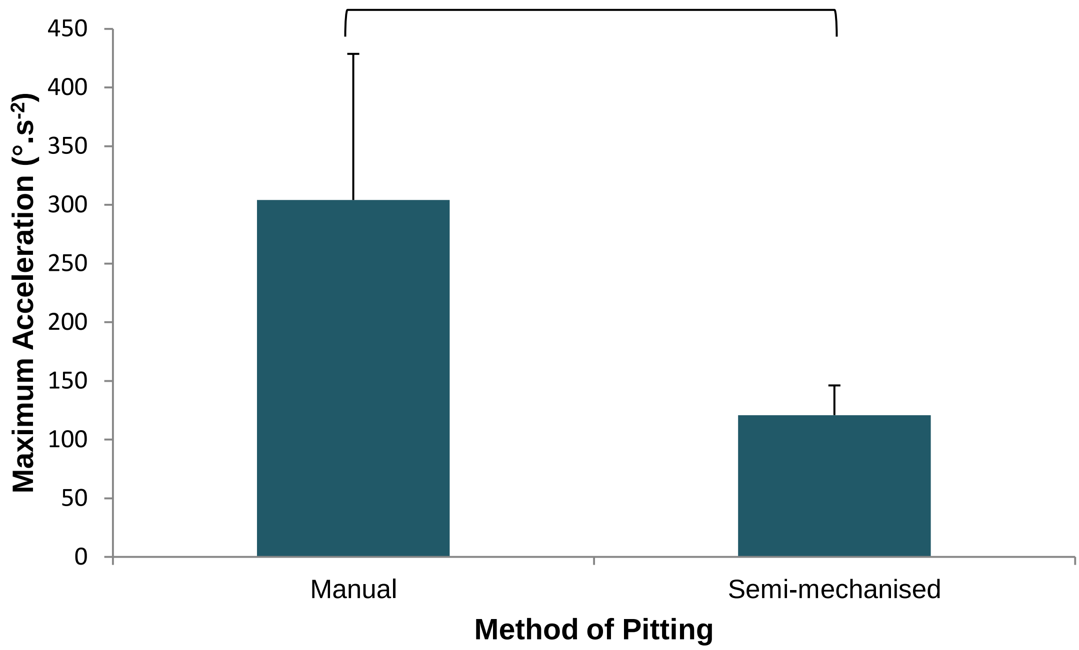


Where: ⌐¬ denotes significant difference ($p<0.05$)

Figure 22: Maximum velocities generated in the transverse plane during manual and semi-mechanised pitting.

Maximum transverse acceleration

The consistent, declining trend associated with all the kinematic variables, as a result of the shift from manual to semi-mechanised pitting, is perpetuated in terms of maximum accelerations in the transverse plane (illustrated in Figure 23). The LMM recorded a mean maximum acceleration of 304.05°.s^{-2} during manual pitting, which was significantly reduced ($p<0.05$) to the 120.84°.s^{-2} corresponding with the semi-mechanised method. The variability results in this case differed to those found for maximum velocity in the transverse plane. In fact, the results were reversed, with manual pitting producing a higher degree of variability (CV>40%) as opposed to the coefficient of variation of 20% observed in semi-mechanised pitting.



Where: ⌐¬ denotes significant difference ($p<0.05$)

Figure 23: Maximum accelerations recorded in the transverse plane during manual and semi-mechanised pitting.

L5/S1 Forces

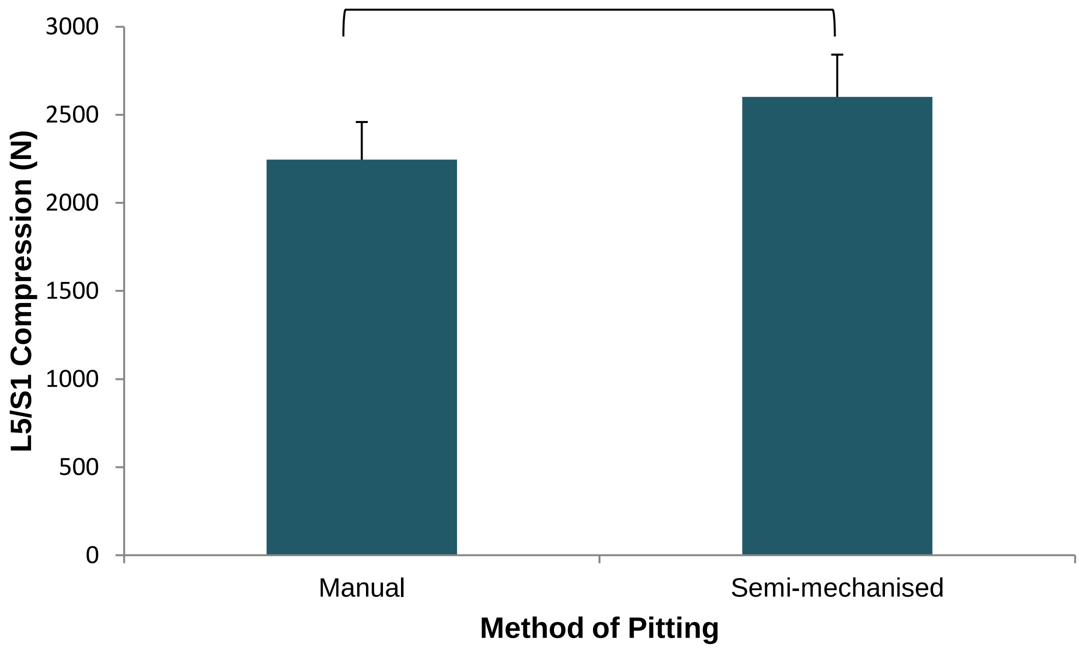
The following section presents the L5/S1 compression and shear force estimates generated by the 3D Static Strength Prediction Programme.

Table X: Sagittal flexion and compression and shear force estimates generated by the 3DSSPP.

	Manual Pitting (n=27)	Semi-mechanised Pitting (n=27)
Compression (N)	2245.37 (213.94)	2601.70 (239.87)
Shear (N)	320.59 (37.64)	360.78 (30.46)

Compression

When considering the estimated compression forces exerted on the spine during manual and semi-mechanised pitting, it was observed that the latter was associated with a higher level of compression, by 356.33 N, compared to the former. In fact, the L5/S1 compression forces reported by the 3DSSPP were 2245.37 N for manual pitting, and 2601.7 N for the semi-mechanised method. When referring to Figure 24, It can be seen that the compression force generated during semi-mechanised pitting proved to be statistically higher than that found for the manual technique. When considering the degree of variability associated with this factor, it was found that both tasks showed very little variability, each producing CVs of below 10%.

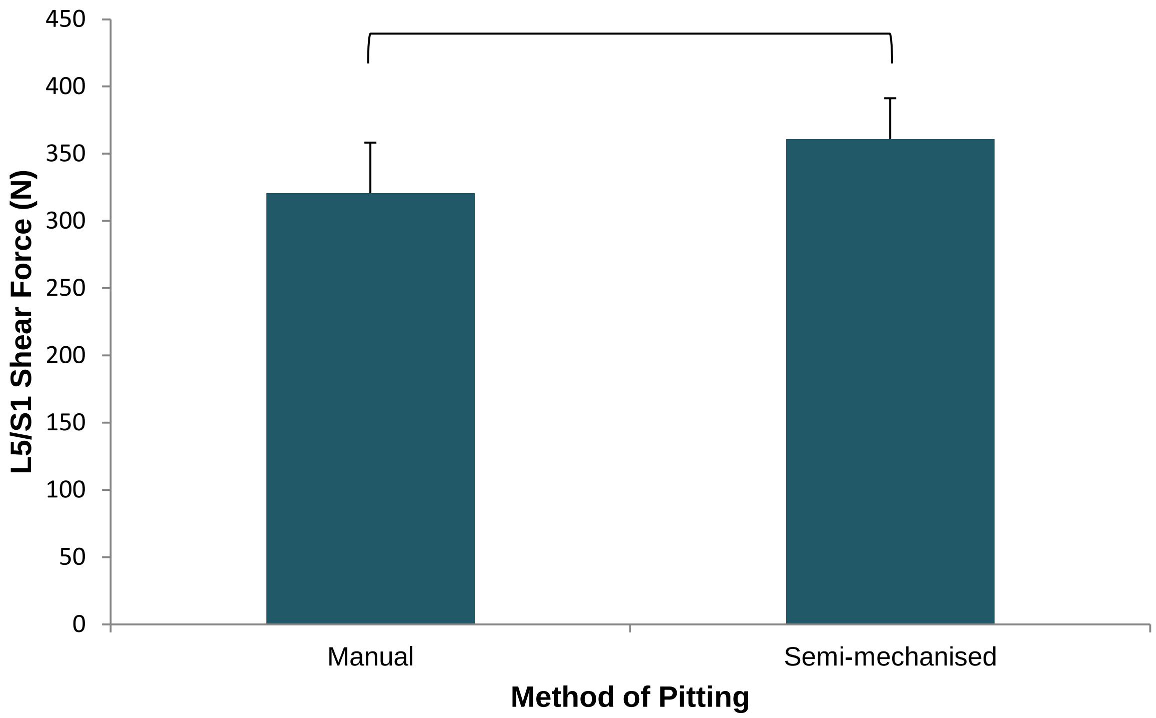


Where: [bracket] denotes significant difference ($p<0.05$)

Figure 24: Compression force estimates at the L5/S1 joint for manual and semi-mechanised pitting.

Shear

Figure 25 highlights the differences in the shear forces for manual and semi-mechanised pitting. In this case, the shear force estimate for semi-mechanised pitting of 360.78 N, was higher ($p<0.05$) than that of the 320.59 N reported for the manual method of task performance, with both methods of pitting associated with low levels of variability (CV<12%). In terms of the ranges in shear for each pitting method, it was found that the 75.28 N associated with manual pitting was within 15 N of the semi-mechanised range of 60.92 N.



Where: [bracket] denotes significant difference ($p<0.05$)

Figure 25: Shear force estimates at the L5/S1 joint for manual and semi-mechanised pitting.

PHYSIOLOGICAL FINDINGS

The physiological results are presented in Table XI and Figures 26 to 28. Heart rate was recorded for the duration of one shift, as well as during six minutes continuous of manual and semi-mechanised pitting. Oxygen consumption and energy expenditure were calculated during the six minutes of manual and semi-mechanised pitting.

Table XI: Heart rate, oxygen consumption and EE recorded during pitting.

	Pitting Assessment Stage		
	Shift duration - Manual (n=26)	**6 min. Manual (n=10)**	**6 min. Mechanised (n=10)**
HR ($bt.min^{-1}$)	109.98 (20.15)	156.74 (11.78)	143.2 (16.84)
VO_2 ($L.min^{-1}$)	*	2.25 (0.39)	1.96 (0.66)
EE ($kcal.min^{-1}$)	*	11.27 (1.96)	9.80 (3.32)

Where: HR = Heart Rate
EE = Energy Expenditure
* = not recorded at this stage

Heart Rate

From the results represented in Table XI and Figure 26, it can be seen that mean heart rate recorded for the duration of a pitting shift was just below 110 bt.min^{-1}. This value included the phases of continuous work, as well as the walking phases between sites and rest periods. When assessing only a continuous work bout, for both manual and semi-mechanised pitting, steady-state heart rates were found to be 157 and 143 bt.min^{-1} respectively. Statistical analyses found no significant difference in heart rate between the two methods of task performance.

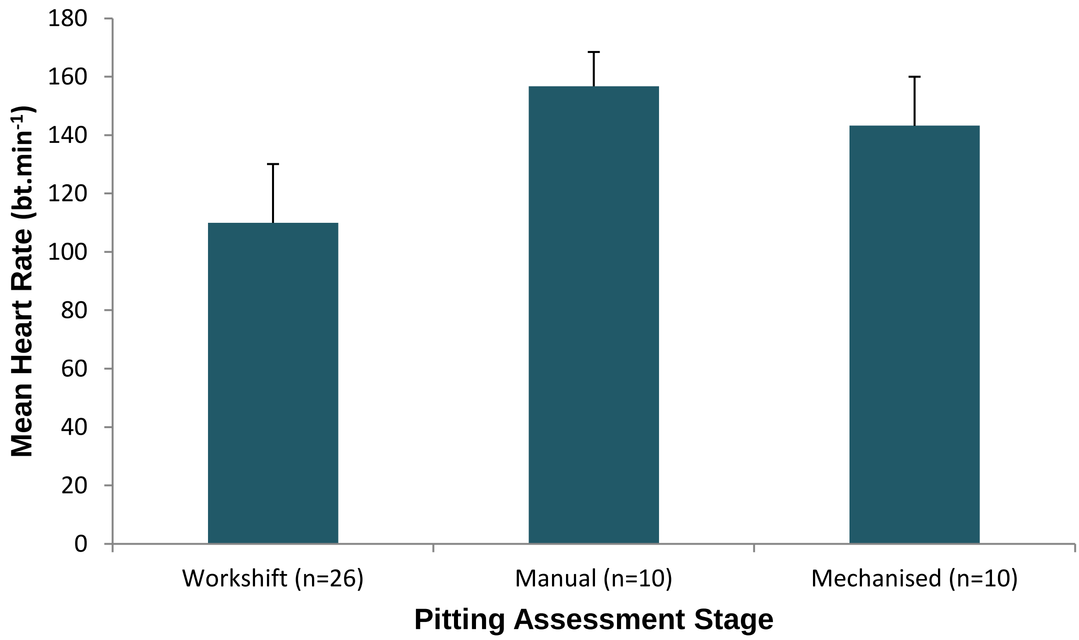


Figure 26: Mean heart rates recorded during the performance of one shift, six minutes of manual, and six minutes of semi-mechanised pitting.

Oxygen Consumption (VO_2)

When considering the volume of oxygen consumed during continuous manual and semi-mechanised pitting (Figure 27), it can be seen that the manual technique, with a recorded value of 2.25 (±0.0.39) L.min^{-1}, was associated with a higher level of oxygen consumption than the semi-mechanised technique, with workers consuming 1.96 (0.66) L.min^{-1}. This difference in steady-state oxygen consumption was not found to be significantly different.

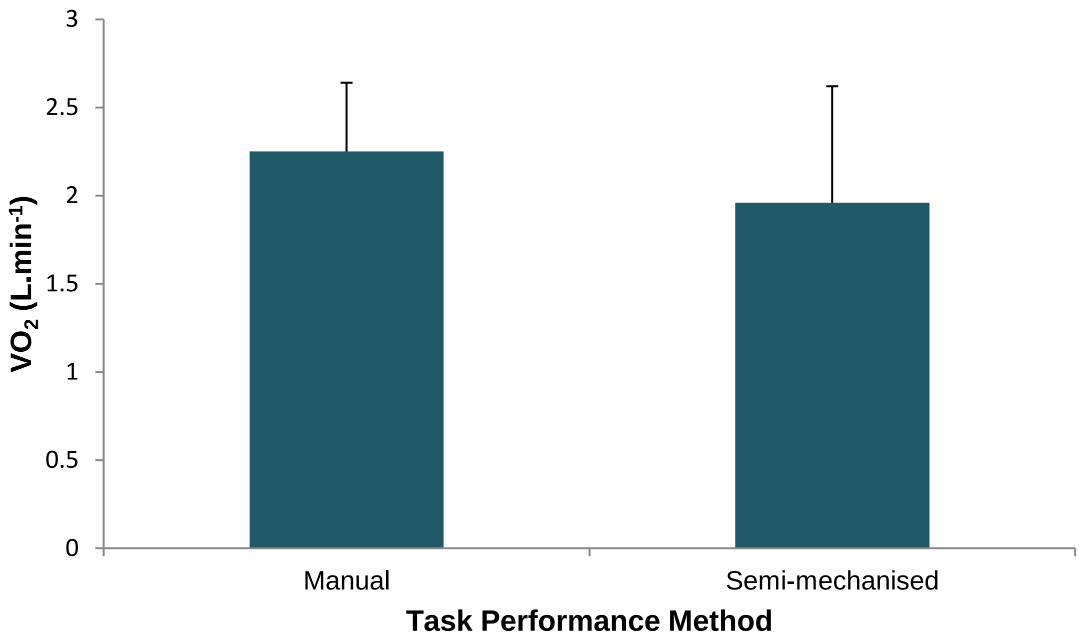


Figure 27: Steady-state oxygen consumption ($L.min^{-1}$) recorded during continuous manual and semi-mechanised pitting.

Energy Expenditure

Using the volume of oxygen (VO_2) consumed per minute (see table XI), steady-state energy expenditure was calculated for the final two minutes of continuous manual and semi-mechanised pitting (Figure 28). Manual pitting reported a higher energy expenditure of 11.27 $kcal.min^{-1}$ compared to the 9.80 $kcal.min^{-1}$ associated with the semi-mechanised task performance, however according to a p-value of 0.22, this difference proved statistically insignificant.

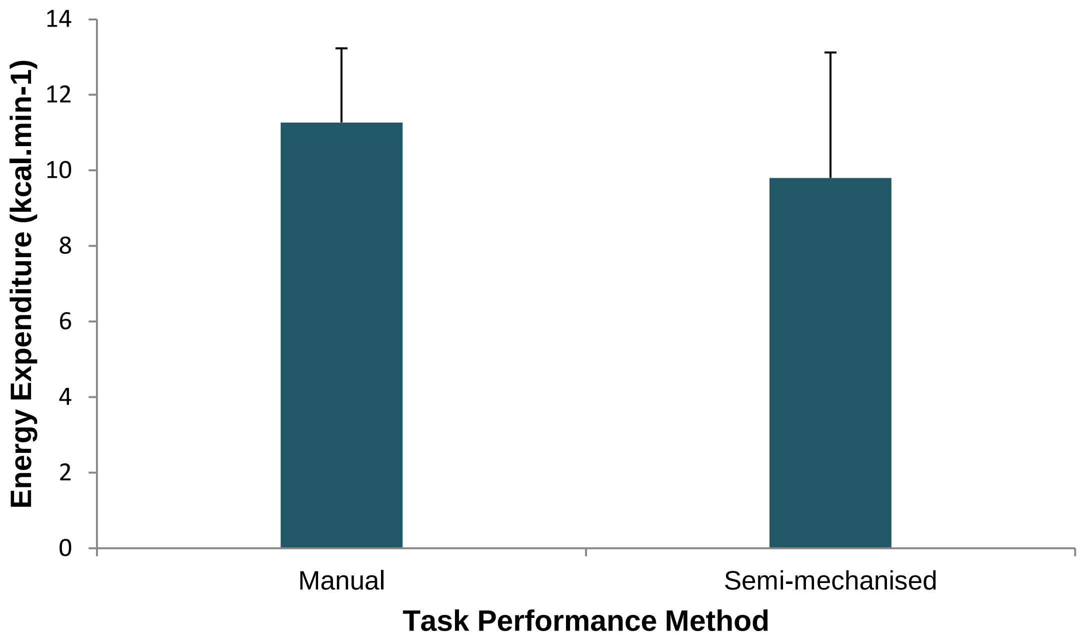


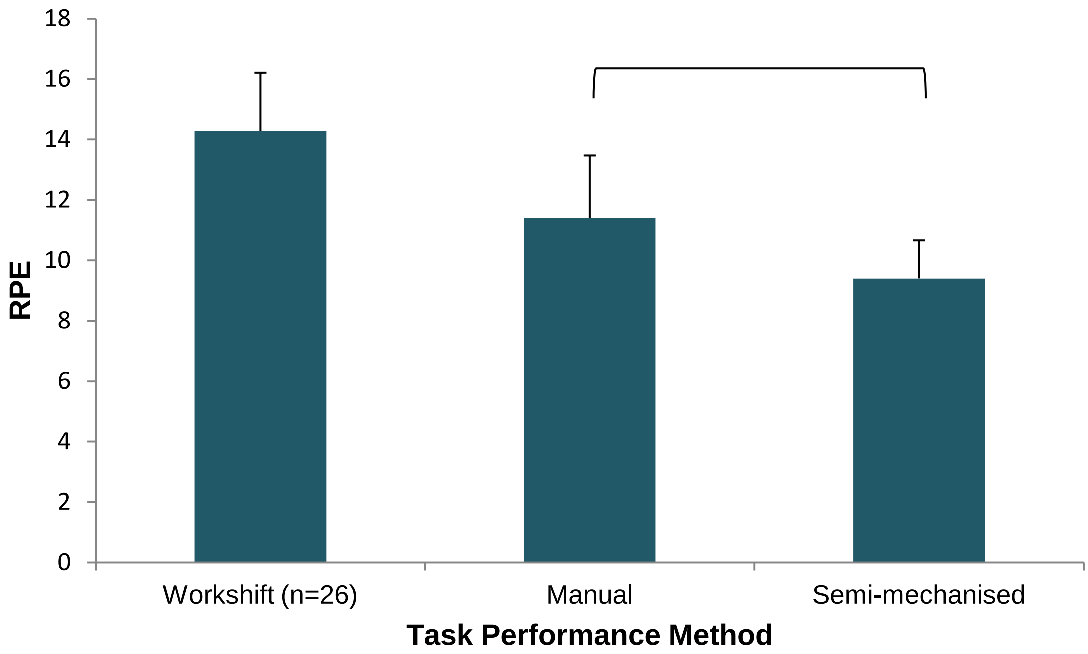
Figure 28: Steady-state energy expenditure recorded during continuous manual and semi-mechanised pitting.

PSYCHOPHYSICAL FINDINGS

Perceptual responses associated with the performance of an entire work shift were assessed using the Body Discomfort Map, and Ratings of Perceived Exertion (RPE). Comparisons of continuous manual pitting to the semi-mechanised pitting were based on RPE findings only.

Ratings of Perceived Exertion

For the assessment of an entire work shift, the mean RPE was found to be 14.28, however, lower ratings of 11.4 and 9.4 were found for the continuous phases of manual pitting and semi-mechanised pitting respectively (Figure 29). After further statistical analysis, mean RPE associated with semi-mechanised pitting was found to be significantly higher than that of manual pitting ($p = 0.015$).



Where: [bracket] denotes significant difference ($p<0.05$)

Figure 29: Mean RPE values recorded for shift duration and continuous manual and semi-mechanised pitting.

Body Discomfort

For the purposes of this study body discomfort was only assessed during the manual pitting work shift. The perceptual ratings of discomfort for the body regions that were rated more than three pitters during the work shift were included for assessment (Table XII). As can be seen, the back region received the most ratings of discomfort, with the lower back receiving complaints from seven workers, the middle back from 12 workers, and the upper back four workers. In terms of the peak intensity of discomfort for this region, it was found that values ranged between 4.3 for the lower back, and 4.7 for the upper back, which would indicate moderate levels of discomfort. When considering the other body regions of discomfort, the shoulders were identified by seven workers, with a moderate intensity of 4.13. The remaining regions where discomfort was acknowledged during manual pitting were the neck, forearms and biceps, all of which were identified by a total of three individuals.

