A FIELD INVESTIGATION OF PHYSICAL WORKLOADS IMPOSED ON HARVESTERS IN SOUTH AFRICAN FORESTRY

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ABSTRACT

The focus of this field investigation was an analysis of the work demands being placed on South African forestry workers, in particular Chainsaw Operators and Stackers.

Working postures, physiological and perceptual responses were assessed on a sample of 58 workers (29 Chainsaw Operators and 29 Stackers) during a ‘normal’ working shift. Body mass was measured before and after work in order to determine dehydration levels. Polar heart rate monitors were fitted to six workers each day over a period of two weeks in order to record ‘working’ heart rates. Fluid and food intake was monitored and recorded during this initial data collection phase. The Rating of Perceived Exertion and Body Discomfort Scales were explained in Zulu, their native language, and workers were asked to rate their perceptions of effort at regular intervals during work, while areas and intensity of body discomfort was obtained on completion of work. After completing a work shift, a 30 minute ‘recovery’ period was given, thereafter a portable ergospirometer, the $k4b^2$, was attached to the worker who then participated in a progressive, submaximal step test for the purpose of establishing individual, and group, heart rate-oxygen uptake (HR/VO_2) regressions for predicting oxygen uptake from ‘working’ heart rate responses. These procedures were repeated four weeks later following the introduction of a fluid and nutritional supplement during work which was delivered to the workers while they were executing their tasks.

The results revealed awkward working postures with a predominance of trunk flexion during all the harvesting tasks; these postures, adopted for long periods during work, are very likely to lead to the development of musculoskeletal injuries. The mean working heart rates were 123.3 $bt.min^{-1}$ and 117.6 $bt.min^{-1}$ during chainsaw operations and stacking respectively. During the step test, the mean heart rate and oxygen uptake responses were 127.9 $bt.min^{-1}$ and 22.9 $mlO_2.kg^{-1}.min^{-1}$ (Chainsaw Operators) and 116.9 $bt.min^{-1}$ and 24.0 $mlO_2.kg^{-1}.min^{-1}$ (Stackers), revealing no significant difference between the ‘working’ heart rates and the heart rates recorded

during the step test. Physiological responses were analyzed over the full work shift which was divided into four quarters. Heart rate and oxygen uptake were significantly higher during the last half of the Chainsaw Operators' work shift compared to the first half. Heart rate increased from 120.7 $bt.min^{-1}$ during the first quarter to 127.4 $bt.min^{-1}$ during the last quarter of chainsaw operations. Likewise, oxygen uptake increased from 19.9 $mlO_2.kg^{-1}.min^{-1}$ to 22.9 $mlO_2.kg^{-1}.min^{-1}$ from the first to the last quarter of work. During stacking the heart rate (mean of 117.6 $bt.min^{-1}$) and oxygen uptake (mean of 24.6 $ml.kg^{-1}.min^{-1}$) responses remained stable over the duration of the working shift. Workers lost, on average, 2.8% body mass during work while felling and cross-cutting and 3.6% during stacking. This reduced significantly to a loss of 0.4% body mass when re-tested following the introduction of water and food during the work period. Likewise, the energy deficit was significantly improved due to the introduction of a nutritional supplement. Pre-intervention the deficit was 8861.8 kJ (Chainsaw Operators) and 8804.2 kJ (Stackers) while in the post-intervention phase this deficit was reduced by approximately 50% for both groups of workers.

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CHAPTER I
INTRODUCTION

BACKGROUND TO THE STUDY

It is an irony that in spite of increasing automation and the extensive ergonomics research being conducted world wide, injuries due to manual materials handling (MMH) are still a major concern in most industries globally (Marras, 2000). When focusing specifically on the forestry industry it is evident that mechanisation is not as advanced as in other industries, and the widespread ergonomics-related forestry research conducted in many, mostly advanced countries, has done little to lessen the horrendous injury and fatality statistics associated with work in this physically taxing industry (ILO, 1991; Wästerlund *et al.*, 2004).