Table XII: Number of individuals perceiving discomfort at different body sites and their average peak intensities recorded during a manual pitting shift.

Location	Number of Workers	Mean Peak Intensity
Lower back	7	4.3
Middle back	12	4.4
Upper back	4	4.7
Neck	3	4.5
Forearms	3	3
Biceps	3	4.5
Shoulders	7	4.13

PLANTING TASK

The following section illustrates the biomechanical findings associated with manual and semi-mechanised planting, as well as the physiological and psychophysical demands imposed on workers during manual planting. These results are structured in the same manner as those presented for the pitting task.

BIOMECHANICAL FINDINGS

Spinal Kinematics

The spinal kinematic means and standard deviations recorded by the LMM during planting are presented in Tables XIII to XV And Figures 30 to 41. As in the case of the pitting task, the subdivisions are structured according to the three cardinal planes and the variables of interest.

Sagittal Plane

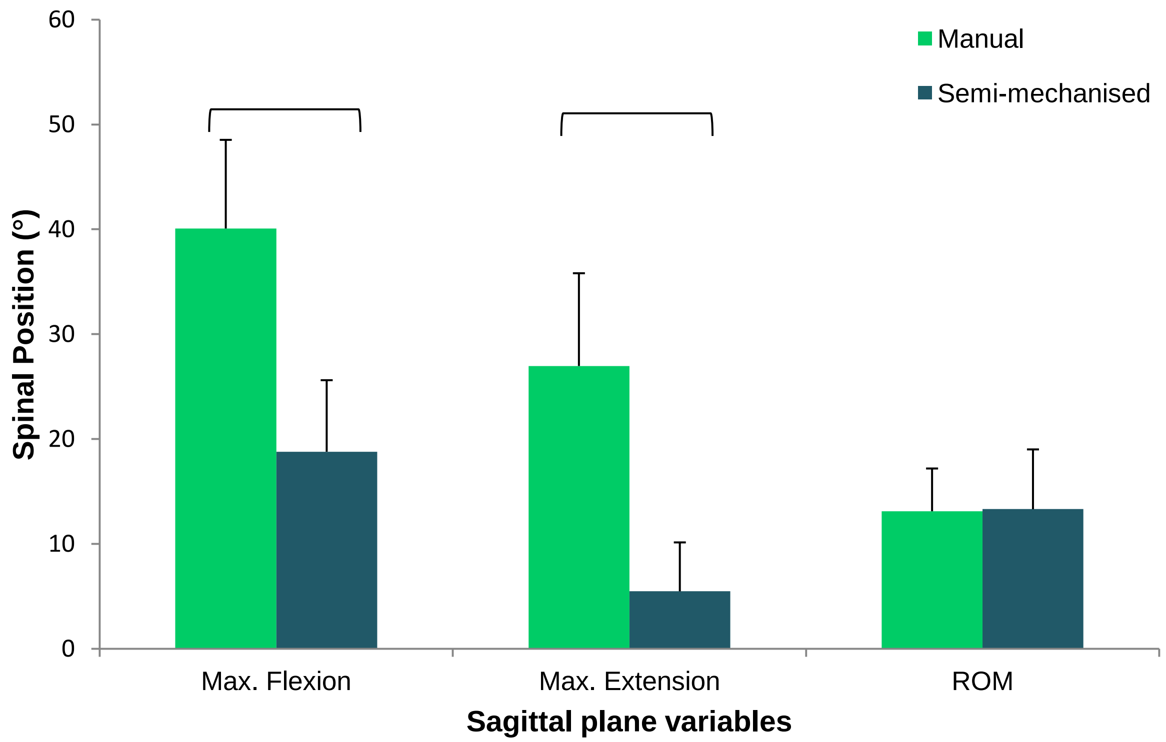
The spinal kinematic responses recorded in the sagittal plane for manual and semi-mechanised planting are presented in Table XIII.

Table XIII: Spinal kinematics of the sagittal plane for manual and semi-mechanised planting.

	Manual Planting	**Semi-mechanised Planting**
Max. Extension (°)	26.97 (8.85)	5.48 (4.67)
Max. Flexion (°)	40.08 (8.46)	18.8 (6.82)
Sagittal ROM (°)	13.12 (4.08)	13.32 (5.7)
Average Velocity (°.s^{-1})	2.23 (0.93)	4.46 (1.91)
Max. Velocity (°.s^{-1})	19.24 (5.35)	24.51 (10.75)
Max. Acceleration (°.s^{-2})	130.94 (30.7)	159.35 (74.67)

<u>Maximum sagittal extension</u>

Manual planting was associated with a maximum extension of 26.97°, which would indicate that the workers were never in an entirely erect position for the duration of task performance. A similar case was found for semi-mechanised planting, although the maximum extension value of 5.48° proved less extreme compared to the manual method. As a result of this large difference, mean maximum extension for semi-mechanised planting was statistically lower ($p<0.05$) than that of manual planting (Figure 30). Interestingly, the degree of variability within the manual planting data, although fairly high (CV=32%), was 53% lower than that of the semi-mechanised method. The wide range (9.34°) in maximum extension for semi-mechanised planting suggests that, while some workers remained in sagittal flexion during task performance, otherwise were almost fully upright.



Where: ⎡‾‾‾⎤ denotes significant difference ($p<0.05$)

Figure 30: Maximum flexion and extension, and sagittal range of motion (°) recorded during manual and semi-mechanised planting.

<u>Maximum sagittal flexion</u>

The maximum sagittal flexion recorded for the two planting methods are presented in Figure 30 Manual task performance had a considerably high level of flexion, which averaged 40.08°, however, this was lowered by more than half, to a maximum flexion of 18.8° during semi-mechanised planting. This equates to an overall reduction of 21.28° ($p<0.05$).

Maximum sagittal ROM

The maximum ROM for manual and semi-mechanised planting were very similar ($p>0.05$) in the sagittal plane, with a recorded mean of 13.12° for the former, and 13.32° for the latter (refer to Figure 30). However, despite these similarities, the significantly different maximum flexion and extension values resulted in differing positions of each ROM within the sagittal plane. When referring to Figure 31, it can be seen that the lowest point of flexion for semi-mechanised planting (18.8°), was still 8.17° above the highest point of flexion reached during manual planting (26.97°).

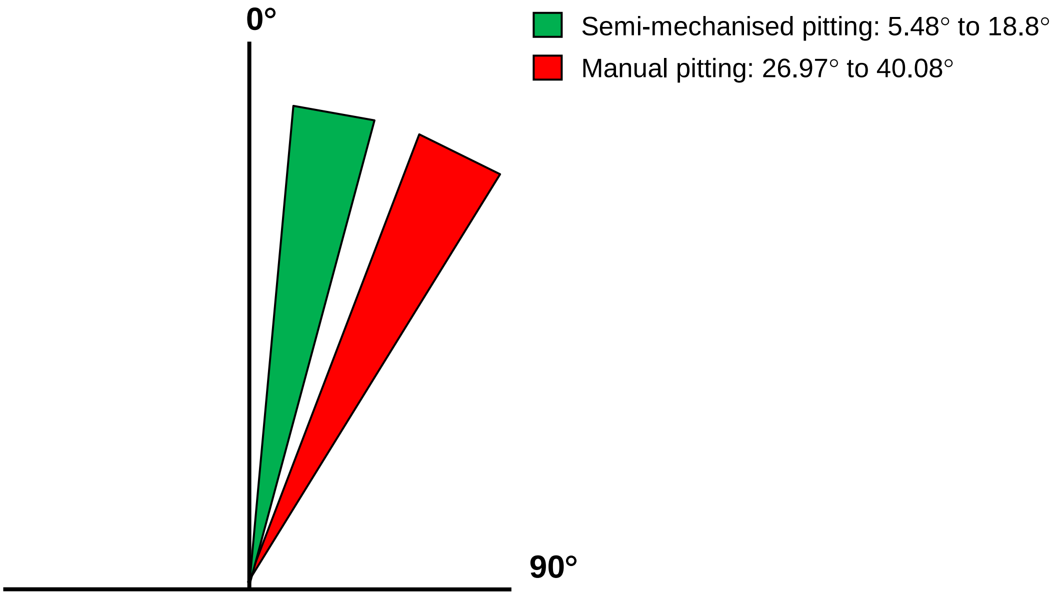
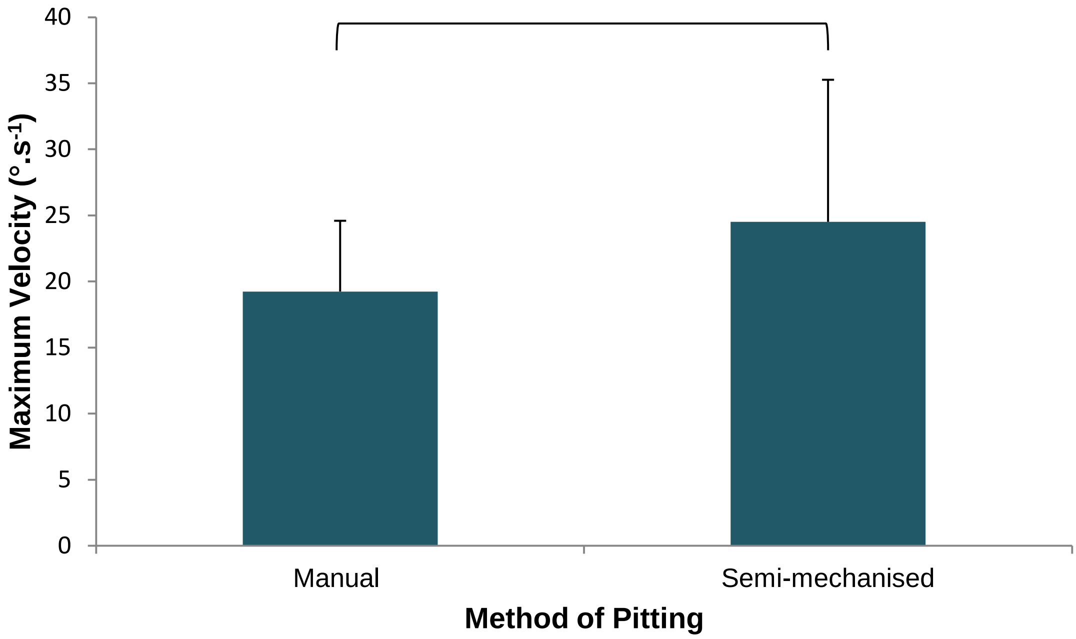


Figure 31: Visual representation of the sagittal plane ranges of motion generated during manual and semi-mechanised planting.

Maximum sagittal velocity

When considering the maximum velocities recorded during the two methods of planting (see Figure 32), it was observed that the move from manual to semi-mechanised task performance resulted in a significant increase of 20% in maximum velocity, from 19.24°.s^{-1} to 24.51°.s^{-1}. In combination with this increase, there was a change in the variability associated with task performance, with an increase of 17% associated with semi-mechanised planting. This would suggest that the new method of planting was influenced by individual work technique to a greater degree than that of manual task performance.

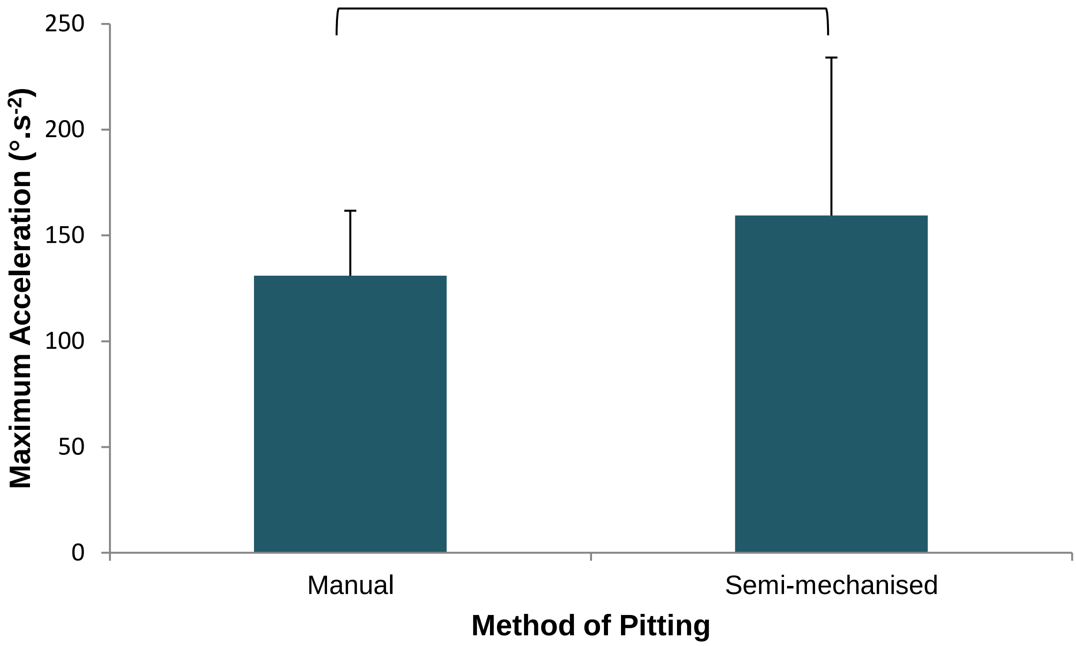


Where: ⌐¬ denotes significant difference ($p<0.05$)

Figure 32: Maximum velocities generated in the sagittal plane during manual and semi-mechanised planting.

Maximum sagittal acceleration

When referring to Figure 33, it was found that, as in the case of the peak velocities, maximum sagittal acceleration increased when moving from manual planting to the semi-mechanised method. The average of 130.94$°.s^{-2}$ for the manual technique, gained an additional 28.41$°.s^{-2}$ to reach a mean maximum acceleration of 159.35$°.s^{-2}$ ($p<0.05$) during semi-mechanised planting. The differences in individual performance associated with the new method of planting did however result in a large increase in variability when compared to the manual technique. The coefficient of variation of 23% for manual planting, was in fact doubled to 46% with regards to the semi-mechanised method.



Where: ⌐¬ denotes significant difference ($p<0.05$)

Figure 33: Maximum accelerations generated in the sagittal plane during manual and semi-mechanised planting.

Lateral Plane

The lateral plane spinal kinematic responses associated with manual and semi-mechanised planting are presented in Table XIV.

Table XIV: Spinal kinematic responses recorded in the lateral plane for manual and semi-mechanised planting.

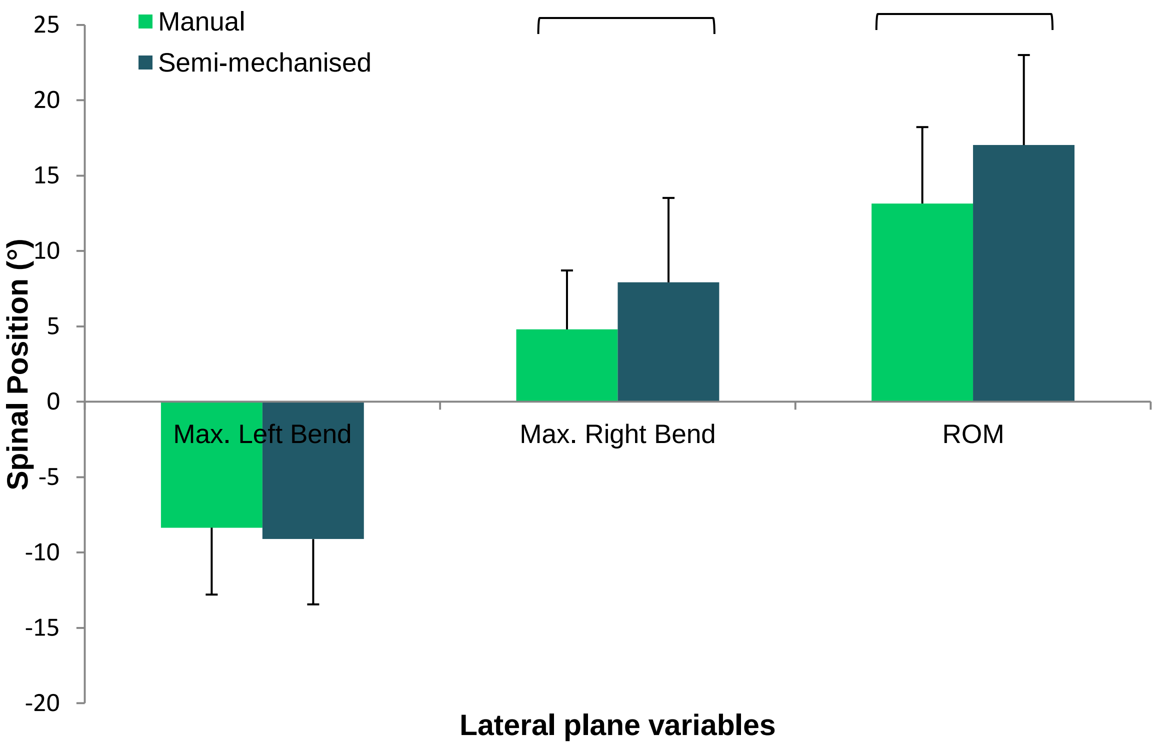
	Manual Planting	**Semi-mechanised Planting**
Max. Left Bend (°)	-8.35 (4.44)	-9.11 (4.33)
Max. Right Bend (°)	4.8 (3.91)	7.92 (5.6)
Lateral ROM (°)	13.15 (5.07)	17.03 (5.97)
Average Velocity (°.s^{-1})	2.48 (1.11)	6.02 (2.02)
Max. Velocity (°.s^{-1})	18.99 (5.79)	27.13 (9.43)
Max. Acceleration (°.s^{-2})	126.06 (41.04)	146.59 (43.27)

Maximum left bend

The differences in maximum left bend are highlighted in Figure 34. Manually, the planting task generated a mean maximum left bend of -8.35°, which proved slightly lower ($p>0.05$) than that of -9.11° found for semi-mechanised planting. The high standard deviations for both techniques indicate the variability associated with task performance, in fact, maximum left bend for both manual and semi-mechanised planting was associated with a range of more than 8°.

Maximum right bend

In terms of maximum right bend, the semi-mechanised task produced a higher degree of movement, averaging 7.92°, compared to the 4.8° recorded during manual planting. This difference of 3.12° was found to be statistically different (refer to Figure 34).



Where: denotes significant difference ($p<0.05$)

Figure 34: Maximum left bend and right bend, and lateral range of motion for manual and semi-mechanised planting.

Maximum lateral ROM

The combined effect of a lower maximum left bend and lower maximum right bend generated during manual planting, resulted in a smaller range of motion in the lateral range when compared to the semi-mechanised method, as highlighted in Figure 34. The 13.15° ROM associated with manual planting, was increased ($p<0.05$) by 3.88° as a result of the semi-mechanisation, producing a lateral ROM of 17.03°. The overlap of these ranges is presented graphically in Figure 35.

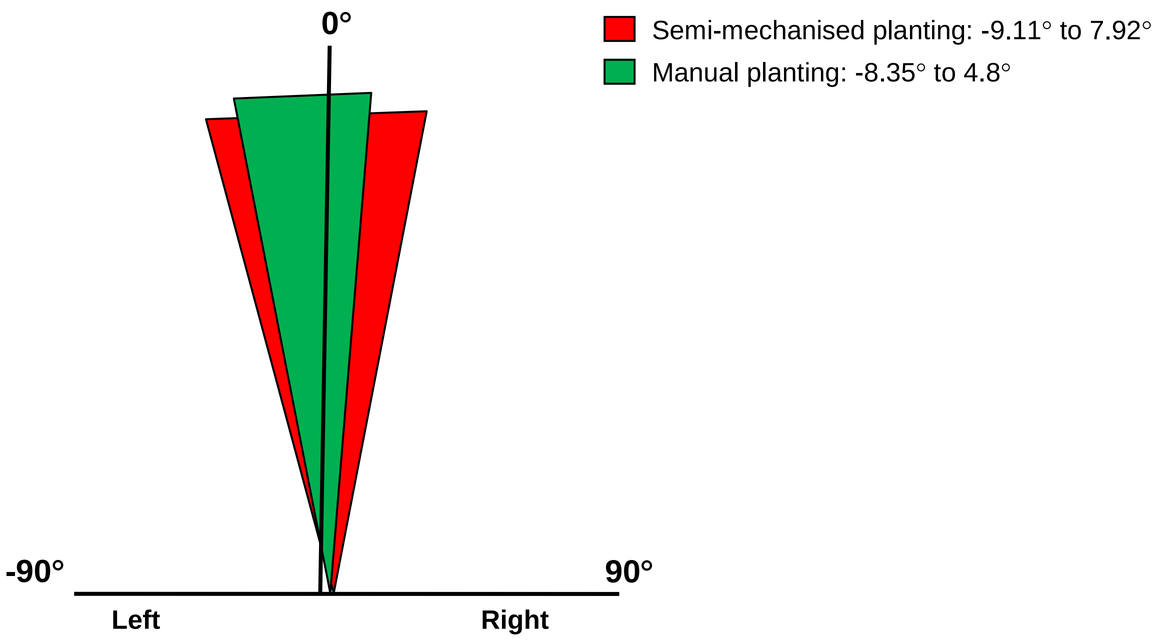
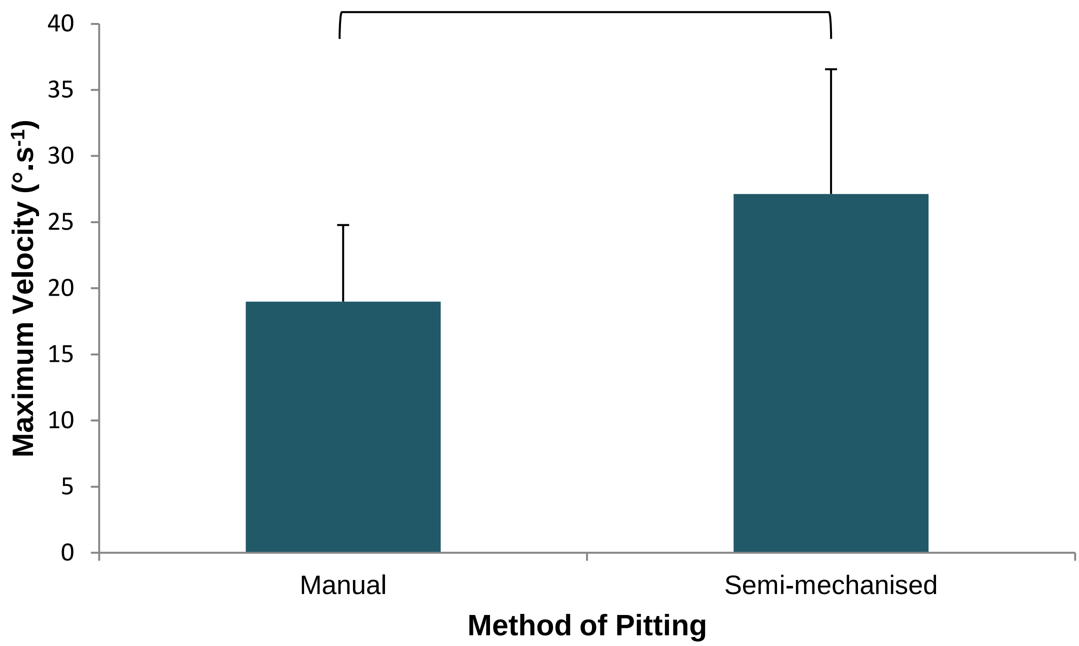


Figure 35: Visual representation of the differences in lateral ROM for manual and semi-mechanised planting.

Maximum lateral velocity

When considering Figure 36, it can be seen that maximum lateral velocity is associated with an increasing trend when moving from the manual to semi-mechanised planting technique. In this case, the introduction of new technology saw an increase in velocity from 18.99°.s^{-1} to 27.13°.s^{-1}, a total increase of 43% ($p<0.05$). The variability within the data, although fairly high, was similar for both the manual (CV=31%) and semi-mechanised (35%) planting methods, indicating that the changes in task design did not significantly impact the differences generated by individual performance for this particular variable.

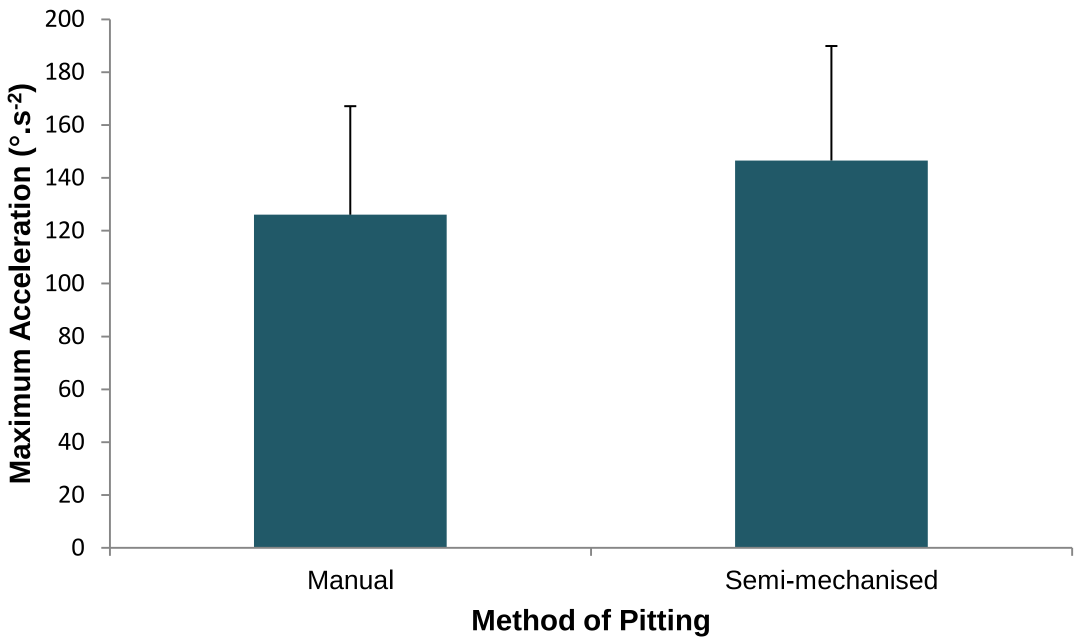


Where: ⌐¬ denotes significant difference ($p<0.05$)

Figure 36: Maximum velocities recorded in the lateral plane during manual and semi-mechanised planting.

Maximum lateral acceleration

Figure 37 emphasises the difference in maximum lateral acceleration for manual and semi-mechanised planting. As in the case of velocity, the introduction of technology to task performance resulted in an increase ($p<0.05$) from the manually generated 126.96°.$s^{-2,}$ to the 146.59°.s^{-2} produced during semi-mechanised planting. Once again, the degree of variability for each performance method was similar, although both were associated coefficients of variation exceeding 30%.



Where: ⌐ denotes significant difference ($p<0.05$)

Figure 37: Maximum accelerations generated in the lateral plane during manual and semi-mechanised planting.

Transverse Plane

LMM measures recorded in the transverse plane for manual and semi-mechanised planting are highlighted in Table XV.

Table XV: Spinal kinematic measures from the transverse plane for manual and semi-mechanised planting.

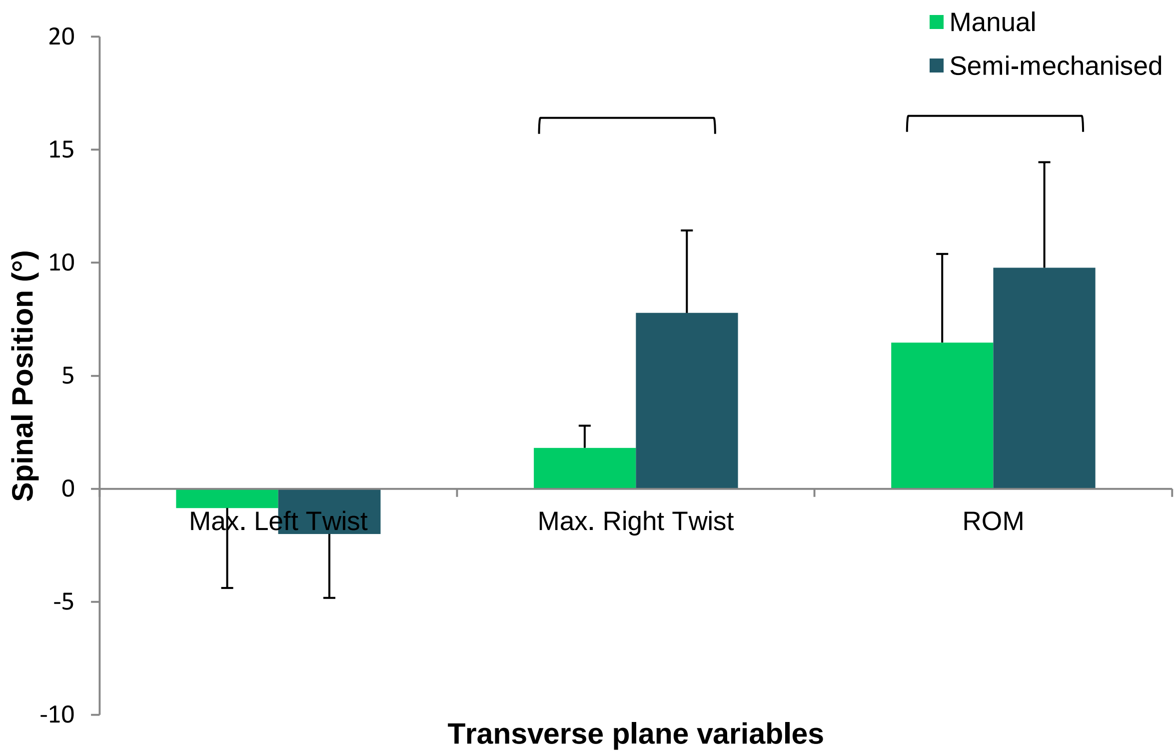
	Manual Planting	**Semi-mechanised Planting**
Max. Left Twist (°)	-0.85 (3.54)	-2.0 (2.83)
Max. Right Twist (°)	5.62 (3.78)	7.78 (3.65)
Max Twist Angle (°)	6.47 (3.92)	9.78 (4.67)
Average Velocity (°.s^{-1})	1.28 (0.66)	3.50 (1.28)
Max. Velocity (°.s^{-1})	14.18 (5.39)	21.25 (6.73)
Max. Acceleration (°.s^{-2})	108.94 (32.65)	141.97 (36.77)

Maximum left twist

When focusing on the transverse plane (refer to Figure 38), it was found that the angle of maximum left twist for manual and semi-mechanised planting differed by only 1.15°. As a result, the maximum left twist of -2.0° recorded for semi-mechanised planting was not found to be significantly higher than that of the -0.85° produced during manual task performance. However, the range within this variable for manual planting was found to be higher than that for semi-mechanised planting, with values of 7.08° and 5.66° respectively.

Maximum right twist

The difference between manual and semi-mechanised planting with respect to maximum right twist is presented in Figure 38. In this case, the semi-mechanised task generated an angle of 7.78 (±3.65)°, which proved to be higher ($p<0.05$) than that of 5.62 (±3.78)° found for manual planting. In this case, the introduction of new technology resulted in an increase in maximum right twist by almost 40%.



Where: ⌐¬ denotes significant difference ($p<0.05$)

Figure 38: Maximum left twist and right twist, and transverse range of motion for manual and semi-mechanised planting.

Maximum transverse ROM

Comparisons of transverse ROM for manual and semi-mechanised planting can be seen in Figure 38 and 39. Despite the fact that no significant difference was found between the maximum left twists for the two planting methods, the semi-mechanised ROM, which averaged 9.78°, proved to be statistically higher than that of the 6.47° recorded during manual planting, equating to an increase of over 50%. The variability reported within the ranges of motion for each method of planting proved to be relatively high for both techniques, with the coefficient of variation exceeding 45% in each case.

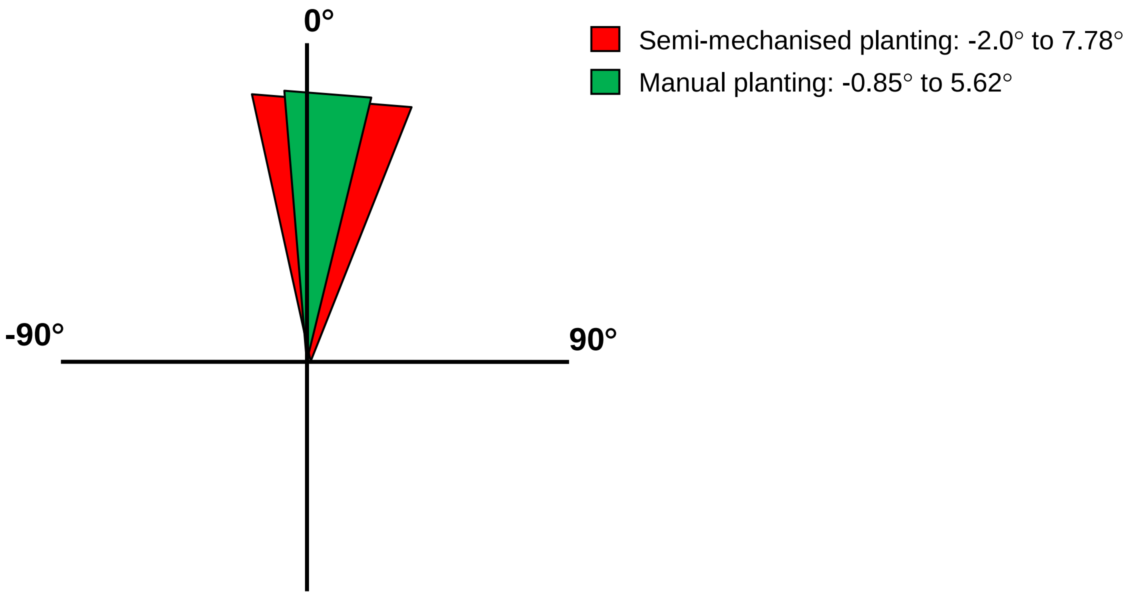
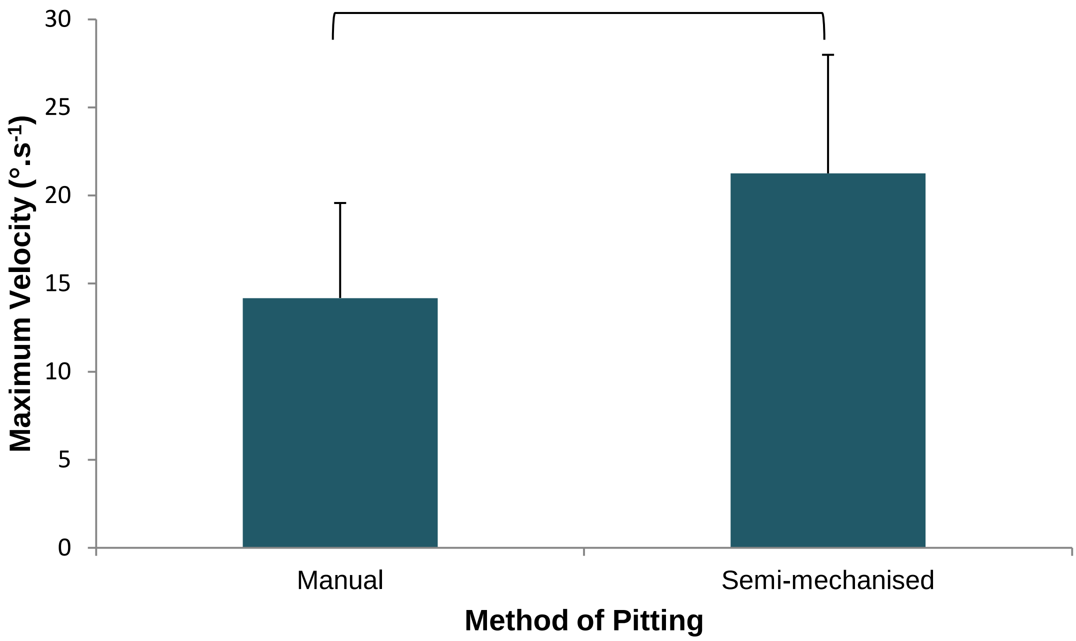


Figure 39: Illustration of the transverse plane range of motion during manual and semi-mechanised planting.

Maximum transverse velocity

In consideration of the maximum twisting velocities produced by the manual and semi-mechanised planting methods, it can be seen that the introduction of new technology was associated with an increase in the maximum velocity (see Figure.40). This increase of $7.07°.s^{-1}$ from $14.18°.s^{-1}$ to $21.25°.s^{-1}$, proved to be a statistically significant finding. Although the variability was high in both cases, the introduction of the semi-mechanised task showed to decrease the extent of the variability associated with maximum transverse velocity, reducing the coefficient of variation from 38% to 31%.

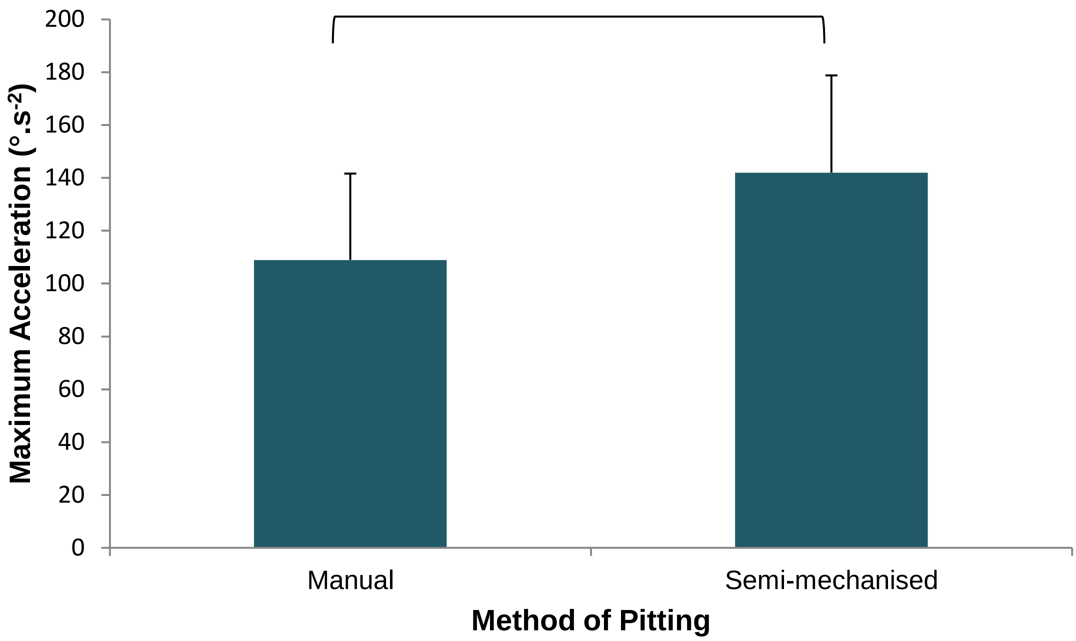


Where: ⌐ ¬ denotes significant difference ($p<0.05$)

Figure 40: Maximum velocities generated in the transverse plane during manual and semi-mechanised planting.

Maximum transverse acceleration

The maximum transverse acceleration showed a similar trend to maximum velocity when moving from manual to semi-mechanised planting, with a significant increase from 108.94°.s^{-2} to 141.97°.s^{-2} (see Figure41). The range of 65.3°.s^{-2} for maximum acceleration during the manual method was very similar to that corresponding with semi-mechanised planting, which equated to 73.54°.s^{-2}.



Where: ⌐ ¬ denotes significant difference ($p<0.05$)

Figure 41: Maximum accelerations recorded in the transverse plane during manual and semi-mechanised planting.

L5/S1 Forces

Photographs uploaded to the 3D Static Strength Prediction Program were used to estimate the compression and shear forces exerted on the lower back during manual planting. The same analyses were not conducted for the semi-mechanised technique, due to the fact that the exact task design had not yet been confirmed at the time of data collection, therefore additional weights could not be included. The mean compression recorded for the manual planting technique was 2456.2 (±275.11), whereas the mean shear force generated by the 3DSSPP was 508.4 (±40.11).

PHYSIOLOGICAL FINDINGS

As the semi-mechanised planting design had not been completed at the time of data collection, the following section highlights only the responses recorded during one work shift, and those associated with six minutes of continuous manual planting. The applicable mean heart rates, and oxygen consumption ($L.min^{-1}$) and energy expenditure ($kcal.min^{-1}$) values are presented in Table XVI.

Table XVI: Heart rate, oxygen consumption and EE recorded during manual planting

	Planting Assessment Stage	
	Shift duration - Manual (n=29)	**6 min. Manual (n=10)**
Mean HR ($bt.min^{-1}$)	100.98 (8.21)	114.17 (12.05)
VO_2 ($L.min^{-1}$)	*	0.8 (0.09)
EE ($kcal.min^{-1}$)	*	3.99 (0.45)

Where: HR = Heart Rate
EE = Energy Expenditure
* = not recorded during this stage

Heart Rate

The mean heart rate recorded for the shift duration was found to be 100.98 $bt.min^{-1}$. This average included measures taken during all stages of the work shift, therefore continuous work periods, as well as walking between sites, and rest periods. Steady-state heart rate, measured after six minutes of continuous manual planting was found to be slightly higher, with a value of 114.17 $bt.min^{-1}$ (Figure 42).

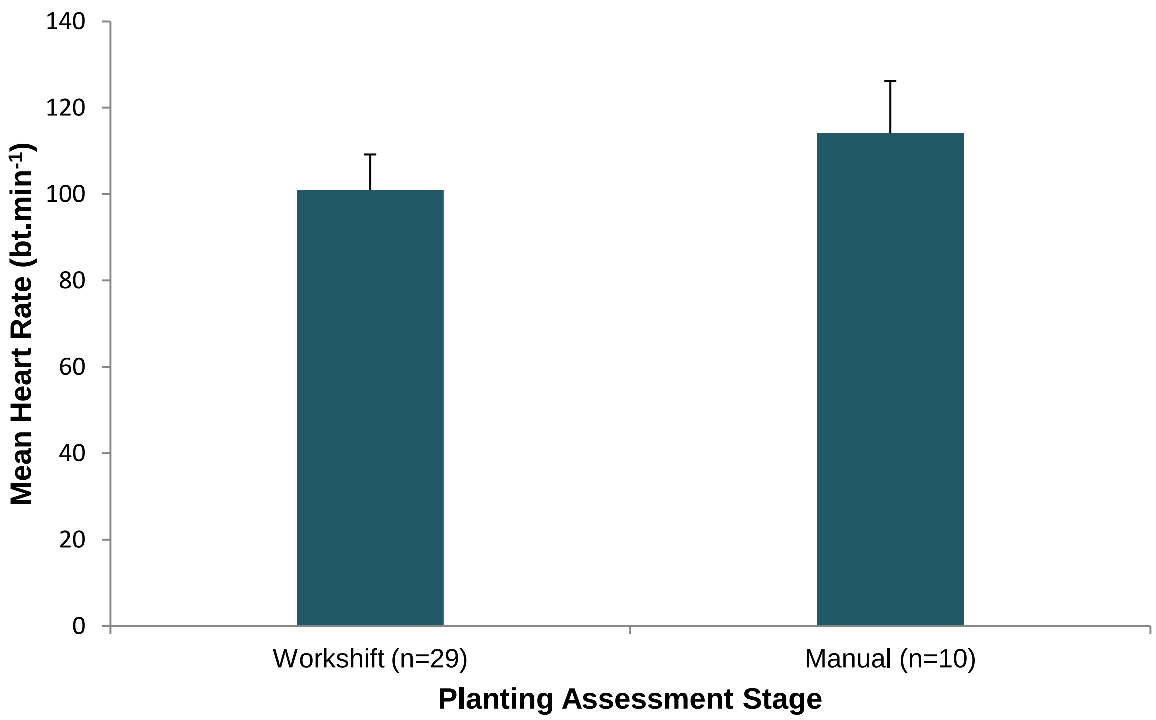


Figure 42: Mean heart rate responses for the duration of a work shift and six minutes of manual planting.

Energy Expenditure

Oxygen consumption values, recorded during the final two minutes of the continuous manual planting assessment stage, were used to calculate mean energy expenditure (Table XVI). It was found that 3.99 kcal of energy was used per minute during this stage of manual planting.

PSYCHOPHYSICAL FINDINGS

The Body Discomfort Map and RPE scale was once again used to assess the perceptual responses of planting workers for the duration of a work shift. During the assessment stage which focused on the performance of six minutes of continuous manual planting, only RPE responses were obtained upon completion of the task.

Ratings of Perceived Exertion

Mean RPE recorded for the work shift duration was found to be 13.69, whereas that found after the six minutes of continuous work was reportedly lower, with a value of 9.60 (Figure 43).