An intrinsic characteristic of forestry work is that it is an activity which places undue physical demands on workers (Wästerlund, 1998), and is recognised as one of the most dangerous industries in which to be employed (Lilley *et al.*, 2002). The high injury and accident occurrence in forest harvesting has been accredited to physical fatigue resulting from difficult working postures (Apud *et al.*, 1989), high energy-demanding tasks (Lilley *et al.*, 2002) and hostile environmental conditions including falling trees and debris (Golsse and Rickards, 1990; Wästerlund *et al.,* 2004). Not surprisingly, reports indicate a high turnover with the forest harvesting workforce (ILO, 1991) with the majority of foresters only staying in the industry for approximately five years (Manyuchi *et al.*, 2003). Harvesting fatalities have also been shown to be excessively high in advanced countries such as Sweden (Thelin, 2002), New Zealand (Feyer *et al.*, 2000) and Australia (Driscoll *et al.*, 1995).

If this problem of work place hazards in forestry is so severe in the more developed nations, it is likely to be exacerbated in Industrially Developing Countries (IDCs) such as South Africa. According to O'Neill (2000), the greatest disparity between IDCs and advanced countries is the amount of materials moved by manual effort. The forestry industry may be the exception as it is clear that forestry demands are universally recognised as being excessive. However, in developing countries there are many additional compounding factors, independent of the working environment, which impact performance at work. For example Apud (1983), who undertook his forestry research in Chile, argued that when conducting ergonomics research in poorer societies, consideration must be given to the workers' nutritional status, hygiene, education and socio-economic position as these are all known to impact the capacity of the worker. In South Africa it is well known that most of the population are living in poverty with associated poor health and nutritional status (Bradshaw and Steyn, 2001; Christie, 2002). These and other issues such as poor education, violence and unemployment contribute to the burden that workers in South Africa and other IDCs have to deal with on a daily basis. In industrialised countries these burdens may appear irrelevant since most of the workers basic needs are met, while in IDCs the compounding affect of these poverty-related circumstances must ultimately have a negative impact on worker well-being and work performance. With specific reference to the working environment, additional concerns surround the fact that since the out-sourcing of forestry operations to contractors within South Africa it is believed that work practices have been further negatively influenced due to contractors lacking the appropriate knowledge, or resources concerning safe work practices (Manyuchi *et al.*, 2003). Furthermore, the workers are also affected by the payment of low wages compounding the poor socio-economic status of these people.

The applicability of First World forestry recommendations to Third World countries is therefore questioned when the situation is so different within the developing world. Ergonomics should, according to Haines and McAtamney (1995), aim to benefit the workers, the company and the industry as a whole which they argue can only be achieved when the research is conducted on the population group for which the recommendations are being made. Turning specifically to South Africa, Scott (2003) contends that there is a clear need for ergonomics research in industries within South Africa and that we should not simply draw on research done by those in more affluent societies. She further maintains that this South African-specific research will assist in reducing the negative spiral associated with excessive physical workloads and poor living conditions seen in the country.

Commercial forestry in South Africa is a major contributor to the country's gross agricultural output with an annual turnover of billions (Tewari, 2001). The industry is also a major provider of rural employment with most of the workers in the harvesting sector coming from rural backgrounds (Scott and Christie, 2004). The harvesting tasks performed encompass the felling and cross-cutting of trees which are then debarked and stacked into piles for mechanical removal from the area. The workloads imposed are dependent on the work area and type of tree, but typically these workers adopt a 'work-to-task' regime where they are required to fell or stack a certain amount of timber per shift, and once the task has been completed they are permitted to go home. The three tasks assessed in the present investigation were felling, cross-cutting and stacking, tasks all known to place substantial physical demands on workers (Kaminsky, 1960; Apud *et al.*, 1989; Mazzoni *et al.*, 1998; Lilley *et al.*, 2002).

The working postures adopted during these tasks are awkward, contributing to a high injury occurrence and early worker retirement (Mazzoni *et al.*, 1998; Manyuchi *et al.*, 2003). Furthermore, although energy expenditure research is limited, due to equipment and experimental constraints, harvesting tasks are categorised as placing "heavy" to "unduly heavy" demands on workers contributing to early onset fatigue indicators and compromised work safety (Lilley *et al.*, 2002). Noteworthy is the widespread disparity in the energy expenditure findings. For example, some studies have shown energy cost of values of 4-5 kal.min^{-1} during chainsaw operations (Kaminsky, 1960; Durnin and Passmore, 1967), while others have reported much higher costs of between 8 kcal.min^{-1} and 9 kcal.min^{-1} (Apud *et al.*, 1989) during the same type of work. Similar discrepancies are evident in the research on Stackers with some indicating that stacking costs in excess of 12 kcal.min^{-1} (Durnin and Passmore, 1967; Apud *et al.*, 1989), while others report a cost of 6-7 kcal.min^{-1} (Apud, 1983). Apud *et al.* (1989) attribute these discrepancies to the fact that each forestry region is unique, and identifies the need for ongoing ergonomics research in different forestry areas with the local work force.