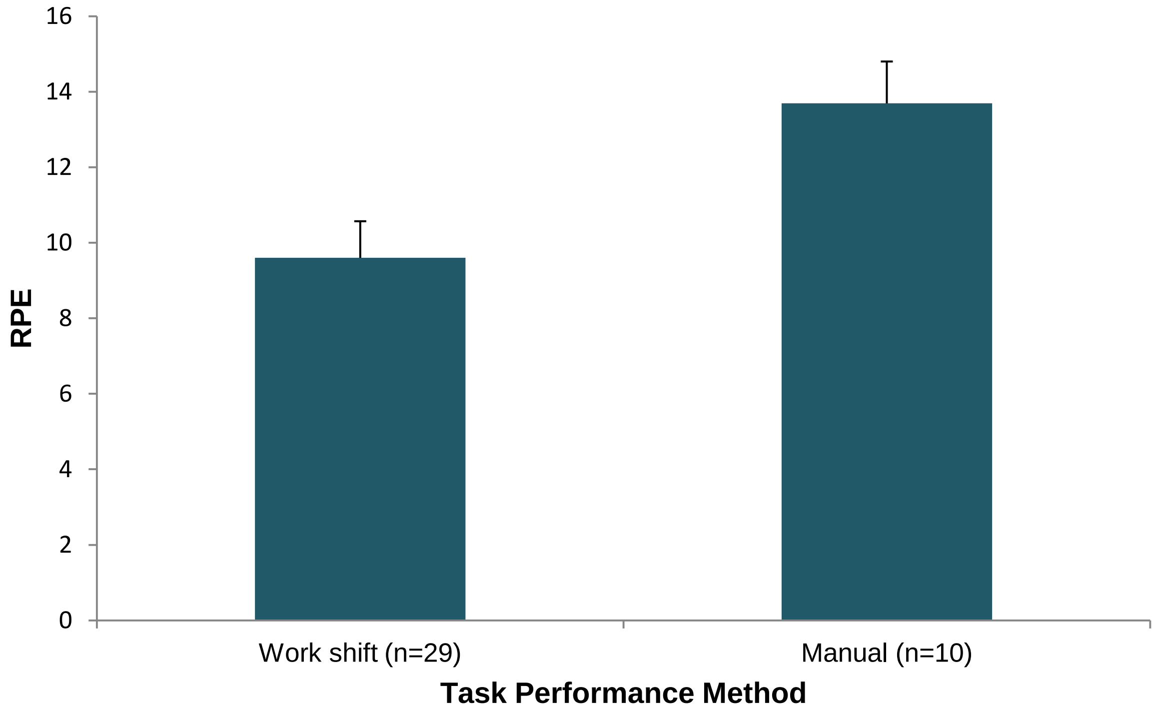


Figure 43: Mean RPE values recorded for shift duration and continuous manual planting.

Body Discomfort

As in the case of pitting, body discomfort was only assessed during the manual planting work shift (Table XVII). Included in this assessment are ratings of discomfort for those body parts identified by three or more planting workers. In this case, only three body locations were identified by the female planters, specifically the lower back, middle back and the wrists. Eight of the planters reported discomfort in both regions of the back, with the lower back associated with an intensity of 4.75, and the middle back one of 4.25. Both of these would therefore be classified as moderate levels of discomfort. Discomfort in the wrists was reported by three workers, with a slightly lower level of intensity of 3.67.

Table XVII: Number of individuals perceiving discomfort at different body sites and their average peak intensities recorded during a manual planting shift.

Location	Number of Workers	Mean Peak Intensity
Lower back	8	4.75
Middle back	8	4.25
Wrists	3	3.67

CHAPTER V
DISCUSSION

INTRODUCTION

The importance of using a holistic approach, in research aimed at understanding job demands imposed on individuals, has been advocated by multiple authors (Wilson, 2013; Genaidy, 2007; Karwowski, 2005; Karwowski, 2001 and Dempsey, 1998). The methods of assessment selected from the biomechanical, physiological and psychophysical domains therefore vary between studies. As a result, and due to insufficient research focusing on silviculture work within the South African forestry industry, comparisons of the present findings to existing literature is difficult. In order to facilitate the discussion of the current results, the following chapter is subdivided according to the variables assessed from the biomechanical, physiological and psychophysical fields. As such, the pitting and planting tasks will be discussed as subsections of the primary variables. The final section presents a summative, integrated discussion of the collective findings associated with pitting and planting.

PERSONAL CHARACTERISTICS

While a sound understanding of the task demands imposed on workers is vital in order to establish compatibility between worker capabilities and task requirements (Ayoub and Mital, 1989), an accurate knowledge of a workers' physical status is equally important (Christie, 2001). In developing countries, the economic cycle of disease has been closely correlated with negative lifestyle factors, such as undernourishment, particularly in rural areas. The culmination of these factors, as well as the participation of these workers in physically demanding, low wage jobs inevitably leads to reduced productivity (O'Neill, 2000), which frequently results in the perception of a 'lazy' workforce (Christie, 2006). In reality, the socio-economic factors which play a role in a workers' 24 hour cycle, can substantially alter their capacity to perform work. While it appears that these negative repercussions are well recognised, the general worker profile, including personal characteristics and health factors, is frequently overlooked. As such, one aim of the current research was to provide a base understanding of the forestry workforce investigated, particularly due to the severely limited set of relevant, South African specific data.

PITTERS

The average stature and mass values recorded for the male pitting workers is indicative of their slight build, a finding which is in agreement with forestry harvesting workers assessed in Kwa-Zulu Natal previously (Christie, 2006). Basic anthropometric findings of this nature have further been observed in black workers in the Eastern Cape of South Africa (Christie and Scott, 2005 and Todd, 2002). In terms of morphological characteristics, the pitting workers were associated with a low average body fat percentage, as well as BMI, indicative of an ectomorphic body type, which is once again comparable to the harvesters assessed by Christie (2006). While these measures are not considered ‘unhealthy’ based on body fat and BMI standard classifications, it is likely that the physically demanding nature of forestry work, as well as potential undernourishment of the workforce (Christie, 2001), contribute significantly to the slight build of these workers.

Worker age was found to be higher than expected, given the probability of low education levels and the low income associated with this kind of heavy manual work. In comparison to the research conducted by Christie (2006) however, the average age of the pitters was in fact lower than the harvesters (chainsaw operators) by more than 8 years. This is an interesting finding, as both jobs are considered low income, and workers are sourced from the same population, specifically Zulu speaking, rural black individuals. It is probable that the level of skill required for chainsaw operation is higher than that needed for pitting, which would imply that these workers require more years of work experience in order to perform their jobs safely and effectively. Evidence for this can in fact be seen in the differences in work experience between the pitters and harvesters, with pitters having a very low level of work experience of just under three years, whereas that of the harvesters was found to be almost 10 years (Christie, 2006).

PLANTERS

The workers assessed for the planting task in the forestry silviculture sector were all female, with divergent anthropometric and morphological characteristics when compared to the male pitters. While the average mass of the planters was found to be similar ($p>0.05$) to that of the males, the significantly lower stature resulted in sex-related differences in terms of morphology. The average BMI for the females was comparably higher than the males, with almost 50% of the women classified as overweight or obese. A similar case was observed for body fat percentage, with the planters being associated with almost three times the amount of the male pitters.

It has been acknowledged globally that obesity is far more prevalent among women than men (Case and Menendez, 2009). Research conducted by Case and Menendez (2009) into sex-related obesity differences in an urban South African township, purported three primary factors for the higher rates in black women. These were specifically associated with childhood circumstances, socioeconomic status and perceptions of ideal body weight. However, the applicability of these factors to the rural black force investigated in the current study is brought into question, primarily due to the fact that male pitters and female planters live in the same rural area, and have similar socioeconomic statuses. Therefore, it is more likely to assume that perceptions of body image play a large role in perpetuating female obesity in rural populations. This is based on the fact that, from a cultural perspective, over-weight females are considered more attractive, because it is believed to be a sign of good health (Fitzgibbon and Flynn, 1998). A study conducted by Furnham and Baguma (1994) on Ugandans, also found supporting evidence for this, where more obese bodies were considered more attractive and healthy. While this perception appears to be changing in more urban areas due to an introduction of the westernised culture, rural populations, which are associated with lower education levels, are likely to maintain a more traditional opinion of what a desirable body image is.

HEALTH STATUS

Although the socioeconomic status of the workers in the present study was expected to negatively impact health, the results from the questionnaire would suggest otherwise. When considering the non-communicable diseases, no reports of diabetes, high cholesterol or heart disease were observed in both the female planters and the male pitters, although 17% of the females reported high blood pressure. The presence of non-communicable diseases is a characteristic of developed countries however, South Africa is currently undergoing a dramatic health transition, which is characterised by a quadruple burden of disorders (Mayosi *et al*., 2009). An increased prevalence of cardiovascular disease, diabetes and other non-communicable diseases is now being observed, particularly in poor populations living in urban areas (Mayosi, 2009). The low prevalence of these diseases in the current sample workers is therefore likely attributable to the very rural nature of their lifestyles. At this point it is important to acknowledge that these findings are limited in that the majority of workers had not in fact ever been tested for the conditions, other than hypertension. As a result, only proper medical tests will provide a sufficient understanding of worker health. When considering the questions relating to infectious diseases, it is the opinion of the author that these findings are an underestimation of the actual situation. The reasoning behind this is based on two facts. The first is that the participants did not clearly understand what each disease referred to, despite the assistance of a translator, and therefore reported not having suffered from the illnesses. Secondly, it is possible that the workers intentionally denied having experienced these conditions due to a perceived level of embarrassment associated with the questionnaire.

BIOMECHANICAL RESPONSES

SPINAL KINEMATICS

The results displayed in Chapter 4 show that all spinal kinematic variables, with the exception of maximum extension, were significantly higher during manual pitting than semi-mechanised pitting. Important observations with regards to the manual technique, were the sagittal flexion (28.82°), maximum left bend (-7.71°) and maximum left twist (-5.11°), maximum lateral velocity ($53.58°.s^{-1}$), maximum lateral acceleration ($383.11°.s^{-2}$) and the mean transverse velocity ($8.38°.s^{-1}$).

The risk of lower back disorder (LBD) development has long been correlated with industrial work, as well as lifting and manual materials handling tasks (Marras *et al*., 1995; Snook, 1989; Bigos *et al*., 1986 and Spengler *et al*., 1986). Epidemiological studies conventionally focused on the risk contribution of five physical work factors, specifically heavy physical work, bending and twisting, lifting and forceful movements, whole body vibration and static work postures (Marras, 2000 and Bernard, 1997). In more recent years, research conducted by Marras and colleagues has purported the importance of trunk motion in activities associated with spinal loading, suggesting that dynamic trunk characteristics have a role to play in the proliferation of LBDs (Marras *et al*., 1995, Marras *et al*., 1993). When considering forestry-related tasks, including those associated with silviculture work such as pitting and planting, trunk motion as a risk factor has largely been overlooked, and therefore studies comparable to the current research are, for the most part, unattainable.

An important factor to bear in mind with regards to these trunk motion characteristics is the variability associated with each factor. Several studies, including those conducted by Marras *et al*. (1993), Marras *et al.* (2000) and Allread *et al.* (2000), state that, although individual differences are observed within the trunk motion factors, the variability is attributable to job design and workplace factors, rather than as a result of individual performance techniques within the same job. While there is no direct link to this literature with respect to silviculture, the tasks investigated by Allread *et al*. (2000) were considered repetitive tasks that involved some form of MMH, which would be congruent to pitting and planting performance. However, the variability associated with the trunk motion characteristics measured in the current research project, is in contrast to the results generated by the aforementioned studies. Indeed all trunk motion factors associated with pitting performance, both the manual and semi-mechanised methods, were associated with coefficients of variation above 25%, whereas those relating to the planting techniques were greater than 21%. In fact, the semi-mechanised techniques of both pitting and planting often generated CVs which exceeded 100%. This would imply that spinal kinematic measures change considerably for the same task, depending on the performance technique adopted by individual workers. The higher variability recorded during semi-mechanised pitting is to be expected, based on the assumption that workers are less experienced with this technique of task performance, compared to the existing manual method, as a result of the recent introduction of the new equipment.

However, further consideration with regards to the degree of variability observed within each trunk motion characteristic must be given to the actual magnitude of each measure. Low values, such as the 7.87° sagittal range of motion recorded during semi-mechanised pitting, would mean that even slight variations in movement could generate large coefficients of variation. In general, this was observed more frequently during the semi-mechanised technique, due to the significant decrease in the magnitude of several variables. In the case of manual pitting, large CV values were still reported, despite relatively high means, such as in the case of the velocities and accelerations generated within all three planes. This would suggest that individual performance techniques have a role to play in trunk motion variability.

Lower back disorder risk of pitting and planting

In order to overcome the challenge of quantifying the influence of trunk motion on the risk of developing LBDs in industry, Marras and colleagues (1995) carried out extensive investigations in over 400 industrial lifting jobs, making use of the medical records within each industry and classifying jobs according to low, medium and high risk for LBD development. Following this, workers within these jobs were assessed directly, which allowed for the angular positions, velocities and accelerations characteristic to each risk group, to be quantified. Upon further investigation into these findings, Marras *et al*. (1995), determined that a combination of five factors, which, if suitably varied, can decrease the odds of developing an LBD by more than ten times. These include two task characteristics, specifically maximum moment and frequency, and three trunk motion variables, including maximum sagittal flexion, maximum lateral velocity and average twisting velocity (Marras *et al*., 1995 and 1993), as discussed in Chapter 2. Although the pitting and planting tasks investigated in the current research project cannot be classified as lifting jobs, the recommendations proposed by Marras *et al*. (1995) are used as guidelines for risk determination in this case. While acknowledging that the ability of each factor to predict risk in isolation is significantly lower than the five combined variables, the following section discusses each variable individually, in order to draw distinctions between the manual and semi-mechanised techniques. Following this, the Multivariate Approach is used to highlight risk based on the combination of factors.

Pitting

The classification of the spinal kinematic responses recorded during manual and semi-mechanised pitting into high, medium or low risk, according to the recommendations generated by Marras and colleagues in 1995, are shown in Table XVIII.

Table XVIII: Spinal kinematics of manual and semi-mechanised pitting in relation to high, medium and low risk industrial jobs (recommendations from Marras *et al.* (1995)).

	Manual Pitting	Semi-Mechanised Pitting
Sagittal Plane		
Max. Flexion (°)*	28.82 (high risk)	11.59 (medium risk)
Max. Extension (°)	6.34 (low risk)	3.73 (low risk)
ROM (°)	13.12 (low risk)	13.32 (low risk)
Max. Velocity (°/s)	19.24 (low risk)	24.51 (low risk)
Max. Acceleration (°/s^2)	130.94 (low risk)	159.35 (low risk)
Lateral Plane		
Max. Left Bend (°)	-7.71 (high risk)	-4.31 (high risk)
Max. Right Bend (°)	11.86 (low risk)	1.78 (low risk)
ROM (°)	19.56 (low risk)	6.06 (low risk)
Max. Velocity (°/s)*	53.58 (high risk)	11.36 (low risk)
Max. Acceleration (°/s^2)	383.11 (high risk)	84.26 (low risk)
Transverse Plane		
Max. Left Twist (°)	-5.11 (high risk)	-2.95 (high risk)
Max. Right Twist (°)	10.72 (low risk)	2.5 (low risk)
ROM (°)	15.82 (low risk)	5.45 (low risk)
Mean Velocity (°/s)*	8.38 (medium risk)	2.4 (low risk)
Max. Velocity (°/s)	42.53 (medium risk)	18.76 (low risk)
Max Acceleration (°/s^2)	304.05 (medium risk)	120.84 (low risk)

[red] = high risk activity
[yellow] = medium risk activity
[blue] = low risk activity
* = best trunk motion variables for predicting risk group

When referring to the ranges of motion in all three planes, it can be seen that both manual and semi-mechanised pitting would be classified as low risk activities. However, although the range through which the spine is displaced is considered small, one must bear in mind the importance of the position of the trunk within each plane. Indeed, the degree of sagittal flexion has been advocated as having a significant role to play in establishing LBD risk for different tasks (Todd, 2008 and Marras, 2000). When referring to Figure 12, Page 56, it can be seen that a large degree of flexion is maintained throughout task performance, indicating that the low reported range of motion is in fact misleading, as it does not adequately express the position of the trunk. In the case of manual pitting, it can be seen that the mean angle for maximum sagittal flexion of 28.82° would be associated with a classification of high risk. As such, the internal forces responsible for supporting the head, arms and trunk would likely heighten the compression exerted on the L5/S1 joint, relative to increases in flexion.

In the case of semi-mechanised pitting, while the maximum sagittal flexion angle is reduced by more than half ($p<0.05$), the value of 11.59° would still fall into a medium risk level. At this point it is important to acknowledge that, although sagittal flexion is only at a medium risk level for semi-mechanised pitting, this variable represents one of the three strongest predictors of risk from the trunk motion factors (Marras *et al*., 1995). In addition to this, the maximum extension values for both pitting techniques, although considered low risk, indicate that a degree of flexion is maintained for the duration of task performance (Figure 12, Page 56). This would suggest that the trunk is kept in a flexed position for a large portion of the work shift. When considering trunk position in the lateral and transverse planes, while these variables do not contribute significantly to the risk classification, maximum left bend, right bend, left twist and right twist would be considered high risk for the development of an LBD.

In consideration of the velocities generated in each cardinal plane, it can be seen that semi-mechanised pitting is associated with a low risk of LBD development from a sagittal, lateral and transverse perspective. In contrast, manual pitting showed varying results for each plane. Within the sagittal plane, mean maximum velocity is also categorised as low risk. However, within the lateral plane, it is evident that manual pitting generated a very high velocity of $53.58°.s^{-1}$, which correlated with the high risk group guidelines proposed by Marras *et al*. (1995). In terms of the multivariate approach, maximum lateral velocity is an important contributory variable to the prediction of risk, when considering the five most important factors proposed by Marras *et al*. (1995). Similarly, mean average velocity associated with the transverse plane has also been identified as an important measure for risk classification, forming the third and final trunk motion characteristic that contributes to the multivariate approach. In this case, it can be seen that the average transverse velocity of 8.38°.s^{-1} generated during manual pitting would place this task at a moderate level of risk, potentially contributing to a significantly higher overall chance of falling into the high risk category.

The final kinematic variables of significance are the accelerations associated with trunk motion within the three planes. The probability of tissue damage is increased as a result of high accelerations, due to the 'jerking' motions imposed on the spine (Todd, 2008). In the case of pitting, maximum sagittal acceleration proved to be within acceptable limits, according to the low risk task guidelines, for both the manual and semi-mechanised methods. In terms of the lateral plane however, the maximum acceleration generated during manual pitting was high risk, with a peak mean value of 383.11°.s^{-2}, indicating that the forces acting on the spine are heightened, and therefore the risk of injury increased. In contrast, the semi-mechanised technique saw a reduction of the lateral acceleration peak to a low risk classification, according to the recommendations presented in Table XVIII. The acceleration responses associated with the transverse plane were found to be medium risk for manual pitting, and low risk for semi-mechanised pitting.

In summary, eight of the 16 trunk motion variables assessed during manual pitting (as presented in Table XVIII) were associated with a classification of above average risk, five of which were considered high risk, and three medium risk. In contrast, the probability of high risk group membership for the same variables measured during semi-mechanised pitting was much lower, with only two variables categorised as very risky, and one as medium risk. Therefore, based on the risk of incidence associated with each pitting technique, it can be said that the highest risk occurred for the manual technique. In conclusion, from the standpoint of spinal kinematics, the use of the semi-mechanised pitting technique should be adopted in preference to the manual task.

Planting

As in the case of pitting, the trunk motion characteristics recorded during manual and semi-mechanised planting, displayed in Table XIX, are classified according to the high, medium and low risk task guidelines generated by Marras et al. (1995). When taken as a whole, it can be seen that both the manual and semi-mechanised planting techniques could be considered fairly low risk, due to the fact that the ranges of motion, velocities and accelerations associated with all three cardinal planes correlate with those of the low risk tasks presented in Marras et al. (1995). However, when considering the trunk motion characteristics where above average risk is expected, sagittal flexion, maximum left bend and maximum left twist were identified as variables of interest for both manual and semi-mechanised techniques.

Table XIX: Spinal kinematics of manual and semi-mechanised planting in relation to high, medium and low risk industrial jobs (recommendations from Marras *et al.* (1995)).

	Manual Planting	Semi-Mechanised Planting
Sagittal Plane		
Max. Flexion (°)*	40.08	18.8
Max. Extension (°)	26.97	5.48
Range (°)	13.12	13.32
Max. Velocity (°/s)	19.24	24.51
Max. Acceleration (°/s^2)	130.94	159.35
Lateral Plane		
Max. Left Bend (°)	-8.35	-9.11
Max. Right Bend (°)	4.8	7.92
Range (°)	13.15	17.03
Max. Velocity (°/s)*	18.99	27.13
Max. Acceleration (°/s^2)	126.06	146.59
Transverse Plane		
Max. Left Twist (°)	-0.85	-2.0
Max. Right Twist (°)	5.62	7.78
Range (°)	6.47	9.78
Mean Velocity (°/s)*	1.28	3.5
Max. Velocity (°/s)	14.18	21.25
Max Acceleration (°/s^2)	108.94	141.97

= high risk activity
= medium risk activity
= low risk activity
* = best trunk motion variables for predicting risk group

In this case, the angle of sagittal flexion is of particular importance, due to its role in establishing LBD risk, as highlighted previously (Marras, 2000). The manual planting technique was associated with an extreme sagittal flexion of 40.08°, which would be classified as high risk, the importance of which relates to the fact that this variable is one of the three trunk motion characteristics used in the multivariate approach. Of further concern with regards to the sagittal position maintained during manual planting, is the degree of maximum extension. While this variable is considered low risk based on the classifications in Table XIX, it can be seen that the spine is actually kept in a flexed position for the entirety of task performance (Figure 30, Page 77). With a maximum extension angle of 26.97°, this variable actually correlates with high risk tasks, when viewed as a sagittally flexed position. When considering semi-mechanised planting, it can be seen that the angle of sagittal flexion was reduced to 18.8° when compared to the manual technique, thereby shifting the risk level from a classification of high risk to one of medium risk, a change which proved to be statistically significant. In correspondence with this decrease, the maximum extension angle of 5.48° would also be correlated as low risk, from the perspective of sagittal flexion.

In terms of maximum left bend, it was found that both manual and semi-mechanised planting were correlated with a classification of high risk, whereas maximum left twist was found to be at a medium risk level for both planting techniques. From this it can be seen that each planting method reported only three of the sixteen trunk motion characteristics as medium risk or higher. However, the fact that manual planting was associated with one medium risk and two high risk variables, as opposed to the semi-mechanised technique, with one high risk and two medium risk characteristics, suggests that the chance of injury is reduced during semi-mechanised planting compared to the existing manual method.