The energy-generating capabilities of rural South African forestry workers are also questioned, as according to Barac-Nietro (1987), under nutrition impacts both work effort and endurance time. It is therefore contended that due to issues surrounding reduced worker capacities, the required effort to sustain the tasks of felling, cross-cutting and stacking will be markedly affected compared to the same type of work being performed by workers from more developed nations. Several studies have reported on the poor nutritional status of rural South Africans (Richter *et al.*, 1984; Charlton *et al.*, 2001), while others have discussed the high energy demands of manual work in the country (Christie, 2002; Scott and Charteris, 2004). However, limited research has examined the relationship between the energy cost of manual labour and the associated poor caloric intake (Christie, 2002). One of the few studies which has considered this relationship revealed an energy deficit of approximately 8 846 kJ during work (Lambert *et al.*, 1994). This study, conducted on sugar cane cutters and stackers in Kwazulu-Natal South Africa, showed that energy expenditure during work was over 14 000 kJ, while energy intake over the same time period was only marginally above 5 000 kJ (Lambert *et al.*, 1994). These authors reported reduced work efficiency due to this energy deficit.

A further contributor to the lack of research in this field appears to be related to the fact that the investigations are limited to *in situ* analyses as the replication of harvesting tasks within a laboratory setting is technically unfeasible. Most of the sophisticated equipment available to assess physical workloads is more appropriate for laboratory assessment with limited use within the actual field of work (Scott and Christie, 2004). The main problem encountered surrounds predominantly the equipment, which can only test one worker at any given time, interferes with ‘natural’ work patterns and can be affected by climatic conditions (Garg *et al.*, 1978). The present study was therefore an *in situ* investigation supporting the contention of Scott and Renz (2006) that there is a need to recognise more fully that ergonomics is an “applied” science with a need for more scientists to go out into the ‘real world’ to assess work demands in order to provide effective intervention strategies. Recognising this, the main focus of this investigation was to assess the physical demands of chainsaw operations and stacking within the actual field of work.

Due to the complexities surrounding research in forestry, it is contended that any ergonomics investigation in the industry needs to consider three important elements;

characteristics intrinsic to the tasks being executed, the capabilities of the indigenous workforce and the local conditions, including exposure to the prevailing climate and the natural and material hazards. Although the significance of keeping task demands within the physical capabilities of the worker has been emphasised, in forestry operations generally task demands tend to push workers to their limits on a daily basis. Dempsey (1998) contends that workers who are continuously challenged to their limits will ultimately show signs of fatigue, discontentment, discomfort and injuries. The prime objective of ergonomics is to improve work efficiency thereby ensuring good quality output, while at the same time enhancing worker well-being. The focus of ergonomic investigations is therefore on the “Man-machine/task” interface (Grandjean, 1986). An incompatibility between these two key components, within the general work environment, will result in physical and/or mental strain being experienced by the worker, with poor quality and quantity of productivity being the ultimate outcome.

Charteris *et al.* (1976), recognising the many influences which impact performance, proposed the “Centre-M: Human Kinetic” model. The four broad areas of this model include the physical, biological and psychophysical parameters of human movement. The final domain proposed by Charteris *et al.* (1976) is of a conceptual nature and highlights the need for a holistic, interdisciplinary approach, an approach supported by others (Ayoub and Mital, 1989; Dempsey, 1998; Marras, 2000). The present study therefore took a holistic stance by acknowledging those factors likely to directly or indirectly impact on work performance in the forestry sector of South Africa.

STATEMENT OF THE PROBLEM

Recognising the universally accepted fact that forest harvesting is an excessively physically demanding job and that each geographical area has its own distinct challenges, the problem addressed in this project was to assess the physical capabilities of an indigenous forestry work force as well as these workers’ responses to harvesting tasks with the main emphasis being on worker responses to felling, cross-cutting and stacking. IDCs in general, and specifically South Africa, have distinct challenges to address which encompass characteristics fundamental to both the tasks and the human operators. The current project was therefore conducted on local harvesters, in South Africa. Finally, as the forestry area investigated in this study is situated in a tropical area, consideration of the effect of the environment on work performance was also a critical issue.

RESEARCH HYPOTHESIS

The hypothesis proposed was that analyses of the harvesting tasks would reveal that excessive physical (biomechanical and physiological) and psychophysical demands are being imposed on forestry harvesters, and that these demands would be intensified over the duration of the work shift. In addition it was hypothesised that the provision of fluid and a nutritional supplement during the work shift would improve the workers' responses during task execution.

STATISTICAL HYPOTHESES

The following null hypotheses were generated for investigation:

1 (a) During outdoor forestry work the physiological responses will remain unchanged over time.

Ho: $\mu CV_{(1st\ Quarter)} = \mu CV_{(2nd\ Quarter)} = \mu CV_{(3rd\ Quarter)} = \mu CV_{(4th\ Quarter)}$

Ha: $\mu CV_{(1st\ Quarter)} \neq \mu CV_{(2nd\ Quarter)} \neq \mu CV_{(3rd\ Quarter)} \neq \mu CV_{(4th\ Quarter)}$

1 (b) In addition, the perceptual responses during outdoor forestry work will remain constant for the duration of the work shift.

Ho: $\mu PER_{(1st\ Quarter)} = \mu PER_{(2nd\ Quarter)} = \mu PER_{(3rd\ Quarter)} = \mu PER_{(4th\ Quarter)}$

Ha: $\mu PER_{(1st\ Quarter)} \neq \mu PER_{(2nd\ Quarter)} \neq \mu PER_{(3rd\ Quarter)} \neq \mu PER_{(4th\ Quarter)}$

2 (a) Physiological responses would not differ between the two experimental conditions. This hypothesis incorporated the examination of cardiovascular responses, in addition to the assessment of fluid and energy balance.

(i) Ho: $\mu CV_{(Pre)} = \mu CV_{(Post)}$

Ha: $\mu CV_{(Pre)} \neq \mu CV_{(Post)}$

(ii) Ho: $\mu FB_{(Pre)} = \mu FB_{(Post)}$

Ha: $\mu FB_{(Pre)} \neq \mu FB_{(Post)}$

(iii) Ho: $\mu EB_{(Pre)} = \mu EB_{(Post)}$

Ha: $\mu EB_{(Pre)} \neq \mu EB_{(Post)}$

2 (b) There would be no difference in the perceptual responses pre and post fluid and food supplementation.

Ho: $\mu PER_{(Pre)} = \mu PER_{(Post)}$

Ha: $\mu PER_{(Pre)} \neq \mu PER_{(Post)}$

Where:

1st Quarter = First quarter of the work shift; 2nd Quarter = Second quarter of the work shift; 3rd Quarter = Third quarter of the work shift; 4th Quarter = Fourth quarter of the work shift

CV = Cardiovascular responses of heart rate, oxygen consumption and energy expenditure

PER = Perceptual responses including “Central” and “Local” Ratings of Perceived Exertion

FB = Fluid balance

EB = Energy balance

Pre = Pre-implementation of fluid and food replenishment

Post = Post-implementation of fluid and food replenishment

DELIMITATIONS

This study was delimited to 58 forestry workers ranging in age from 20-51 years. The sample consisted of South African forestry workers from the Kwazulu-Natal region of South Africa who were involved in outdoor forestry work, specifically harvesting.

After a general ergonomics survey of the tasks associated with forest harvesting, and in consultation with management and contractors, the following tasks were selected as the focus of this research project:

- Felling
- Cross-cutting
- Stacking

The initial phase was to assess the indigenous forestry worker characteristics. For this purpose, laboratories were set up near the work sites. During these sessions workers were provided with an outline of the project and were requested to volunteer for participation. Basic data were recorded for all subjects including stature, mass, body composition and resting cardiovascular function. A questionnaire relating to their health status and incidence of musculoskeletal disorders during the preceding 12 months was administered during an interview session in Zulu.