Multivariate logistic model of risk

The Multivariate Approach to risk classification, also referred to as The Lower Back Disorder Risk Model developed by Marras and colleagues in 1993, incorporates the five characteristics (referred to previously) that, in combination, are best able to classify tasks according to the risk of developing an LBD. As the tasks investigated in the current project are not lifting based per se, and are associated with dynamic movement in multiple planes, the measurement of specific maximum moments and frequencies is difficult. Despite this, the probability of high risk group membership for both techniques of pitting and planting was assessed based on the percentage contributions of the three trunk motion characteristics that are fundamental to the Multivariate Approach. In order to do this, the maximum moments and frequencies were assigned hypothetical values of zero, therefore providing no contribution to the risk probability. Although this analysis is limited, due to the fact that it is the combination of all five factors that contribute to overall risk, the three trunk motion variables are capable of predicting a portion of the probability of high risk group membership, albeit it slightly reduced.

Figure 44 highlights the probability of high risk group membership based on three (maximum sagittal flexion, maximum lateral velocity and average twisting velocity) of the five variables used in the model developed by Marras et al. (1993). From this it can be seen that manual pitting corresponded to more than 50% probability of high risk, based on only three variables. Therefore, had the two task characteristics been incorporated, the expected probability would be even higher for this method. In terms of the semi-mechanised pitting technique, the percentage probability was reduced to only 17.8%. Consequently, these findings are in agreement with the risk classifications highlighted in Table XIX However, differing results were found for the planting methods, with the probability of high risk group membership of 41.8% reported for semi-mechanised planting, exceeding that of 33.4% probability associated with the manual technique. This would imply that semi-mechanised planting is in fact more likely to cause injury when compared to the manual method, which is in contrast to the findings reported in Table XIX, suggesting that the two methods are more closely related in terms of risk. For this reason, the inclusion of the task characteristics would be essential to draw definitive conclusions.

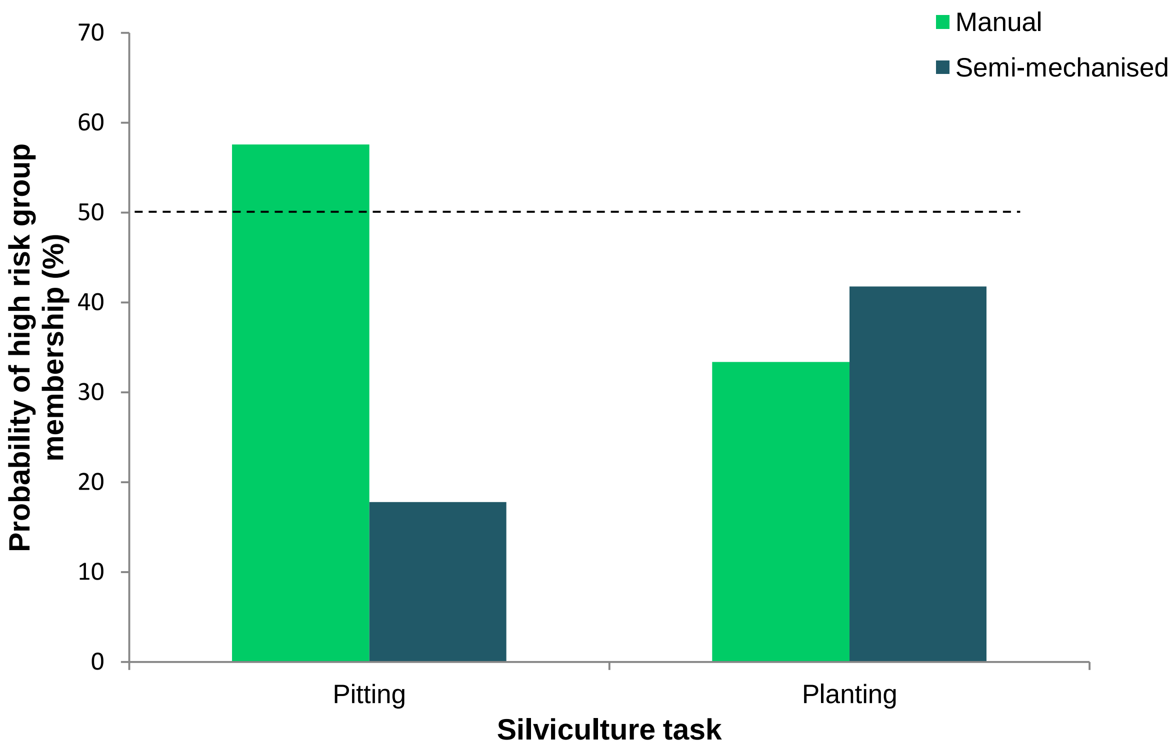


Figure 44: Probability of high risk group membership for the manual and semi-mechanised techniques of pitting and planting.

FORCES IMPOSED ON L5/S1

The difficulties associated with directly measuring the forces imposed on the spine during pitting and planting, stem from the field-based nature of the current research project, as well as the intrinsically dynamic nature of the silviculture tasks investigated. However, estimates of these forces can be obtained through the combination of the postures adopted and the loads manoeuvred, using static, theoretical models. The issue with these static tools is that they overlook the effect of motion, which has been highlighted as an important risk factor for LBD development (Marras *et al*., 2003). According to McGill and Norman (1985), and Granata and Marras (1999), spinal compression can be under-predicted by as much as 40%. While the use of static models to assess dynamic motion must be approached with caution, basic estimates of the forces acting at L5/S1 provide invaluable additional information pertaining to risk of injury. In this case, the University of Michigan's Three Dimensional Static Strength Prediction Programme was used to analyse photographs relevant to each task. From this, estimates of compression and shear forces in the sagittal plane were obtained based on the most extreme postures adopted by individuals within manual and semi-mechanised pitting and planting.

Pitting

An increased bending of the torso, associated with a greater angle of sagittal flexion, has been purported as generating higher compressive forces at the level of the spine, due to increased co-contraction of trunk musculature (Granata *et al*., 2005 and Resnick and Chaffin, 1995). For this reason, it was expected that manual pitting, with a sagittal angle classified as high risk according to spinal kinematics, would correspond with the highest compressive forces, when compared to the semi-mechanised technique. However, the opposite was in fact found (Figure 24, Page 69), with the compression force measured for the semi-mechanised method, exceeding that of manual pitting by over 350N. Therefore, although semi-mechanised pitting was systematically classified as lower risk according to the Low Back Disorder Model (Marras *et al*., 1993), the associated compression forces may contribute significantly to the stress placed on the L5/S1 joint. This observation is likely attributable to the differences in the handheld weights associated with the two pitting methods. Although the 'recommended weight limit' proposed by NIOSH (1993) for lifting is 23 kilograms, provided all other conditions are ideal (Waters *et al*., 1993) the 18 kilogram Auger weight would contribute substantially to spinal compression when compared to the approximately seven kilograms supported during manual pitting.

In terms of acceptable compression forces, it can be seen that, although semi-mechanised pitting is associated with higher forces, both techniques are in fact lower than the acceptable limit of 3400N proposed by NIOSH (1981) (Jäger and Luttmann, 1999). If considering the potential underestimation by 3DSSPP of up 40%, these tasks could be associated more closely with the NIOSH acceptable limit, with a compression force estimate of 3143.5N for manual pitting, and an unacceptable value of 3642N for semi-mechanised pitting. However, it must be kept in mind that this compression limit developed by NIOSH was specifically designed for lifting tasks (Marras, 2003 and Ferguson *et al*., 1992), while the consideration of other more diverse, dynamic and repetitive tasks was limited.

Of the forces associated with spinal loading, compression has been the primary focus of scientific research (Gallagher and Marras, 2012, Adams *et al.,* 2006 and Bogduk, 1997). However the additional, concurrent action of shear and torsional forces (Adams and Dolan, 1995) has been accepted as contributory to the development of LBDs (Granata and Marras, 1999). In this case, the shear forces for manual and semi-mechanised pitting were found to be 320.59 and 360.78 respectively, with semi-mechanised pitting showing higher force estimates. Once again this proved to be in contrast to the spinal kinematic classifications of high risk, where manual pitting was associated with greater movements in the lateral and transverse planes. When considering the prescribed acceptable limits, various tolerance limits have been reported, including 2500N (Yingling *et al*., 1997) and 1000N (McGill *et al*., 1998 and McGill, 1997). However, in a recent review conducted by Gallagher and Marras (2012), it was noted that a drawback of these previous studies was the fact that these exposure limits are not based on the frequency of the loadings. In this review it was found that the 1000N limit was acceptable for shear loadings of less than 100 per day, however, this decreased to a shear limit of 700N for repetitive loadings of between 100 and 1000 per day. In the case of pitting, both techniques would be considered highly repetitive (>500pits/day), however the shear forces for each are well below the 700N prescribed by Gallagher and Marras (2012), therefore both tasks would be considered acceptable from this viewpoint.

Planting

When focusing on the forces imposed on the spine during manual planting, two important factors must be taken into consideration. Firstly, sagittal flexion was maintained at an extreme degree, ranging between 26.97° and 40.08°, which is expected to substantially increase the compression forces (Granata *et al*., 2005 and Resnick and Chaffin, 1995). Secondly, the peak handheld weight of 22 kilograms is very closely related to the ‘recommended weight limit’ of 23 kilograms proposed by NIOSH. Despite the influence of these factors, the mean compression of 2456.2 (±275.11) N was still below the accepted limit of 3400N. In terms of the shear forces, the average of 508.4 (±40.11) N would also be considered acceptable according to the 700N limit (Gallagher and Marras, 2012).

PHYSIOLOGICAL RESPONSES

HEART RATE

Pitting

As highlighted in Chapter 2, the use of physiological criteria to define work limits has not been sufficiently substantiated, however basic heart rate ranges have been suggested in order to categorise work as light, moderate or heavy. In the case of pitting, whilst task performance was highly repetitive, heart rate was not maintained at a steady-state for the duration of a work shift, implying that rest break heart rates would be much lower than those associated with phases of sustained pitting. According to Kilbom (1995) the manual pitting average heart rate of 110 $bt.min^{-1}$ recorded for shift duration, would fall into the 'moderate' category range of 90 to 110 $bt.min^{-1}$, while Kumar *et al*. (2000) purports that this would be considered acceptable, according to a range of 104 to 114 $bt.min^{-1}$. However, when considering the phase of continuous pitting assessment (Table IX, Page 70), it can be seen that the physical demands of sustained manual pitting generated a mean heart rate of 157 $bt.min^{-1}$, which, in accordance with the ranges proposed by Kilbom (1995), would be considered extremely heavy work indicating the variability of the imposed task demands. This suggests that, although the average shift heart rates may indicate acceptable limits, the stages of actual pitting performance, are likely associated with excessive demands.

In reference to the heart rate responses recorded for semi-mechanised pitting, while shift duration measures could not be obtained, the six minute continuous assessment generated a mean of 143.2 $bt.min^{-1}$. This would be considered unacceptable according to Kumar (2000), however, it would not be defined as excessive, based on the ranges proposed by Kilbom (1995). At this point it is important to acknowledge that the mean heart rate for continuous, semi-mechanised pitting performance was not significantly lower than that found for the continuous, manual pitting. Therefore, as the allocation of rest phases during a shift remains the same, it can be surmised that the average heart rate for a shift of semi-mechanised pitting, would likely be similar to that of the manual technique, inferring 'moderate' or 'acceptable' demands. These findings would suggest that, in terms of heart rate, the introduction of technology would not significantly improve the demands already imposed on the workers during manual pitting.

Planting

The heart rate measures obtained for planting were based purely on manual task performance. It can be seen that the average heart rate of 101 $bt.min^{-1}$ obtained for the duration of shift performance, which would be considered moderate (Kilbom, 1995), was closely related to the 114 $bt.min^{-1}$ recorded during six minutes of continuous planting (Figure 42, Page 89). While the heart rate associated with continuous planting would be considered slightly higher than moderate, as suggested by Kilbom (1995), it would still be viewed as acceptable, based on the range put forward by Kumar and colleagues (2000). From these findings, it can tentatively be suggested that, due to only slight differences in heart rate between shift duration planting and continuous steady-state planting, the manual planting technique as a whole, could be considered 'safe' from a physiological perspective.

OXYGEN CONSUMPTION AND ENERGY EXPENDITURE

Pitting

As oxygen consumption and energy expenditure were only recorded during six minutes of continuous pitting performance, the overall energy costs of an entire work shift cannot be presented. However, the immediate energy expenditures associated with task performance can be compared to the absolute value recommendations proposed by McArdle *et al*. (2001) for men performing physical work. In terms of manual pitting, continuous performance was associated with an oxygen consumption of 2.25 $L.min^{-1}$, which equates to an energy expenditure of 11.27 $kcal.min^{-1}$ (Table XI, Page 70). According to the work intensity levels presented in Chapter 2, these variables would be associated with a range of 2.0 to 2.49 $L.min^{-1}$ for oxygen consumption, and 10.0 to 12.4 $kcal.min^{-1}$ for energy expenditure (McArdle *et al*., 2001) and, as a result, manual pitting would be considered very heavy work. The universal recommendation for energy expenditure during long duration physical work is that it should not exceed 5 $kcal.min^{-1}$. As the shift average cannot be calculated, it is not possible to determine the influence of rest break and walking phase energy expenditures on the absolute average of 11.27 $kcal.min^{-1}$, and whether or not long duration task performance would be within the universally accepted recommendation. This therefore warrants further investigation into the physiological requirements of a whole shift, however the immediate energy demands of the task itself is of concern. Semi-mechanised pitting was associated with lower absolute values for oxygen consumption and energy expenditure, when compared to the manual technique. Although these differences were found to be insignificant, semi-mechanised pitting was in fact associated with a lower work intensity level, as proposed by McArdle and colleagues (2001). As can be seen, the oxygen consumption of 1.96 $L.min^{-1}$ and energy expenditure of 9.8 $kcal.min^{-1}$, would be classified as heavy work, as opposed to the very heavy classification of manual pitting. As in the case of the manual technique, the acceptability of the task for the duration of the shift cannot be determined, necessitating the need for further research in this field.

Planting

The oxygen consumption and energy expenditure values for planting were assessed for six minutes of continuous manual performance only. The recorded responses of 0.8 $L.min^{-1}$ and 3.99 $kcal.min^{-1}$ would be classified according to the work intensity levels proposed by McArdle *et al*. (2001) as moderate. Furthermore, the 3.99 $kcal.min^{-1}$ energy expenditure level, associated with the most physically demanding aspect of planting work, is well below the universal recommendation limit of 5 $kcal.min^{-1}$. Therefore, due to the fact that these averages do not incorporate oxygen consumptions and energy expenditures associated with rest breaks and walking phases of an entire work shift, it is safe to say that the demands associated with an entire planting shift would not exceed a classification level of light to moderate work intensity.

PSYCHOPHYSICAL RESPONSES

RATINGS OF PERCEIVED EXERTION

Pitting

The RPE scale used in the current research project was aimed at assessing each workers perception of their central cardiovascular strain. When considering the difference in RPE between the continuous manual and semi-mechanised pitting assessments, it was observed that the manual technique was correlated with a significantly higher measure of 11.4, compared to that of 9.4 associated with the semi-mechanised technique. This would indicate that worker perception of the biomechanical and physiological strains was closely correlated to the realistic physical demands being imposed during each task performance, with manual pitting perceived as more taxing. However, despite the considerably heavy biomechanical and physiological demands recorded for manual pitting, the reported RPE, as classified according to the scale ratings, would define this task as ‘fairly light’. In terms of the semi-mechanised task, the lower RPE of 9.4, would categorise this task as ‘very light’ despite the relatively high physiological demands, and to a lesser degree biomechanical demands. In reference to the average RPE values recorded for the duration of a manual pitting shift, the value of 14.28, which falls between a rating of ‘somewhat hard’ and ‘hard’, is significantly higher than those reported for the six minute assessments. This would suggest that the strains associated with long duration pitting are perceived well by the workers assessed. While comparative literature is essentially nonexistent, these findings support the probability that biomechanical and physiological demands will result in a certain degree of psychophysical strain (Dempsey, 1998 and Oliver and Scott, 1994). The implication of this is that worker perceptions have a role to play in task design.

The use of the RPE scale in this case would therefore appear to have validly distinguished a physiologically and biomechanically more taxing task from another. However, when considering the distinction of the task demands into the appropriate levels of strain, the accuracy of this scale may be reduced. The most likely explanation for this discrepancy is the level of understanding of the workers assessed. The conceptual basis of assigning numeric values to physical strain is, in itself, a difficult idea to grasp. In the case of individuals whose first language is one other than English (Christie, 2006), clear and detailed explanations are required to ensure appropriate ratings (Legg and Myles, 1985). However, on several occasions during the present study, participants stated their lack of understanding of the scale, despite multiple explanations. The ‘fairly light’ and ‘very light’ perceptions would therefore be indicative of an underrating of imposed task demands, as a result of an inadequate understanding of the scale.

Planting

When considering the RPE findings relating to the planting task, one must bear in mind that measures were only obtained for the duration of one manual shift, and for six minutes of continuous manual performance. As in the case of pitting, the short duration task performance reported a value of 9.60, rated as between 'very light' and 'fairly light', which was significantly lower than the average of 13.69 reported for the manual planting shift. The higher value associated with long duration planting, correlates to a rating of between 'somewhat hard' and 'hard'. In this case a greater perception of effort was reported as a result of the extended period of task performance, which was likely closely correlated with temperature changes over the shift, as well as greater walking distances covered, when compared to the short six minute continuous planting stint.

BODY DISCOMFORT

The perceptual reports of body discomfort proved to be similar for both manual pitting and planting. In both manual performance shifts, the back was the highest rated body region for discomfort. In terms of the pitters, complaints from four workers were made for the upper back, 12 for the middle back and seven for the lower back. These perceptual findings therefore lend support to the spinal kinematic evidence which suggests that manual pitting would be classified as a high risk task for LBD, according to the recommendations proposed by Marras *et al*. (1995). Similarly, manual planting resulted in eight workers perceiving discomfort at the level of the lower back, as well as the middle back. Additional discomfort associated with manual pitting was identified at the shoulders and is most likely attributed the repetitive swinging motion of the pick. The wrist discomfort reported during manual planting can be explained by the fine motor movements associated with the repetitive loosening of the soil and planting of seedlings.

INTEGRATED DISCUSSION

The present study involved the measurement of a substantial number of responses from the biomechanical, physiological and psychophysical domains. As such, an integration of these results is necessary in order to inform industry in a cohesive manner, as well as to ensure that the musculoskeletal system is not negatively impacted by potentially conflicting findings. In order to facilitate the interpretation of the different results, each set of characteristics from the biomechanical, physiological and psychophysical domains has been provided with a classification in Table XX. In this table it can be seen that the results for the manual and semi-mechanised techniques of pitting and planting are assigned a level of acceptability, or are classified as inconclusive. In the cases were no measures were obtained, variables were assigned a classification of unknown.

Table XX: The collective demands imposed on male pitters and female planters, classified as acceptable, unacceptable, inconclusive or unknown.

		PITTING		PLANTING	
		Manual	***Semi-mech***	***Manual***	***Semi-mech***
BIOMECHANICS	***Spinal kinematics***	unacceptable demands	acceptable demands	unacceptable demands	acceptable demands
	Forces	acceptable demands	acceptable demands	acceptable demands	unknown
PHYSIOLOGY	***Heart rate***	inconclusive	inconclusive	acceptable demands	unknown
	VO_2	inconclusive	inconclusive	acceptable demands	unknown
	EE	inconclusive	inconclusive	acceptable demands	unknown
PSYCHOPHYSICS	***RPE***	acceptable demands	acceptable demands	acceptable demands	unknown
	Body Discomfort	unacceptable demands	unknown	unacceptable demands	unknown

[red] = unacceptable demands
[green] = acceptable demands
[orange] = inconclusive
[purple] = unknown

MANUAL VERSUS SEMI-MECHANISED PITTING

When considering the biomechanical measures, it was found that all spinal kinematic responses during manual pitting, excluding maximum sagittal extension, were higher than those associated with the semi-mechanised technique. It was observed that, of the eight variables classified as either medium or high risk (Table XVIII), six were reduced to a lower risk classification level – based on the recommendations proposed by Marras *et al*., (1995) – as a result of the introduction of technology to pitting. In terms of the forces imposed on the spine, it can be seen in Table XX that both manual and semi-mechanised pitting were associated with acceptable levels of compression and shear. Therefore, from a biomechanical perspective, it can be said that implementing the new semi-mechanised pitting method would reduce the risk of injury to workers. From a physiological standpoint however, it was observed that both manual and semi-mechanised techniques generated high heart rate and energy expenditure levels, with no significant improvement as a result of the introduced technology. Finally, the psychophysical ratings of perceived exertion were in agreement with the biomechanical findings. Although both pitting techniques were considered acceptable from this perspective, the semi-mechanised method was perceived as less demanding than manual pitting. Therefore, it can be concluded that the semi-mechanised method of pitting is better than the manual technique, as a result of the improved biomechanical and psychophysical demands. However, physiologically, the imposed demands are still of concern, suggesting that further development of the equipment is required, and potentially more intensive training of workers, in order to reduce these loads. Therefore in order to determine conclusively the optimal technique for task performance, a variety of follow-up studies would be required, assessing the impact of long duration performance, such as for the duration of a shift, as well as the nature of the terrain and types of soil.

MANUAL VERSUS SEMI-MECHANISED PLANTING

In the case of planting, spinal kinematic measures are the only variables where comparisons can be drawn between the manual and semi-mechanised techniques. This is primarily due to the fact that the final design of the semi-mechanised method had not yet been finalised at the time of data collection. When considering the biomechanical perspective, a large portion of the spinal kinematic measures were actually found to increase as a result of the introduction of the new equipment. However, it is important to bear in mind that despite these increases, no measures were associated with an increased level of risk according to the recommendations proposed by Marras *et al*. (1995) (see Table XIX). In fact, 13 of the 16 variables were rated as low risk for both manual and semi-mechanised planting. Although the tasks appeared to be very similar with regards to these demands, the semi-mechanised technique has still been reported as better in terms of musculoskeletal strain. This is specifically due to the dramatic reduction in sagittal flexion, which saw a decrease from 40.08° recorded during manual planting, to 18.8° during semi-mechanised planting. Finally, in reference to the physiological and psychophysical demands of manual planting, it can be seen that the heart rate, oxygen consumption, energy expenditure and ratings of perceived exertion were all considered to be within acceptable limits. This indicates that, while biomechanically, manual planting is not ideal, it does not exceed the demands of the other domains. Therefore, the appropriate design of the semi-mechanised task is vital in order to ensure that these systems are not exposed to increases in strain as a result of the incoming technology.

CHAPTER VI
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Ergonomics as a profession is intrinsically based on people and their interaction with work performance (Scott, 2009). However, as the concentration of research in this domain has centred on developed countries, the majority of the world's working population, primarily based in developed countries, has been inadequately served by the benefits associated with ergonomics (Christie, 2012). In South Africa, despite significant first-world influences, the implementation of appropriate ergonomics principles in order to alleviate the extreme physical demands imposed on workers remains substandard.