The next phase involved in-depth analyses of the selected tasks *in situ*. This included both the characteristics of the task requirements and the workers' responses to the specific tasks. The experiment focused on physical, physiological and perceptual responses. Dependent variables were the biomechanical stresses which incorporated the analyses of working postures; working heart rates and predicted oxygen consumption (VO_2) and energy expenditure indicated the physiological stresses experienced. Oxygen uptake and energy expenditure responses were predicted from HR/VO_2 regressions obtained from a progressive step test which each worker performed on completion of the work shift. Ratings of Perceived Exertion and Body Discomfort ratings were recorded to obtain a tangible measure of the workers' personal perception of the task demands.

While the workers were assessed *in situ*, fluid and food intake during the shift was carefully monitored and recorded by the researchers. This was done in order to determine potential fluid imbalances, and a possible deficit between energy intake during work and the associated energy cost of the tasks. A month later, these same workers were re-assessed *in situ* executing the same tasks. During this final phase of assessment appropriate nutritional replenishments, both fluid and food were given to the workers during their working time a week before, and for the duration of re-testing. These supplements were delivered to the workers at their specific work area. The same measurements obtained during the initial session were recorded during, and post, the second work shift. Following this second *in situ* assessment, workers were asked a series of questions by a Zulu speaking research assistant. These questions were related to their perceived benefit to their work efficiency due to the nutritional supplementation they had received.

The nutritional assessment was two-fold in that firstly, in order to establish the overall nutritional status of the workers, habitual dietary intake was assessed by the 24-hour dietary recall method presented in their language of choice. Secondly, during work, energy intake was assessed both with, and without the supplement. All the nutritional information was entered into a food finder software programme (*FoodFinder3*) to obtain information pertaining to energy intake and dietary composition.

LIMITATIONS

The major limitation of this investigation was the lack of control over extraneous factors which were highly likely to affect worker responses. This was because experimentation was conducted *in situ*. While the importance of laboratory research is acknowledged and accepted, a laboratory simulation of the harvesting tasks chosen for investigation was not possible. As little is known about the physical demands placed on workers within the South African forestry industry, it was considered necessary to conduct a detailed ergonomics investigation within the field of work under current working conditions and within 'natural' working constraints. This was particularly pertinent to the environmental conditions. Therefore, in order to control for the impact of the environmental conditions on work performance, experimentation was only conducted within a narrow environmental 'window' of 10^0C. Testing was cancelled if environmental conditions were deemed to be extreme.

Since a month elapsed from the first to the second assessment of the task (for the investigation of the impact of the fluid and food replenishment) other extraneous factors may have impacted worker performance over time. These include the incorporation of a short vacation over Christmas which may have assisted in recovery from the excessive demands placed on these workers in the previous year. However, this break was only a few days and was highly unlikely to have a substantial beneficial effect and most workers had been back at work for several weeks when the second testing session was conducted.

Although subjects were requested to maintain habitual dietary intake and home activities for the duration of testing, there was no control over the 24 hour life cycle of the workers. How these factors may have impacted performance at work could therefore not be controlled.

Probably the greatest limitation was the findings obtained from the 24 hour dietary recall and the questionnaires relating to health and musculoskeletal integrity. As all the workers were Zulu speaking a translator was used to assist in this part of the experiment. The author concedes that these results are highly unlikely to be reliable despite every effort to ensure that the translator and workers understood what was required.

CHAPTER II
REVIEW OF RELATED LITERATURE

INTRODUCTION

The forestry and forest products industry is a significant part of the South African economy contributing approximately 1–2% to the Gross Domestic Profit (GDP). The total forestry industry employs approximately 1 million people, mainly rural South Africans, who depend on the industry for survival (Minister of Water Affairs and Forestry, 1996). Approximately 150 000 of these are employed in the harvesting sector of Commercial Forestry, and the manual labourers from this sector were the focus of the present investigation.

It is universally accepted that manual forestry work is considered 'high risk' employment. These risks are predominantly due to the labour-intensive nature of the tasks and the natural and material hazards, all of which contribute to an increased threat of injury to the forestry worker (Driscoll *et al.*, 1995; ILO, 1991; Bentley *et al.*, 2002; Wästerlund *et al.*, 2004; Scott and Christie, 2004). In contrast to other tasks in forestry, harvesting is particularly hazardous contributing between 38% and 90% of all the accidents in the industry (ILO, 1991; Manyuchi *et al.*, 2003). Although falling trees and hand held machinery increase this risk, it has been argued that injuries in forestry are predominantly due to the tremendous biomechanical and physiological load associated with the type of work required (Kukkonen-Harjula and Rauramaa, 1984; Gaskin, 1990; Parker and Kirk, 1994; Parker *et al.*, 1999; Sullman *et al.*, 1999; Manyuchi *et al.*, 2003). These high loads are likely to result in the premature onset of fatigue resulting in a decrease in vigilance and an increase in risk taking on the part of the worker which in turn, increases the likelihood of injury from material hazards (Lilley *et al.*, 2002).

Although these work-related hazards are generally well accepted, and despite the plethora of research in the field, it has done little to alleviate the excessive demands being placed on these workers, and as a result forestry has a higher accident frequency than most other industrial sectors around the globe (ILO, 1991).

Furthermore, limited literature exists on the physical workloads placed on forestry workers in the South African sector (Scott and Christie, 2004). Despite the political changes which have occurred in the country since the first democratic elections in 1994, the injustices of the past have resulted in the majority of South Africans living below the poverty line (Bradshaw and Steyn, 2001). The consequence is that many manual workers in the country are living in appalling conditions with a lack of safe drinking water and adequate food. The majority of the work force is therefore under nourished with associated poor health status (Christie, 2001) which ultimately must affect work performance.

SOUTH AFRICAN FORESTRY INDUSTRY

South African Forestry is divided into the three major components of Commercial Forestry (Plantation Forestry), Conservation Forestry and Community Forestry (statsSA, 2000). A component of Commercial Forestry, and the workers involved in that sector, was the area of interest in this study.

COMMERCIAL FORESTRY

Commercial Forestry also referred to as plantation or industrial forestry is divided into the three broad categories of silviculture, harvesting and processing. The Commercial forest industry is the second largest cultivator of land in South Africa and has a capital base of R30 billion and an annual turnover of R12 billion (Tewari, 2001). It meets 95% of the country's needs in wood-based products and has a positive trade balance of R2 billion per annum. The forest industry is one of the strongest forces in creating rural employment with more than 200 000 people benefiting directly from employment, or indirectly by income-generating opportunities (Tewari, 2001).

Forestry contributes 7.3% to the gross value of agricultural output and forestry plantations, on more than 1.5 million hectares, cover the second largest land area of grown crops, following maize (4 million ha) in South Africa (Refer to Figure 1).

Despite this, South Africa is not a natural forest-rich area with most of its indigenous forests concentrated on the eastern coast in the provinces of Mpumalanga and Kwazulu-Natal. This latter forestry area, Kwambonambi in Kwazulu-Natal, was where the present investigation was conducted (See Figure 1).