When considering forestry work, the state of ergonomics research is unsatisfactory on a global scale, implying that the problem is exacerbated in developing countries including South Africa. The relationship between worker capacity and work demands associated with existing silviculture methods has never been investigated, and in spite of this, the forestry industry in South Africa is seeing the introduction of new technologies, thereby increasing the mechanisation of tasks. As a result, the impact of the new equipment, be it beneficial or detrimental, is not yet known.

In correspondence with the above issue, laboratory-based research, which undeniably invaluable, reduces the ability to accurately assess the extreme work conditions associated with physically demanding tasks such as those within forestry. As such, the applicability of findings, and the capacity of ergonomics to influence these conditions is severely diminished. The current research project was therefore structured on the two aforementioned concepts, aiming to assess and generate knowledge based on a South African workforce, but also to do so in a field-based manner which would allow for the most applicable ergonomics interventions to be formulated.

SUMMARY OF PROCEDURES

The experimentation for this research was conducted in Kwa-Zulu Natal, South Africa. The procedures used were divided into three phases, designed to assess the basic characteristics of pitting and planting workers, and the physical workloads imposed on them during task performance. Prior to the main in-field assessments, the first phase involved the collection of anthropometric, demographic, morphological, and reference cardiovascular data, as well as basic details associated with health status and incidence of musculoskeletal injuries. The following two phases, conducted within the field, holistically assessed work demands according to biomechanical, physiological and psychophysical variables, as highlighted below. Due to the more rapid progression of the pitting task, both the manual and semi-mechanised methods were assessed using all three principles. In the case of planting, the manual technique was assessed in the same manner, however the semi-mechanised planting was considered from a biomechanical perspective only, focusing specifically on spinal kinematics.

In consideration of the above holistic approach, the following variables were measured:

> Biomechanical parameters: Spinal kinematic variables (sagittal, lateral and transverse ranges of motion, velocities and accelerations) and spinal forces (compression and shear at the L5/S1 joint).
>
> Physiological parameters: Heart rate, oxygen consumption and energy expenditure.
>
> Psychophysical parameters: Ratings of Perceived Exertion and body discomfort.

The first phase focused on the assessment of the biomechanical demands, as well as heart rate and psychophysical responses associated with the duration of one work shift, performed manually. Heart rates and perceptual ratings were obtained at regular intervals for the duration of one work shift. Within the first two hours of the work shift, participants were fitted with the Lumbar Motion Monitor (LMM) and were required to perform five repetitions of the manual task, and five repetitions of the semi-mechanised task, following which they returned to their normal shift routine. The second phase involved more in-depth physiological assessments, including the measurements of oxygen consumption and energy expenditure. The assessment of these physiological measures took place within the first two hours of a work shift. Once participants were fitted with the Metamax portable ergospirometer, they performed six minutes of the manual task and six minutes of the semi-mechanised task. A six minute rest period was allocated between each technique to allow resting responses to return to normal.

SUMMARY OF RESULTS

PITTING WORKERS

Personal characteristics

The sample of black male pitting workers recruited for participation in this study showed the following personal characteristics; age of 27.04 (±8.25) years, stature of 1663.6 (±75.4) mm, body mass of 60.08 (±8.84) kg, BMI of 21.65 (±2.26) kg^2 and body fat percentage of 10.61 (±2.36) %. From a cardiovascular perspective, reference heart rate was found to be 64.12 (±10.16) $bt.min^{-1}$ and systolic and diastolic blood pressures were 126 (±17) and 81 (±12) mmHg respectively. It was expected that workers would be associated with a compromised health status due to the influence of the economic cycle of disease, however, non-communicable diseases were minimal, and infectious diseases were not particularly prevalent, despite the likelihood of poor sanitation and undernourishment.

Biomechanical responses

When considering the spinal kinematic responses, it was found that manual pitting was associated with significantly higher measures than the semi-mechanised technique, including maximum sagittal, lateral and transverse ranges of motion, maximum flexion, maximum left bend and right bend, maximum left twist and right twist, and maximum velocities and accelerations. Taking into account the recommendations proposed by Marras *et al.* (1995), it was found that eight of the 16 spinal kinematic variables reported on in Chapter V were classified as either medium or high risk the for manual pitting, whereas only three variables were considered above average risk for the semi-mechanised technique. The three spinal kinematic variables, maximum sagittal flexion, maximum lateral velocity and average transverse velocity are considered the three strongest predictors of risk from the perspective of spinal kinematics. In this case, it was observed that manual pitting was considered high risk based on a maximum sagittal flexion of 28.82° and a maximum lateral velocity of 53.58°.s^{-1}, whereas it was associated with a medium risk in terms of an average transverse velocity of 8.38°.s^{-1}. In comparison, while the maximum sagittal flexion of 11.59° was medium risk for semi-mechanised pitting, the maximum lateral velocity of 11.36°.s^{-1} and average transverse velocity of 2.4°.s^{-1} categorised semi-mechanised pitting as low risk.

In contrast to the spinal kinematic responses, it was found that the compression and shear forces imposed on the L5/S1 joint were significantly higher during semi-mechanised pitting when compared to the manual technique. Although the compression force of 2601.7 N for the semi-mechanised method was higher than the 2245.37 N recorded for the manual pitting, both of these forces are not considered excessive according to the most commonly accepted compression limit of 3400 N proposed by NIOSH. In terms of shear forces, the semi-mechanised pitting value of 360.78 N, although found to be higher than that of the 320.59 N reported for the manual method of pitting, both tasks were well below the 700 N limit recently prescribed by Gallagher and Marras (2012).

Physiological responses

According to the in-field assessments of heart rate, an average value of 110 bt.min^{-1} was recorded for the duration of the manual shift. The heart rates of 157 bt.min^{-1} and 143.2 bt.min^{-1}, associated with continuous manual and semi-mechanised pitting performance respectively, were not found to be significantly different. Similarly, the average energy expenditure of 11.27 kcal.min^{-1} recorded during six minutes of continuous manual pitting, did not prove to be significantly higher than that of 9.8 kcal.min^{-1} generated during the semi-mechanised task performance.

Psychophysical responses

The average RPE value of 14.28 found for the shift of manual pitting meant that these workers perceived their task as ‘somewhat hard’ to ‘hard’. When assessing the manual technique in comparison to the semi-mechanised technique, the six minutes of continuous task performance revealed that workers perceived the manual pitting, with a mean RPE of 11.4, to be more difficult than the semi-mechanised technique, with an RPE of 9.4, a difference which proved to be significant. In terms of body discomfort for manual pitting, the lower, upper and middle back regions were the most frequently identified areas of discomfort, suggesting a good correlation between this psychophysical measure and the spinal kinematic results.

PLANTING WORKERS

Personal characteristics

The cohort of female planters assessed during the current study was associated with the following characteristics; age of 28.69 (±11.11) years, stature of 1583.1 (±61.75) mm, body mass of 64.07 (±10.13) kg, BMI of 25.54 (±3.62) $kg.m^{-2}$ and body fat percentage of 29.39 (±4.93) %. In terms of the reference cardiovascular measures, reference heart rate was 79.03 (±8.77) $bt.min^{-1}$, with a mean systolic and diastolic blood pressure of 122 (±15) and 76 (±13) mmHg respectively. In terms of health status, a similar situation was found for the planters, as was observed in the pitters, with a limited prevalence of non-communicable diseases, and low levels of infectious diseases.

Biomechanical responses

In the case of spinal kinematic responses recorded during planting, it was found that the semi-mechanised technique was correlated with significantly higher values for maximum extension, left bend, right bend, left twist, right twist and ranges of motion in the lateral and transverse planes. A similar case was also found for maximum velocities and maximum accelerations in all three cardinal planes. The only variable which was found to be significantly higher during manual planting was that of sagittal flexion. However, despite the fact that semi-mechanised planting appeared to place workers at a higher risk, it was observed that both techniques were largely associated with a low risk classification level, based on the recommendations developed by Marras *et al*. (1995). In fact, only three of the 16 variables were correlated with above average risk for both planting methods, specifically maximum sagittal flexion, maximum left bend and maximum left twist. It is therefore important to acknowledge the fact that, of these three variables, sagittal flexion is one of the three strongest predictors of LBD risk. In the case of manual planting, a maximum sagittal flexion of 40.08° is associated with high risk, whereas the 18.8° recorded during semi-mechanised planting is related to moderate risk. The two other motion variables purported as strong predictors of risk by Marras and colleagues (1995), specifically maximum lateral velocity and average twisting velocity, were deemed low risk for manual and semi-mechanised planting.

Physiological responses

When considering the heart rate responses recorded during a manual planting shift, a mean value of 101 $bt.min^{-1}$ was obtained, which according to the reviewed literature, would be considered moderate or acceptable. During the six minutes of continuous manual performance, a mean heart rate of 114 $bt.min^{-1}$ was also deemed acceptable.

Psychophysical responses

In reference to the perceived demands of manual planting, workers considered their job as ‘somewhat hard’ to ‘hard’, with an RPE value of 13.69, when recorded for the duration of one work shift. After assessing this task for six minutes only, this value was decreased to 9.6, correlating to a work perception of ‘very light’ to ‘fairly light’. As in the case of pitting, manual planters complained most frequently of back discomfort, and to a lesser extent, the wrists.

RESPONSE TO HYPOTHESES

PITTING

Hypothesis 1: The first statistical hypothesis states that there will be no difference in the biomechanical responses to each technique of pitting.

When referring to spinal kinematics, the following variables force the rejection of the null hypothesis, with manual pitting generating significantly higher values than semi-mechanised pitting:

- Maximum sagittal flexion, sagittal ROM, maximum sagittal velocity, maximum sagittal acceleration, maximum left bend and right bend, lateral ROM, maximum lateral velocity, maximum lateral acceleration, maximum left twist and right twist, transverse ROM, maximum transverse velocity, average transverse velocity and maximum transverse acceleration.

With regards to the forces exerted at L5/S1, the compression and shear forces associated with semi-mechanised pitting were significantly higher than those of manual pitting, therefore the null hypothesis is once again rejected.

Hypothesis 2: The second statistical hypothesis proposes that there will be no difference in the physiological responses to each technique of pitting. This hypothesis is tentatively accepted, as no significant differences were found for the following variables:

- Heart rate, oxygen consumption and energy expenditure

Hypothesis 3: The final hypothesis for pitting stated that there would be no difference in the psychophysical responses associated with each work technique. The significantly higher RPE associated with manual pitting therefore force the rejection of this hypothesis.

PLANTING

Hypothesis 4: This hypothesis stated that there would be no difference in the biomechanical responses, specifically measures of spinal kinematics, to each planting technique. The following variables force the rejection of this hypothesis:

- Manual planting statistically greater than semi-mechanised – maximum flexion and maximum extension

- Semi-mechanised planting statistically greater than manual – maximum sagittal velocity, maximum sagittal acceleration, maximum left bend and right bend, lateral ROM, maximum lateral velocity, maximum lateral acceleration, maximum right twist, transverse ROM, maximum transverse velocity and maximum transverse acceleration.

CONCLUSIONS

The field-based nature of this research brought into light the extreme work conditions found in South Africa as a developing country, specifically with regards to the manual pitting, and to a lesser extent the manual planting. Workers are required to perform hard manual labour for the majority of a work shift, while being exposed to harsh environmental conditions including temperature extremes, humidity and uneven terrain. From the rejection or acceptance of the null hypotheses, it can been seen that the introduction of technology had a varied impact on the physiological, biomechanical and psychophysical responses of the pitting and planting workers.

In consideration of the pitting adaptations, it was observed that biomechanically, the introduction of technology saw a substantial improvement in imposed demands, with all manual trunk motion characteristics, including spinal positioning, velocities and accelerations showing significant reductions. When considering one of the most important of these factors – sagittal flexion – it was observed that it was decreased by more than half, significantly reducing the contribution of this factor to the risk of developing LBDs. In terms of physiology however, it was found that considerable demands were associated with both techniques, with high reported values for heart rate, oxygen consumption and energy expenditure. With regards to psychophysics, workers perceived the manual pitting as significantly more demanding than the semi-mechanised technique, although the average ratings for both was still considered acceptable.

When focusing on the planting task, it was observed that the majority of factors from the disciplines of biomechanics, physiology and psychophysics were in fact associated with low levels of risk, and within acceptable limits. Although the semi-mechanised task could not be investigated sufficiently in certain cases, the introduction of the new technology saw a reduction of sagittal flexion from an extreme of 40.08° to 18.8°, suggesting that the implementation of the new planting technique would be better from a biomechanical perspective. However, the differences between manual and semi-mechanised planting in terms of physiology and psychophysics is, as of yet, unknown.

RECOMMENDATIONS

While the findings of this study are of major importance for ergonomics in South African forestry, research of this nature in all areas of manual labour is sorely lacking. In order for ergonomics as a profession to fulfil its objectives in a developing country, in this case South Africa, it needs a significantly more directed focus into the physical workloads of the specific workforces exposed to these demands. The following recommendations have been suggested in order to facilitate this in future.

Assessment of manual work within the actual environment that it is performed is vital in order to accurately apply interventions that are valid and applicable to that specific workforce. The use of participants who are not familiar with the tasks performed are inevitably going to generate results that are highly variable compared to the responses of the actual workers. Ideally, research of this nature should comprise two components, one based in-field, and another which can be conducted in laboratory settings within more control of extraneous variables. Furthermore, it is not sufficient to assess task demands from only one perspective. The importance of the holistic approach has been highlighted in the current project, where it was observed that, while one domain may indicate improvements, other areas may not.

A further recommendation with regards to field-based studies, is the need for more extensive research focusing on the performance of long duration tasks, and the imposed demands over an entire work shift. Novel methods are needed to assess individuals for extended periods of time, as at present, equipment interference with the task performance and environmental restrictions limit the in-field knowledge that can be generated.

The socioeconomic status of rural workers also plays a significant role in determining worker capacity as was seen in the case of the current forestry workers, as well as those assessed by Christie (2006). More in-depth research focusing specifically on the domain of worker characteristics is therefore recommended.

The final recommendation for research of this nature is the need for intervention-based research that focuses on the design stage of new performance techniques. If ergonomics research can act in a proactive manner, appropriate assistance can be provided at the level of task design, rather than the reactive manner of assessing already excessive demands and then attempting to find solutions. Unfortunately, the current project was conducted reactively to the existing demands, and further research into the semi-mechanised methods will need to be performed in the same manner, due to the fact that the equipment has already been introduced to the silviculture systems. For example, the assessment of body discomfort associated with the new tasks would be necessary in future, as it could not be assessed at the time of the current research.

REFERENCES

Note: Asterisked citations * are secondary sources. These were not directly consulted and are referenced as fully primary sources, indicated in brackets, permit.

Adams, M.A .and Dolan, P. (1995). Recent advances in lumbar spinal mechanics and their clinical significance. *Clinical Biomechanics*, *10(1):* 3-19.

*Adams, M.A., Bogduk, N., Burton, K. and Dolan, P. (2006). *The Biomechanics of Back Pain*. Second Edition. Edinburgh: Churchill Livingstone. (See Gallagher and Marras, 2012).

Allread, W.G, Marras, W.S and Burr, D.L (2000). Measuring trunk motions in industry: variability due to task factors, individual differences, and the amount of data collected. *Ergonomics, 43(6):* 691-701.

Ayoub, M.M. and Mital, A. (1989). *Manual Materials Handling.* London: Taylor and Francis.

Ayoub, M.M. and Dempsey, P.G. (1999). The psychophysical approach to manual materials handling task design. *Ergonomics. 42(1):* 17-31.

Ayoub, M.M. and Woldstad, J.C. (1999). Models in manual materials handling In S. Kumar (ed): *Biomechanics in ergonomics*. Boca Raton: Taylor and Francis, pp. 267–305.

Banister, E., Robinson, D. and Trites, D. (1990). Ergonomics of tree planting. *FRDA Report 127.* Simon Fraser University, Canada.

Bentley, T.A., Parker, R.J, Ashby, L., Moore, D.J. and Tappin, D.C. (2002). The role of the New Zealand forest industry surveillance system in a strategic ergonomics, safety and health research programme. *Applied Ergonomics*, *33*: 395-403.

*Bernard, B.P. (1997). Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. US Department of Health and Human Services (DHHS) publication no. 97-141 (Cincinnati: National Institute for Occupational Safety and Health) (from Marras, 2000).

Biggs, C. (2008). *The prevalence and degree of dehydration in rural South African forestry workers.* Unpublished Masters thesis, University of Kwazulu-Natal, Pietermaritzburg, South Africa.

*Bigos, S.J., Spengler, D.M., Martin, N.A., Zeh, J., Fisher, L.and Nachemson, A. (1986). Back injuries in industry: A retrospective study. II. Injury factors. *Spine. 11(3):* 246-251. (See Lavender *et al*., 2012).

*Bogduk, N. (1997). *Clinical Anatomy of the Lumbar Spine and Sacrum*. Third Edition. New York: Churchhill Livingstone. (See Desai, 2008).

*****Borg, G.A.V. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise, 14 (5):* 377-381. (See Christie, 2006).

Case, A. and Menendez, A. (2009). Sex differences in obesity rates in poor countries: evidence from South Africa. *Economics and Human Biology*, *7*: 271-282.

Chaffin, D.B. (2009). The evolving role of biomechanics in the prevention of overexertion injuries. *Ergonomics*. *52(1):* 3-14.

Christie, C.J. (2001). Consideration of the effect of nutritional status and disease patterns on work output amongst black South African workers involved in manual materials handling (MMH) tasks. *Ergonomics SA, 13*: 32-36.

Christie, C.J. and Scott, P.A. (2005). Comparison of maximal aerobic capacity during running and lifting activities. *Ergonomics SA***,** *17 (1):* 41-49.

Christie, C.J. (2006). *A field investigation of physical workloads imposed on harvesters in South African forestry*. Unpublished Masters Thesis, Rhodes University, Grahamstown, South Africa.

Christie, C.J. (2012). Straightforward yet effective ergonomics collaborations in South Africa. *Ergonomics in Design: The Quarterly of Human Factors Applications, 20*: 39-42.

Clarke, J. and Isaacs, M. (2005). Forestry contractors in South Africa: what role in reducing poverty? *Programme for Land and Agrarian Studies*, University of the Western Cape, South Africa, and International Institute for Environment and Development, London, UK.

*Corlett, E.N. and Bishop, R.P. (1976). A Technique for Assessing Postural Discomfort. *Ergonomics, 19 (2):* 175-182. (See Christie, 2006).

Crickmay, A., Hlengwa, M. Olivier, W. and Rusk, G. (2004). Productivity in the South African forestry industry over the past decade. *The South African Forestry Journal, 201(1):* 1-2.

Davis, K.G. and Marras, W.G. (2000). The effects of motion on trunk biomechanics. *Clinical Biomechanics. 15*: 703-717.

David, G.C. (2005). Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. *Occupational Medicine. 55*: 190-199.

Dempsey, P.G. (1998). A critical review of biomechanical, epidemiological, physiological and psychophysical criteria for designing manual materials handling tasks. *Ergonomics*, *41(1):* 73-88.

Dempsey, P.G. and Hashemi, L. (1999). Analysis of workers' compensation claims associated with manual materials handling. *Ergonomics. 42(1):* 183-195.

Denis, D., St-Vincent, M., Imbeau, D., Jetté, C. and Nastasia, I. (2007). Intervention practices in musculoskeletal disorder prevention: A critical literature review. *Applied Ergonomics*, *39*: 1-14.

Desai, S. (2008). *The effect of load and technique on biomechanical and perceptual responses during dynamic pushing and pulling*. Unpublished Masters thesis, Rhodes University, Grahamstown, South Africa.

Dickens, D. (2012). Establishing southern pine plantations – site preparation options. *Forestry Productivity: Publication Series.* Warnell School of Forestry and Natural Resources, Georgia.

Driscoll, T.R., Ansari, G., Harrison, J.E., Frommer, M.S. and Ruck, E.A. (1995). Traumatic work-related fatalities in forestry and sawmill workers in Australia. *Journal of Safety Research, 26(4):* 221-233.

Du Toit, B., Smith, C.W., Little, K.M., Boreham, G. and Pallett, R.N. (2010). Intensive, site-specific silviculture: Manipulating resource availability at establishment for improved stand productivity. A review of South African research. *Forest Ecology and Management, 259*: 1836-1845.

*Durnin, J.V.G.A. and Womersley, J. (1974). Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *British Journal of Nutrition, 32*: 77-96. (See Christie, 2006).

*DWAF, (1996). White paper on sustainable forest development in South Africa. *Department of Water Affairs and Forestry.* (See Tewari, 2001).

DWAF, (2005). Draft key issue paper on forestry and poverty in South Africa. *Department of Water Affairs and Forestry.* 1-34. Accessed from: http://dwafapp4.dwafgov.za.

Evans, J. (1992). *Plantation Forestry in the Tropics: Tree Planting for Industrial, Social, Environmental and Agroforestry Purposes.* New York, USA: Oxford University Press.

Ferguson SA, Marras WS and Waters TR (1992). Quantification of back motion during asymmetric lifting. Ergonomics*, 35(7/8):* 845-859.

Ferreira, M. (2004). HIV/AIDS and family wellbeing in Southern Africa: towards an analysis of policies and responsiveness. *A Brief Synthesis Paper*. Prepared for Prepared for a United Nations Department of Economic and Social Affairs Division for Social Policy and Development Policy Workshop. pp 1-23.

Fitzgibbon, M. and Flynn, K.J. (1998). Body images and obesity risk among black females: a review of literature. *Annals of Behavioural Medicine*. *20(1):* 13-24.

Florence, R.G. (2004). *Ecology and Silviculture of Eucalypt Forests.* Collingwood, Australia: Csiro Publishing.

Furnham, A. and Baguma, P. (1994). Cross-cultural differences in the evaluation of male and female body shapes. *International Journal of Eating Disorders. 15(1):* 81-89.

Gallagher, S. and Marras, W.S. (2012). Tolerance of the lumbar spine to shear: A review and recommended exposure limits. *Clinical Biomechanics*, 27: 973-978.

*Gamberale, F. (1972). Perceived exertion, heart rate, oxygen uptake and blood lactate in different work operations,. *Ergonomics. 15*: 545-554.

Garg, A. and Kapellusch, J.M. (2009). Applications of biomechanics for prevention of work-related musculoskeletal disorders. *Ergonomics*. *52(1):* 36-59.

Genaidy, A., Salem, S. Karwowski, W. Paez, O. and Tuncel, S. (2007). The work compatibility improvement framework: an integrated perspective of the human-at-work system. *Ergonomics. 50(1):* 3-25.