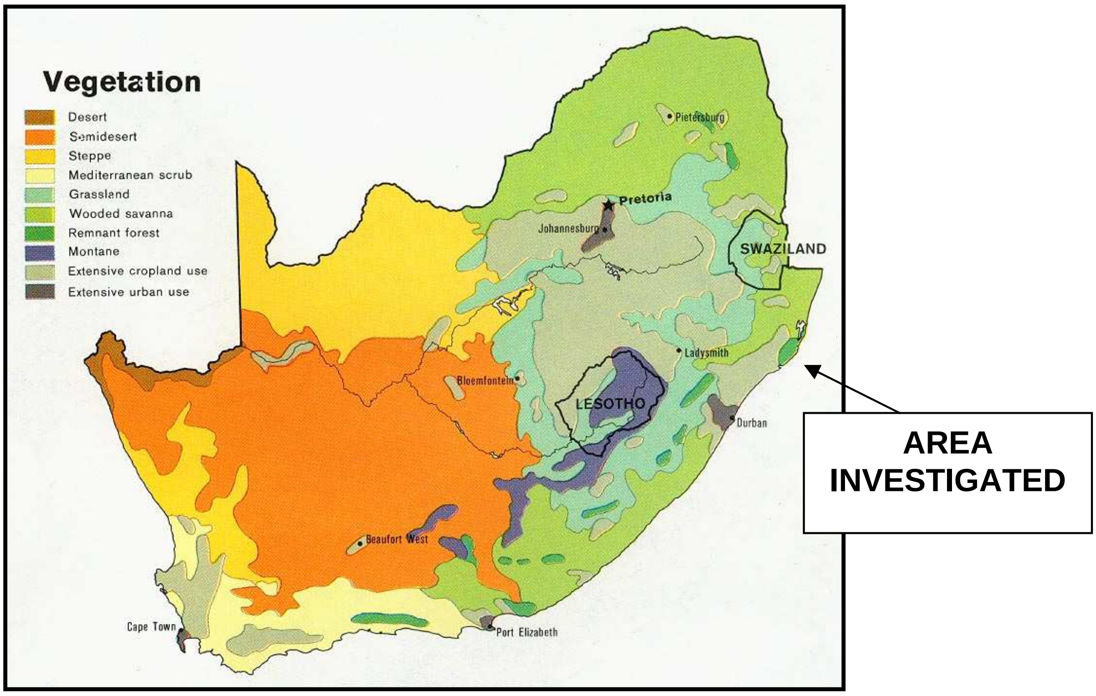


Figure 1: **Wooded savannah and remnant forest areas (shown in green) within South Africa.**

STAKEHOLDERS IN COMMERCIAL FORESTRY

Although there are numerous stakeholders within the industry (Refer to Figure 2), it is argued by Tewari (2001) that the two main ones are management and the workers. Tewari (2001) contends that during the apartheid regime, the power was concentrated with white management and commercial farmers, and the black manual workers were largely disempowered. The main focus at that time was on the economic growth of the industry rather than on sustainable development. In the post-apartheid era however, there has been a rapidly changing face of Commercial Forestry in South Africa with the Commercial forest companies having experienced a gradual weakening of their power and influence (Tewari, 2001). The secondary stakeholders in the industry have therefore increased considerably to include people and the environment beyond the industry itself, which is evident in Figure 2. What is of major concern is that no single group has emerged to gather the power, and the associated accountability, previously had by the larger forestry corporations (Tewari, 2001). As a result, the best interests of the workers are not necessarily a priority in today's forestry industry.