Granata, K.P. and Marras, W.S. (1999). Relation between spinal load factors and the high-risk probability of occupational low-back disorder. *Ergonomics*, *42(9):* 1187-1199.

Granata, K.P., Lee, P.E. and Franklin, T.C. (2005). Co-contraction recruitment and spinal load during isometric trunk flexion and extension. *Clinical Biomechanics*, *20:* 1029-1037.

Hagen, K.B., Hallén, J. and Harms-Ringdahl, K. (1993). Physiological and subjective responses to maximal repetitive lifting employing stoop and squat technique. *European Journal of Applied Physiology. 67*: 291-297.

*Hagen, K.B., Magnus, P., Vetlesen, K. (1998). Neck/shoulder and low-back disorders in the forestry industry: relationship to work tasks and perceived psychophysical job stress. *Ergonomics***,** *41 (10):* 1510-1518. (See Christie, 2006).

Helander, M.G. (1997). Forty years of IEA: some reflections on the evolution of ergonomics. *Ergonomics. 40(10):* 952-961

Hodges, A.N.H., Ellis, J.D. McKenzie, D.C. (2005). The effects of 10 weeks of reforestation work no body composition. *Wilderness and Environmental Medicine. 16:* 3-8.
Hodges, A.N.H. and Kennedy, M.D. (2011). Physical exertion and working efficiency of reforestation workers. *Journal of Occupational Medicine and Toxicology. 6(20):* 1-7.

ILO Encyclopaedia of Occupational Health and Safety. Fourth Edition, Volume III, Part X, Industries Based On Biological Resources, Forestry. Last accessed: October 2013.

Jafry, T. and O'Neill, D.H. (2000). The application of ergonomics in rural development: a review. *Applied Ergonomics. 31*: 263-268.

Jäger, M. and Luttmann, A. (1999). Critical survey on the biomechanical criterion in the NIOSH method for the design and evaluation of manual lifting tasks. *International Journal of Industrial Ergonomics, 23*: 331-337.

Johnson, P.S., Shifley, S.R. and Rogers, R. (2009). *The Ecology and Silviculture of Oaks.* United Kingdom: CAB International.

Karwowski, W. (Ed)., (2001). International Encyclopedia of Ergonomics and Human Factors. London: Taylor & Francis. (See Karwowski 2005).

Karwowski, W. (2005). Ergonomics and human factors: the paradigms for science, engineering, design, technology and management of human-compatible systems. *Ergonomics. 48(5):* 436-463.

Karwowski, W. (2006). The discipline of ergonomics and human factors. *Handbook of Human Factors and Ergonomics* (Edition 3). New York: John Wiley, pp 1-25.

Khosa, M. (2000). Forestry Contracting in South Africa. Instruments for sustainable private sector forestry, South Africa series. International Institute for Environment and Development and CSIR-Environmentek, London and Pretoria.

*Kilbom A (1995). Measurement and assessment of dynamic work. In J.R Wilson and E.N Corlett (eds): *Evaluation of Human Work – A Practical Ergonomics Methodology.* Second Edition. London: Taylor and Francis. (See Christie, 2006).

Kumar, S., Narayan, Y. and Bjornsdottir, S. (1999). Comparison of the sensitivity of three psychophysical techniques to three manual materials handling task variables. *Ergonomics*. *42(1):* 61.73.

Kumar S, Lechelt EC, Narayan Y and Chouinard K (2000). Metabolic cost and subjective assessment of palletizing and subsequent recovery. *Ergonomics, 43 (6):* 677-690.

*Legg, S.J. and Myles, W.S. (1985). Metabolic and cardiovascular cost, and perceived effort over an 8 hour day when lifting loads selected by the psychophysical method. *Ergonomics, 28 (1):* 337-343. (See Christie, 2006).

Lilley, R., Feyer, A., Kirk, P. and Gander, P (2002). A survey of forest workers in New Zealand. Do hours of work, rest and recovery play a role in accidents and injury? *Journal of Safety Research, 33*: 53-71.

Louw, W.J.A. (2004). General history of the South African forestry industry: 1991 to 2002. *The South African Forestry Journal, 201(1):* 65-76.

Manyuchi, K.T. and Pulkki, R.E. (2002). A framework for analyzing workforce dynamics in forest harvesting in South Africa. *The Southern African Forestry Journal, 196(1):* 41-47.

Marras, W.S., Fathallah, F.A., Miller, R.J., Davis, S.W. and Mirka, G.A. (1992). Accuracy of a three-dimensional lumbar motion monitor for recording dynamic trunk motion characteristics. *International Journal of Industrial Ergonomics*. *9:* 75-87.

Marras, W.S., Lavender, S.A., Leurgans, S.E., Rajulu, S.L., Allread, W.G., Fathallah, F.A. and Ferguson, S.A. (1993). The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders. *Spine, 18(5):* 617-628.

Marras, W.S., Lavender, S.A., Leurgans, S.E., Fathallah, F.A., Ferguson, S.A., Allread, W.G. and Rajulu, S.L. (1995). Biomechanical risk factors for occupationally related low back disorders. *Ergonomics*. *38(2):* 377-410.

Marras, W.S. (2000). Occupational low back disorder causation and control. *Ergonomics. 43(7):* 880-902.

Marras, W.S. (2003). Occupational Biomechanics. In W. Karwowski and W.S. Marras (eds). *Occupational Ergonomics: Principles of Work Design*. Boca Raton: CRC Press, pp. 10-1-10-38.

Marras WS, Allread WG and Ried RG (2003). In W. Karwowski and W.S. Marras (eds). *Occupational Ergonomics: Engineering and Administrative Controls.* Boca Raton: CRC Press, pp. 18-1-18-26.

Marras WS (2005). The future of research in understanding and controlling workrelated low back disorders. *Ergonomics, 48(5):* 464-477.

Marras WS and Allread WG (2005). Lumbar Motion Monitor. In N. Stanton, A. Hedge, K. Broohuis, E. Salas and H. Hendrick (eds): *Handbook of Human Factors and Ergonomics Methods.* Boca Raton: CRC Press, pp. 14-1-14-7.

Marras WS (2006). Biomechanical Basis for Ergonomics. In W.S. Marras and W. Karwowski (eds). *The Occupational Ergonomics Handbook: Fundamentals and Assessment Tools for Occupational Ergonomics*. Second Edition. Boca Raton: Taylor& Francis, pp. 11-1-11-43.

May, J. (Ed.), (1999). *Poverty and Inequality in South Africa: Meeting the Challenge.* Cape Town: David Phillip. (See Shackelton *et al*., 2007).

*McArdle, W.D., Katch, F.I. and Katch, V.L. (2001). *Exercise Physiology – Energy, Nutrition and Human Performance*. Fifth Edition. Baltimore: William and Wilkins. (from Christie, 2006).

Macfarlane, D.J. and Wong, P. (2012). Validity, reliability and stability of the portable cortex metamax 3B gas analysis system. *European Journal of Applied Physiology. 112*: 2539-2547.

*McGill SM and Norman RW (1985). Dynamically and statically determined low back moments during lifting. *Journal of Biomechanics*, *8:* 877-885. (See Granata and Marras, 1999).

McGill, S.M. (1997). The biomechanics of low back injury: implications on current practice in industry and the clinic. *Journal of Biomechanics*. *30(5):* 465-475.

McGill, S.M., Norman, R.W., Yingling, V.R.,Wells, R.W., Neumann, P., (1998). Shear Happens! Suggested Guidelines for Ergonomists to Reduce the Risk of Low Back Injury from Shear Loading. *Proceedings of the 30th Annual Conference of the Human Factors Association of Canada (HFAC),* Mississauga, Ontario, Canada, pp. 157–161.

*McLean C (1996). Risk assessment for plant: A practical approach. *Journal of Occupational Health and Safety – Australia and New Zealand. 12 (5):* 603-607 (See Christie, 2006).

Mayosi, B.M., Flisher, A.J., Lalloo, U.G., Sitas, F., Tollman, S.M. and Bradshaw, D. (2009). The burden of non-communicable diseases in South Africa. *Lancet*. *374*: 934-947.

Olivier, S.C. and Scott, P.A. (1994). The effect of frequency on psychophysical responses to lifting. *Ergonomics SA, 6 (1)*: 9-13.

O'Neill, D.H. (2000). Ergonomics in industrially developing countries: does its application differ from that in industrially advanced countries? *Applied Ergonomics, 31*: 631-640.

*Pheasant, S. and Haslegrave, C.M. (2006). *Bodyspace: Anthropometry, Ergonomics and the Design of Work.* Third Edition. Boca Raton: Taylor and Francis. (See Desai, 2008).

Resnick ML and Chaffin DB (1995). An ergonomic evaluation of handle height and load in maximal and submaximal cart pushing. *Applied Ergonomics*, *26(3):* 173- 178.

Rodrick, D. and Karwowski, W. (2006). Manual Materials Handling. In G. Salvenndy (ed): *Handbook of Human Factors and Ergonomics*. Third Edition. Hoboken: John Wiley & Sons, pp. 818-854.

Scott, P.A. (1993). Ergonomic problems associated with industry in developing countries, with South Africa as a model. *Ergonomics SA*, *5*: 27-28.

Scott, P.A. and Charteris, J. (2004). Ergonomics in Industrially Developing Countries (IDCs): Socio-cultural perspectives. In: M. Kaplan (Ed): *Cultural Ergonomics***.** Volume 4. London: Elsevier. pp. 223-248.

Scott, P.A. and Christie, C.J. (2004). An indirect method to assess the energy expenditure of manual labourers in situ. *South African Journal of Science, 100*: 694-698.

Scott, P.A. (2009). The development of, and the need for, ergonomics in industrially developing countries. In P. A. Scott (Ed.): *Ergonomics in developing regions: Needs and applications.* Boca Raton, FL: CRC Press. pp. 3–14.

Schönau, A.P.G. (1984). Silvicultural considerations for high productivity of *Eucalyptus Grandis*. *Forest Ecology and Management*, 9: 295-313.

Shackelton, C.M., Shackelton, S.E., Buiten, E. and Bird, N. (2007). The importance of dry woodlands and forests in rural livelihood and poverty alleviation in South Africa. *Forestry Policy and Economics*, *9*: 558-577.

Singh, S., Sinwal, N., Rathore, H. and Sinwal, S. (2011). Assessment of physiological workload related to selected manual materials handling tasks. *Anthropologist*. *13(4):* 293-298.

Slappendel, C., Laird, I., Kawachi, I., Marshall, S. and Cryer, C. (1993). Factors affecting work-related injury among forestry workers: a review. *Journal of Safety Research, 24(1):* 19-32.

Slot, T.R. (2010). *Occupational biomechanics of tree-planters.* Unpublished PhD thesis, Queen's University, Ontario, Canada.

Smith, C.W., Little, K.M. and Norris, C.H. (2001). The effect of land preparation at re-establishment on the productivity of fast growing hardwoods in South Africa. *Australian Forestry, 64(3):* 165-174.

*Snook, S.H. (1989). The control of low back disability: The role of management. In *Manual Materials Handling: Understanding and Preventing Back Trauma.* Akron, Ohio: American Industrial Hygiene Association. (See Lavender *et al*., 2012).

*Spengler, D.M., Bigos, S.J., Martin, N.A., Zeh, J., Fisher, L. and Nachemson, A. (1986). Back injuries in industry: A retrospective study. I. Overview and cost analysis. *Spine*. *11(3):* 241-245 (See Lavender *et al*., 2012).

Stjernberg, E. (2006). A pilot study to develop guidelines for reducing tree planter injuries. *Focus on Tomorrow.* Forest Engineering Research Institute of Canada. Vancouver, B.C. pp 66.

Sullman, M.J.M. and Byers, J. (2000). An ergonomic assessment of manual planting Pinus Radiata seedlings. *International Journal of Forest Engineering. 11(1):* 53-62.

Tewari, D.D. (2001). Sustainability of commercial forestry in a changing socioeconomic and legal environment: A case study of South Africa. *Africa Today, 48(1):* 51-74.

Todd AI (2002). *Physiological and psychophysical responses of male and female soldiers to changes in marching speed, load and gradient.* Unpublished MSc Thesis, Department of Human Kinetics and Ergonomics, Rhodes University, Grahamstown, South Africa.

Todd, A.I. (2008). A preliminary investigation of spinal kinematics during sugar cane harvesting. *Ergonomics SA. 20(2):* 15-25.

Toupin, D., LeBel, L., Dubeau, D., Imbeau, D. and Bouthillier, L. (2007). Measuring the productivity and physical workload of brushcutters within the context of a production-based pay system. *Forest Policy and Economics. 9*: 1044-1055.

*Trewin, A.R.D. and Kirk, P.M. (1992). Planting bare-rooted seedlings of Radiata Pine on difficult terrain. Proceedings of Harvesting and Re-establishment of Difficult Terrain. LIRO, Rotorua. (See Sullman and Byers, 2000).

Trites, D.G. (1992). *Ergonomics of tree planting work among British Columbia forest workers.* Unpublished Masters Thesis, Simon Fraser University, Canada.

Wilson, J.R. (2000). Fundamentals of ergonomics in theory and practice. *Applied Ergonomics*. *31*: 557-567.

Wilson, J.R. (2013). Fundamentals of systems ergonomics/human factors. *Applied Ergonomics 45*: 5-13.

Waters TR, Putz-Anderson V, Garg A and Fine LJ (1993). Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics, 36 (7):* 749-776.

Waters, T.R., Putz-Anderson, V. and Baron, S. (1998). Methods for assessing the physical demands of manual lifting: a review and case study from warehousing. *American Industrial Hygiene Association Journal. 59(12):* 871-881.

Woolf, A.D. (2008). Prevention of musculoskeletal conditions in the developing world. *Best Practice and Research Clinical Rheumatology, 22(4):* 759-772.

*Yingling, V.R., Callaghan, J.P. and McGill, S.M. (1997). The porcine cervical spine as a model of the human lumbar spine: an anatomical, geometric and functional comparison. *Journal of Spinal Disorders. 12(5):* 415-423 (from Gallagher and Marras, 2012).

Zalk, D.M. (2001). Grassroots ergonomics: Initiating an ergonomics program utilizing participatory techniques. *Annals of Occupational Hygiene*. *45(4):* 283-289.

APPENDIX A: GENERAL INFORMATION

1. Letter of information to participant

2. Participant consent form

3. Equipment checklist

LETTER OF INFORMATION:

RHODES UNIVERSITY
DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS
Cell: 084 429 4564 • Fax: (046) 603 8934 • E-mail: g08p0634@campus.ru.ac.za

Dear participant,
Thank you for agreeing to take part in my Masters Research project entitled:

"A field investigation into the impact of technological advances on task demands and worker responses within the silviculture sector of South African forestry"

AIM OF THE STUDY

Planting and pitting jobs in South African forestry are not very well understood. For this reason, we are investigating the demands of these jobs, and also the capabilities of the workers who carry out these jobs. We will be looking at the way planting and pitting is performed now, and also the way each task is performed with the new tools that are being introduced. The aim of the current project is to look at the task demands of each job and the forestry workers abilities to perform them. We will also measure worker characteristics so that we can get a better understanding of the individuals who work in the forestry industry. This will assist us in designing these jobs in such a way that will help workers to be more productive, but also to make sure they do not get hurt during their work.

PROCEDURE AND REQUIREMENTS

Your participation will be divided into two parts. The first will take place in the afternoon once you have completed a work day, and the second will be conducted the next day, while you perform a normal work shift in the field. Before assessments commence, all procedures will be explained verbally, after which you will need to sign a form stating that you are willing to participate in this study.

Part 1

In the afternoon before your next work shift, you will be given a few questionnaires to answer. These will have questions, for example, about your work experience, whether you have suffered any injuries at work and about your state of health. These will be voluntary, therefore you will not have to answer anything you are uncomfortable with. The following measurements will also be taken:

- Stature (how tall you are)
- Mass (how much you weigh)
- Waist-to-hip ratio (how wide your waist and hips are)
- Body composition (How much of your body is muscle and fat)
- Blood pressure
- Reference heart rate

<u>Part 2</u>

This next phases will take place during your work shift. When you arrive in the morning, the procedures for the day will be explained again, as well as two scales that you will be asked to look at during the course of the day. These scales are the ‘Rating of Perceived Exertion’, which will show us how hard you think you are working, and ‘Body Discomfort’ where you will be able to indicate if any parts of your body feel uncomfortable and if so, how much discomfort you are feeling. Following this we will attach a heart rate monitor around your chest. This is a belt that measures your heart rate while you work and you will be shown how it works before you need to wear it. You will then need to go about your normal work day and we will watch the tasks you perform. At half an hour intervals throughout the day, we will check your heart rate and record how hard you think you are working according to the RPE scale.

Within the first two hours of your work shift, you will be called aside to a designated area of ground in the field. Here you will have a piece of equipment attached to you, called the lumbar motion monitor (LMM), for approximately half an hour. This piece of equipment will tell us about how your body is moving when you work. This equipment will be shown to you before you need to wear it. In this time you will be required to plant/pit five times manually, followed by five times using the new tools. On a separate day, you will be fitted with a different piece of equipment called a Metamax. With this you will be asked to work manually for six minutes and then for a further six minutes using the new tools. You will be given a six minute break between each method of pitting/planting.

Throughout the day, you may have some photographs taken of you, but we will make sure your face is hidden if any of them are used in the final report. Also, when we have gathered all of the information we need, we will give it a special code so that your name no longer needs to be used, and we won’t be able to tell which participant the data belongs to.

RISKS AND POTENTIAL BENEFITS

Since we will be looking at the job you normally do every day, the project will not be placing you at any risk that you may not usually face. The only potential risk is connected to you using the new equipment, if you are not very experienced with how it works. To overcome this risk, we will make sure you have enough time to get used to the equipment and how it works before we ask you to use it properly in the designated testing area. You may also feel a bit embarrassed when you have to wear the equipment, but once you are used to it and you see that some of the others are doing the same thing, you will hopefully feel more confident.

Through your participation, you will benefit by having the chance to be exposed to new experiences, as well as to learn new things about yourself and your job that you might not have known before. Secondly, in the long term, the information discovered through this research will potentially help your employers to improve your work methods to make sure you aren't at any risk of injuring yourself, and that you don't work harder than your body is able to.

It is important for you to know that, if at any point during this procedure you do not feel comfortable, you have the right to remove yourself from the study, and there will be no negative consequences as a result.

Thank you very much for agreeing to participate, we hope it is a valuable experience for you. Please feel free to ask questions at any point through the research process. You will be given feedback in the form of an informal talk, once the project has been completed. Following this, any further questions you may have will be answered immediately.

Yours Sincerely,

Rhiannon Parker
Department of Human Kinetics and Ergonomics, Rhodes University

Contact:

- 084 429 4564
- g08p0634@campus.ru.ac.za

PARTICIPANT CONSENT FORM:

RHODES UNIVERSITY

DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS

Cell: 084 429 4565 • Fax: (046) 603 8934 • E-mail: g08p0634@campus.ru.ac.za

I,______________________, do hereby consent to participate in this study entitled: **"A field investigation into the impact of technological advances on task demands and worker responses within the silviculture sector of South African forestry."** I have been fully informed about the nature of the research, the procedures of the study as well as the potential risks that might occur during testing. This has been explained to me by the primary researcher both verbally and in writing.

Should any injury be sustained due to the protocol, the Department will cover any fees incurred and take steps to rehabilitate the injury. I do however waiver any legal recourse against the researcher, or against Rhodes University, and will take full responsibility in the event that the injury is shown to be self-inflicted and/or due to non-compliance with the researcher's instructions. This waiver shall be binding upon my heirs and personal representatives. I realize that it is necessary for me to promptly report to the researchers any signs or symptoms indicating any abnormality or distress. I am aware that I may withdraw from participation, without consequences, at any time during the research. I was not pressured into participating in this research test and did so voluntary.

I am aware that my anonymity will be protected at all times and that all the information collected, including photographs taken, may be used and published for statistical or scientific purposes. I have read this participant consent form and any questions that may have occurred to me have been answered to my satisfaction.

Signed at ____.

PARTICIPANT

______________ ________________ _____________

(Print name) (Signed) (Date)

RESEARCHER

______________ ________________ _____________

(Print name) (Signed) (Date)

WITNESS

______________ ________________ _____________

(Print name) (Signed) (Date)

<u>EQUIPMENT CHECKLIST:</u>

Anthropometry/ Demographic/ Reference equipment

- Measuring tape
- Scale
- Skinfold callipers
- Heart rate monitors
- Gel
- Sphygomomanometer

Physiological equipment

- Metamax unit
- Calibration kit
- Masks
- Head caps

Biomechanical equipment

- LMM
- Camera: 3DSSPP
- Dynamometers

Psychophysical equipment

- RPE Scale (English and Zulu)
- Body Discomfort Map

General equipment

- Laptop
- Stopwatch
- Whistle

Stationary

- Pens
- Pencils
- Paper
- Clipboards
- Stapler
- Files
- Calculator
- Highlighters

Documents

- Consent forms
- Letters of information
- Questionnaire
- Data Sheets

APPENDIX B: DATA COLLECTION

1. Rating of Perceived Exertion Scale – English

2. Rating of Perceived Exertion Scale – Zulu

3. Zulu Explanation of RPE Scale

4. Body Discomfort Map and Rating Scale

5. Zulu Explanation of Body Discomfort Scale

6. Data collection sheet

7. Health status and Musculoskeletal incidence questionnaire

RATINGS OF PERCEIVED EXERTION (ENGLISH)

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

RATINGS OF PERCEIVED EXERTION (ZULU):

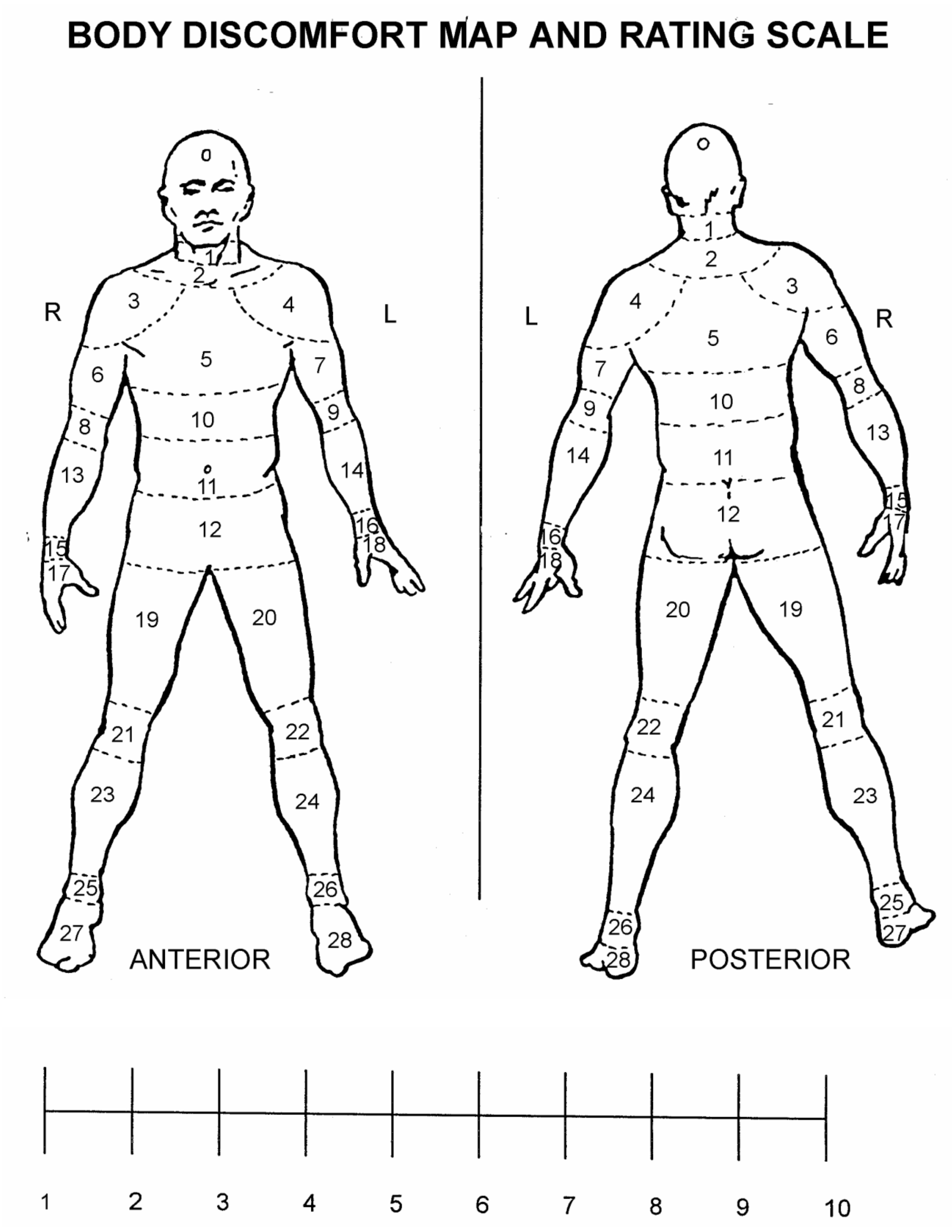
NUMERICAL	VERBAL
6	
7	KULULA KAKHULU
8	
9	KULULA
10	
11	KULULA KANCANE / KULULANA
12	
13	KUNZIMA KANCANE / KULIKHUNYANA
14	
15	KUNZIMA / KULIKHUNI
16	
17	KUNZIMA KAKHULU / KULIKHUNI KAKHULU
18	
19	KUNZIMA NGOKUSEZINGENI ELIPHEZULU / KULIKHUNI NGOKUSEZINGENI ELIPHAKEME
20	

ZULU EXPLANATION OF RPE SCALE:

Ngalesikhathi usebenza kufuneka ukuthi ucabange ukuthi uzizwa ukuthi usebenza kanzima kangakanani: ngolusemandleni akho ucabanga ukuthi usebenza kangakanani. Kuzodingeka ukuthi ukhombe inamba lapha esikalini, ngalenamba uzobe uchaza ukuthi uzizwa kanjani. Okokuqala uzobe uchaza ukuthi inhliziyo yakho namaphaphu akho asebenza kangakanani, lena ibizwa ngokuthi I “Central RPE” okwesibili uzobe ubuzwa ukuthi amamasela(njengemilenze, izingalo noma iqolo) akho asebenza kangakanani.

Kubalulekile ukuthi uphendule ngokuseqinisweni, ungasho ngaphansi noma ngaphezulu kwezinga okuyilona osebenza ngalo. Kuzodingeka ukuthi njalo emuva kwemizuzu elushumi nanhlanu usinike lezizimpendulo kuze kuphele isikhathi sakho sokusebenza. Uma impendulo yakho ingu (6), kuchaza ukuthi uzobe uzizwa ngalendlela ozizwa ngayo njengamanje uhlezi ungenzi lutho. Impendulo engu (20), ichaza ukuthi usebenza kanzima kangangokuthi awusakwazi ukuqhubeka, sekufanele ume.

BODY DISCOMFORT AND RATING SCALE:



MINIMUM INTENSITY MAXIMUM INTENSITY

ZULU EXPLANATION OF BODY DISCOMFORT MAP:

Njalo emuva kwehora kuzodingeka ukuthi ukhombe indawo lapho lapho uzizwe uhlukumezeka khona emzimbeni wakho ngalesikhathi usebenza ngalelohora. Kunephepha elinezitho zomzimba ezihlukile lapho ungakhomba khona ukuthi ubuhlukumezeke kuphi. Lezitho zinikezwe izinombolo kusukela ku 0 kuya ku 27. uma usuzikhombile izitho zomzimba ozwe ubuhlungu noma ukuhlukumezeka kuzo kuzodingeka ukuthi ukhombe ukuthi ubuhlukumuzeke kangakanani kulezozitho. Isikali esisho ukuthi ubuhlukumezeke kangakanani si gcina ku 10. uma uthi 1 uchaza ukuthi ukhululekile ungaqhubeka usebenze kanje isikhathi eside. Uma uthi 10 uchaza ukuthi kubuhlungu kakhulu. Kubalulekile futhi ukuthi uphendule indlela ozizwa ngayo. Ungakali ngaphansi noma ngaphezulu kwezinga lobuhlungu obuzwayo.

DATA COLLECTION SHEET:

GENERAL

Name: ________________________ ***Code:*** __________________________

Sex: __________________________

Date of Birth: ____/____/19______

Task: __________________________

Work experience:

- ____________ (years in current job) ____________ (years in forestry industry)

ANTHROPOMETRY AND BODY COMPOSITION

Stature: ______________________ (mm) ***Mass:*** _____________________ (kg)

Hip circumference: ____________ (mm) ***Waist circumference:*** ____________ (mm)

Skinfold measures

	Measure 1 (mm)	**Measure 2 (mm)**	**Measure 3 (mm)**
Triceps			
Biceps			
Subscapular			
Supra-iliac			
Abdominal			
Thigh			
Calf			

Sum (mm): ______________________ ***Fat (%):*** ___________________

REFERENCE DATA

Reference heart rate (bt.min^{-1}): ___________________________

Reference blood pressure (mmHg):

- *Systolic:* _______________ *Diastolic:* ____________________

PHASE 2: IN-FIELD

Shift duration measures (half hour intervals)

Time	***Heart rate (bt.min^{-1})***	***RPE***	***Activity at time***

Total duration of work shift (hours): ____________________________

Designated testing area measures

Manual task performance

Time	**Heart rate (bt.min^{-1})**	**RPE**

Post rest heart rate (bt.min^{-1}): _____________________________

Mechanised task performance

Time	Heart rate (bt.min^{-1})	RPE

PHASE 3: IN-FIELD PHYSIOLOGICAL RESPONSES

Designated testing area measures

Manual task performance

Time	Heart rate (bt.min^{-1})	EE

Post rest heart rate (bt.min^{-1}): ______________________________

Mechanised task performance

Time	Heart rate (bt.min^{-1})	EE

HEALTH STATUS AND MUSCULOSKELETAL INCIDENCE QUESTIONNAIRE:

HEALTH STATUS

<u>Non-communicable</u>

DIABETES

- Do you have diabetes? _______________
- Are you on medication for it? ___________

____

____

CHOLESTEROL

- Has your cholesterol been measured? _______________________________
- If so, have you been told you have a high cholesterol? _________________
- Do you remember what it is? _______________

HEART DISEASE

- Do you have heart disease? _______________________________
- If so, are you on any medication for it? ______________________

____

____

____

____

HYPERTENSION

- Has your blood pressure been measured? ____________________________
- If so, have you been told you have a high blood pressure? ______________
- Are you on high blood pressure medication? _____________________

SMOKING

- Do you smoke? ________________________________
- If so, how many a day? __________________________
- If you do not smoke now:
    - Are you an ex-smoker (used to), or a non-smoker (never)? ____

ALCOHOL

- Do you drink alcohol? ________________
- What do you usually drink? _______________________
- How many drinks do you have a day? ____________________

<u>Communicable</u>

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

- TB ____
- Pneumonia ____
- Gastro-enteritis ____
- Influenza ____
- Meningitis ____
- Cholera

Do you have any other health problems?

____

____

____

MUSCULOSKELETAL INCIDENCE

EXISTING

- Are you currently suffering from a musculoskeletal injury? ______________
- If so, what part of your body, and what is the injury?

  ____

  ____

- Did your work cause your injury? _______________
- Did you receive treatment and if so what kind?

  ____

  ____

APPENDIX C: ADDITIONAL RESULTS

1. Spinal kinematic walking results for pitting and planting

SPINAL KINEMATIC WALKING RESULTS:

PITTING

Represents significantly different findings between manual and Semi-mechanised pitting

Sagittal plane

	Pitting Phase		Walking Phase	
	Manual	Mechanised	Manual	Mechanised
Max. Extension (deg)	6.34 (6.09)	3.72 (5.65)	0.89 (5.07)	-0.21 (6.04)
Max. Flexion (deg)	28.82 (7.25)	11.59 (6.67)	10.06 (6.06)	5.09 (5.7)
Sagittal Range (deg)	22.48 (6.6)	7.87 (2.43)	9.64 (4.23)	18.86 (73.14)
Average Velocity ($m.s^{-1}$)	11.43 (4.02)	2.58 (1.06)	6.22 (2.68)	3.84 (1.49)
Max. Velocity ($m.s^{-1}$)	76.52 (24.62)	12.92 (3.89)	21.17 (8.91)	14.38 (4.75)
Max. Acceleration($m.s^{-2}$)	541.51 (177.28)	94.12 (27.25)	152.56 (60.39)	110.82 (41.71)

Lateral plane

	Pitting Phase		Walking Phase	
	Manual	Mechanised	Manual	Mechanised
Max. Left Bend (deg)	-7.71 (5.81)	-4.31 (4.71)	-3.43 (4.70)	-2.92 (5.25)
Max. Right Bend (deg)	11.86 (7.29)	1.78 (4.87)	6.29 (3.81)	3.92 (4.95)
Lateral Range (deg)	19.56 (5.89)	6.06 (2.18)	9.66 (3.26)	6.82 (2.38)
Average Velocity ($m.s^{-1}$)	10.61 (3.53)	2.39 (0.93)	8.6 (3.13)	4.85 (1.66)
Max. Velocity ($m.s^{-1}$)	53.58 (16.67)	11.36 (3.63)	27.77 (8.16)	16.16 (4.6)
Max. Acceleration($m.s^{-2}$)	383.11 (132.48)	84.26 (27.13)	206.23 (60.58)	122.34 (28.62)

Transverse Plane

	Pitting Phase		Walking Phase	
	Manual	Mechanised	Manual	Mechanised
Max. Left Twist (deg)	-5.11 (3.83)	-2.95 (3.41)	-1.51 (4.22)	-0.19 (3.15)
Max. Right Twist (deg)	10.72 (3.65)	2.5 (2.77)	7.12 (4.16)	5.26 (3.03)
Max Twist Angle (deg)	15.82 (4.51)	5.45 (1.54)	8.62 (3.77)	5.91 (1.93)
Average Velocity ($m.s^{-1}$)	8.38 (3.66)	2.4 (2.27)	7.32 (3.66)	4.0 (1.59)
Max. Velocity ($m.s^{-1}$)	42.53 (15.23)	18.76 (19.48)	35.51 (62.5)	16.22 (4.83)
Max. Acceleration($m.s^{-2}$)	304.05 (124.49)	120.84 (25.27)	168.82 (56.96)	124.53 (33.65)

PLANTING

Sagittal Plane

	Planting Phase		Walking Phase	
	Manual	Mechanised	Manual	Mechanised
Max. Extension (deg)	26.97 (8.85)	5.48 (4.67)	6.19 (5.81)	1.06 (5.41)
Max. Flexion (deg)	40.08 (8.46)	18.8 (6.82)	22.15 (9.03)	7.59 (5.23)
Sagittal Range (deg)	13.12 (4.08)	13.32 (5.7)	15.95 (6.35)	6.53 (4.11)
Average Velocity ($m.s^{-1}$)	2.23 (0.93)	4.46 (1.91)	7.97 (2.9)	4.24 (2.0)
Max. Velocity ($m.s^{-1}$)	19.24 (5.35)	24.51 (10.75)	28.12 (8.93)	15.34 (6.68)
Max. Acceleration($m.s^{-2}$)	130.94 (30.7)	159.35 (74.67)	198.93 (69.23)	117.64 (45.17)

Lateral Plane

	Planting Phase		Walking Phase	
	Manual	**Mechanised**	**Manual**	**Mechanised**
Max. Left Bend (deg)	-8.35 (4.44)	-9.11 (4.33)	-6.29 (2.68)	-7.28 (3.28)
Max. Right Bend (deg)	4.8 (3.91)	7.92 (5.6)	6.18 (3.25)	3.19 (3.59)
Lateral Range (deg)	13.15 (5.07)	17.03 (5.97)	12.47 (3.21)	10.47 (4.08)
Average Velocity ($m.s^{-1}$)	2.48 (1.11)	6.02 (2.02)	9.85 (1.94)	8.93 (2.68)
Max. Velocity ($m.s^{-1}$)	18.99 (5.79)	27.13 (9.43)	30.78 (6.97)	28.78 (6.56)
Max. Acceleration($m.s^{-2}$)	126.06 (41.04)	146.59 (43.27)	217.26 (38.56)	212.82 (57.15)

Transverse Plane

	Planting Phase		Walking Phase	
	Manual	**Mechanised**	**Manual**	**Mechanised**
Max. Left Twist (deg)	-0.85 (3.54)	-2.0 (2.83)	-2.91 (2.52)	-0.09 (2.47)
Max. Right Twist (deg)	5.62 (3.78)	7.78 (3.65)	5.54 (3.15)	6.44 (3.14)
Max Twist Angle (deg)	6.47 (3.92)	9.78 (4.67)	8.49 (2.59)	6.53 (3.58)
Average Velocity ($m.s^{-1}$)	1.28 (0.66)	3.50 (1.28)	5.94 (1.73)	5.44 (2.66)
Max. Velocity ($m.s^{-1}$)	14.18 (5.39)	21.25 (6.73)	20.3 (5.69)	18.71 (8.31)
Max. Acceleration($m.s^{-2}$)	108.94 (32.65)	141.97 (36.77)	147.98 (32.84)	144.94 (58.22)

APPENDIX D: SUMMARY REPORTS

1. Statistical analyses – Pitting

2. Statistical analyses – Planting

STATISTICAL ANALYSES (PITTING):

SPINAL KINEMATICS

Sagittal plane

Maximum Flexion

T-test for Dependent Samples (Spreadsheet 12) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	28.82231	7.253258						
Semi-mechanised	11.58538	6.669374	26	17.23692	4.778702	18.39232	25	0.000000

Maximum Extension

T-test for Dependent Samples (Spreadsheet 14) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	6.340385	6.087743						
Semi-mechanised	3.720000	5.653855	26	2.620385	6.667429	2.003980	25	0.056021

Range of Motion

T-test for Dependent Samples (Spreadsheet2) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	19.56423	5.885990						
Mechanised	7.86500	2.433880	26	11.69923	5.407747	11.03132	25	0.000000

Maximum Velocity

T-test for Dependent Samples (Spreadsheet1) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	76.52385	24.61858						
Mechanised	12.91923	3.88869	26	63.60462	24.12105	13.44557	25	0.000000

Maximum Acceleration

T-test for Dependent Samples (Spreadsheet7) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	541.5123	177.2846						
Mechanised	94.1185	27.2534	26	447.3938	176.2542	12.94307	25	0.000000

Lateral plane

Maximum Left Bend

T-test for Dependent Samples (Spreadsheet 6) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	-7.70692	5.810845						
Semi-mechanised	-4.31192	4.708340	26	-3.39500	6.544982	-2.64495	25	0.013917

Maximum Right Bend

T-test for Dependent Samples (Spreadsheet 6) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	11.85854	7.291591						
Semi-mechanised	1.78154	4.872593	26	10.07700	7.116955	7.219775	25	0.000000

Range of Motion

T-test for Dependent Samples (Spreadsheet1) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	19.56423	5.885990						
Mechanised	6.06038	2.178134	26	13.50385	5.159878	13.34457	25	0.000000

Maximum Velocity

T-test for Dependent Samples (Spreadsheet6) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	53.58192	16.67126						
Mechanised	11.35577	3.62593	26	42.22615	15.12357	14.23685	25	0.000000

Maximum Acceleration

T-test for Dependent Samples (Spreadsheet5) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	383.1092	132.4771						
Mechanised	84.2631	27.1348	26	298.8462	119.7940	12.72036	25	0.000000

Transverse plane

Maximum Left Twist

T-test for Dependent Samples (Spreadsheet 6) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	-5.10846	3.834947						
Semi-mechanised	-2.95192	3.408660	26	-2.15654	4.366428	-2.51836	25	0.018561

Maximum Right Twist

T-test for Dependent Samples (Spreadsheet) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	10.71538	3.649925						
Semi-mechanised	2.49500	2.770916	26	8.220385	4.420661	9.481818	25	0.000000

Range of Motion

T-test for Dependent Samples (Spreadsheet4) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	15.82308	4.514058						
Mechanised	5.44615	1.542611	26	10.37692	4.094774	12.92187	25	0.000000

Maximum Velocity

T-test for Dependent Samples (Spreadsheet3) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	42.53115	15.23112						
Mechanised	18.76385	19.48176	26	23.76731	25.59891	4.734184	25	0.000074

Maximum Acceleration

T-test for Dependent Samples (Spreadsheet9) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	304.0519	124.4885						
Mechanised	120.8419	25.2698	26	183.2100	124.2332	7.519657	25	0.000000

L5/S1 FORCES

<u>Compression</u>

T-test for Dependent Samples (Spreadsheet 1) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	2245.370	213.9432						
Semi-mechanised	2601.704	239.8688	27	356.3333	261.8451	7.071193	26	0.000000

<u>Shear</u>

T-test for Dependent Samples (Spreadsheet) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	320.5926	37.64333						
Semi-mechanised	360.7778	30.45594	27	40.18519	19.86887	10.50932	26	0.000000

PHYSIOLOGICAL RESPONSES

Heart rate

T-test for Dependent Samples (Spreadsheet 6) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	156.7394	11.77734						
Semi-mechanised	143.2043	16.84173	10	13.53503	21.98136	1.947174	9	0.083344

Energy Expenditure

T-test for Dependent Samples (Spreadsheet 8) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	11.27317	1.963035						
Semi-mechanised	9.79686	3.320726	10	1.476318	3.542444	1.317884	9	0.220099

PERCEPTUAL RESPONSES

Ratings of Perceived Exertion

T-test for Dependent Samples (Spreadsheet 10) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	11.40000	2.065591						
Semi-mechanised	9.40000	1.264911	10	2.000000	2.108185	3.000000	9	0.014956

STATISTICAL ANALYSES (PLANTING):

SPINAL KINEMATICS

Sagittal plane

Maximum Flexion

T-test for Dependent Samples (Spreadsheet 16) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	40.08172	8.464253						
Semi-mechanised	18.80345	6.819399	29	21.27828	8.243893	13.89963	28	0.000000

Maximum Extension

T-test for Dependent Samples (Spreadsheet 18) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	26.96655	8.850902						
Semi-mechanised	5.48034	4.673720	29	21.48621	8.628965	13.40911	28	0.000000

Range of Motion

T-test for Dependent Samples (Spreadsheet 8) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	13.11552	4.080899						
Semi-mechanised	13.32345	5.695177	29	-0.207931	6.027071	-0.185786	28	0.853952

Maximum Velocity

T-test for Dependent Samples (Spreadsheet 16) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	19.23793	5.35112						
Semi-mechanised	24.51103	10.74645	29	-5.27310	10.70293	-2.65315	28	0.012991

Maximum Acceleration

T-test for Dependent Samples (Spreadsheet 24) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	130.9417	30.70468						
Semi-mechanised	159.3538	74.66560	29	-28.4121	71.53502	-2.13886	28	0.041309

Lateral plane

Maximum Left Bend

T-test for Dependent Samples (Spreadsheet 1) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	-8.35034	4.444403						
Semi-mechanised	-9.11034	4.333031	29	0.760000	4.534184	0.902638	28	0.374418

Maximum Right Bend

T-test for Dependent Samples (Spreadsheet 1) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	4.798621	3.905121						
Semi-mechanised	7.921379	5.602863	29	-3.12276	6.439901	-2.6``31	28	0.014332

Range of Motion

T-test for Dependent Samples (Spreadsheet 6) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	13.14862	5.068384						
Semi-mechanised	17.03241	5.967269	29	-3.88379	6.932776	-3.01681	28	0.005388

Maximum Velocity

T-test for Dependent Samples (Spreadsheet 14) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	18.99207	5.791714						
Semi-mechanised	27.12655	9.433526	29	-8.13448	10.08672	-4.34289	28	0.000167

Maximum Acceleration

T-test for Dependent Samples (Spreadsheet 22) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	126.0576	41.04298						
Semi-mechanised	146.5907	43.26803	29	-20.5331	55.45304	-1.99401	28	0.055972

Transverse plane

Maximum Left Twist

T-test for Dependent Samples (Spreadsheet 1) Marked differences are significant at p < .05000

	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p
Manual	-0.85207	3.542534						
Semi-mechanised	-2.00207	2.834565	29	1.150000	3.194561	1.938588	28	0.062692

Maximum Right Twist

T-test for Dependent Samples (Spreadsheet 1) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	5.619310	3.776863						
Semi-mechanised	7.779655	3.646122	29	-2.16034	4.300748	-2.70507	28	0.011489

Range of Motion

T-test for Dependent Samples (Spreadsheet 12) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	6.471724	3.923666						
Semi-mechanised	9.782414	4.671240	29	-3.31069	5.952114	-2.99534	28	0.005683

Maximum Velocity

T-test for Dependent Samples (Spreadsheet 20) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	14.18207	5.388554						
Semi-mechanised	21.24862	6.731275	29	-7.06655	8.705143	-4.37150	28	0.000154

Maximum Acceleration

T-test for Dependent Samples (Spreadsheet 26) Marked differences are significant at p < .05000								
	Mean	**Std.Dv.**	**N**	**Diff.**	**Std.Dv. - Diff.**	**t**	**df**	**p**
Manual	108.9403	32.65444						
Semi-mechanised	141.9745	36.76815	29	-33.0341	49.87766	-3.56661	28	0.001325