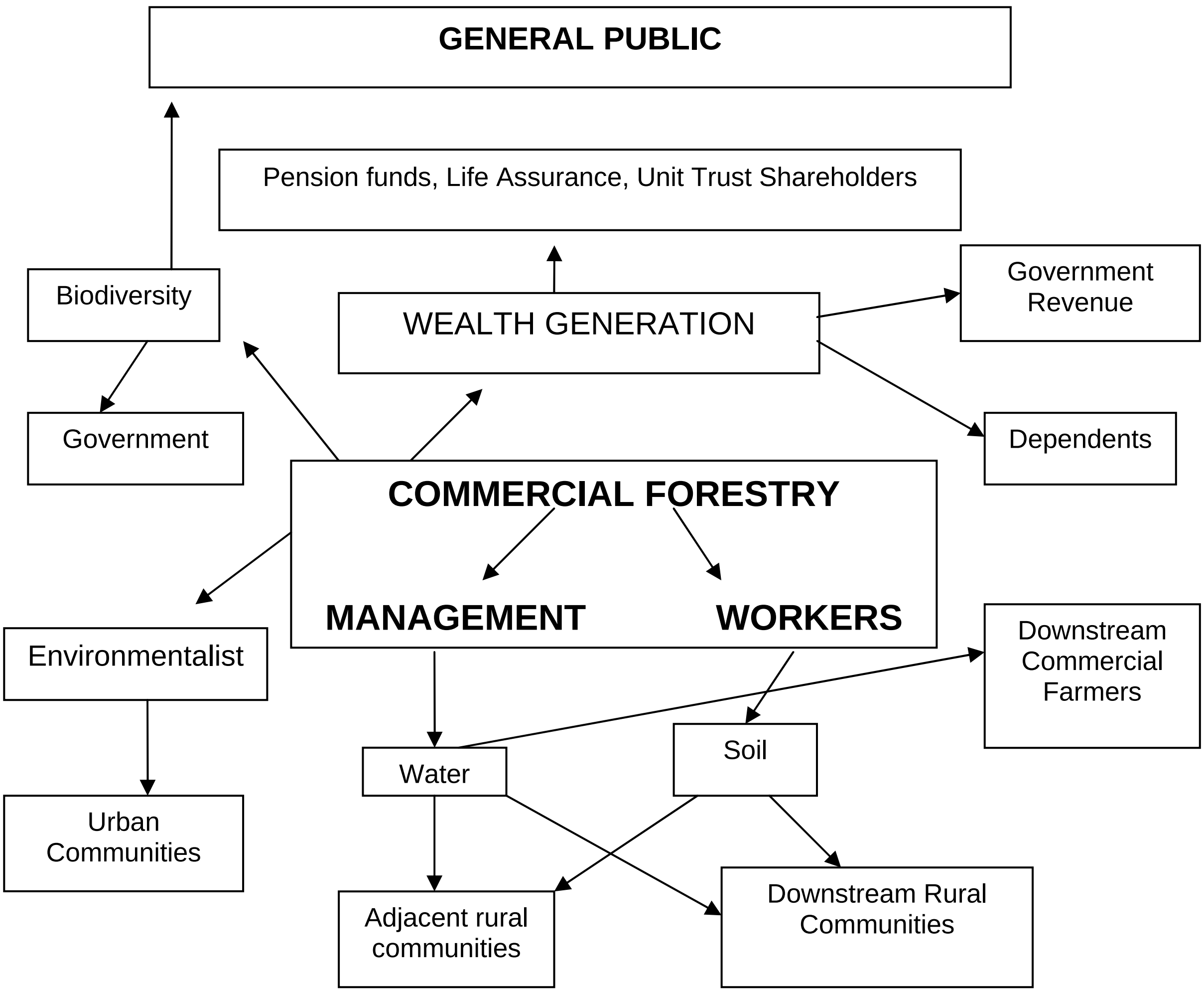


Figure 2: A schematic of stakeholders in Commercial Forestry in South Africa.
(Adapted from Tewari, 2001)

Another change in the post-apartheid era has been the introduction of contracting where the responsibility of work output and hence workers, has shifted from the major companies to smaller contracting companies. According to McLean (1996) the introduction of competitive independent contracting has resulted in poor labour practices in the forestry industry around the world. Even in Sweden, which has a technologically advanced harvesting sector, there has been an upward trend in injury statistics since the introduction of contracting (Thelin, 2002). Tam *et al.* (2003), writing on the behaviour of contractors generally, identified four major areas of concern, these being the lack of: (a) providing and maintaining appropriate tools, (b) adequate training, (c) continuous supervision, and (d) control and organisation. This and other studies contend that contractors are seldom members of an occupational health care system where education and information about work risks are obtainable (Manyuchi *et al.*, 2003; Tam *et al.*, 2003). Limited economic and technical resources also contribute to the lack of training, and to working days with limited rest and recovery.

Otero (1981) described an investigation which found that out of 42 forestry contractors assessed, 41 were infringing the law by paying salaries below the minimum, not having work contracts, providing no safety equipment and by having no safety procedures on site. However, as Apud (1983) points out, the responsibility is not only that of the contractors, but also that of the larger forestry corporations. The contractors are, after all, dependent on the demands of these large companies.

Manyuchi *et al.* (2003) argued that in South Africa, since the out-sourcing of forestry plantations to contractors, the excessive physical demands being placed on the manual workers are being further exacerbated by these poor labour practices. Approximately 23 000 people are estimated to be employed by contractors in the country and Manyuchi *et al.* (2003) purports that this has resulted in employing workers who lack the necessary skills. There is also failure to adhere to acceptable operating standards, the payment of low wages and job insecurity. To address these problems, the South African Forestry Contractors Association (SAFCA) was established which uses a grading system reflecting the quality of work of each contractor. However, the efficacy of this system is not clear. What is disturbing is the employment of workers who lack the necessary skills; this tends to be a common practice in industrially developing countries where unemployment and minimal education predominate (Scott and Charteris, 2004). The reality is that the nature of forestry harvesting work is physically demanding which is exacerbated by these negative influencing variables, and is an ergonomics issue which requires rigorous research.

HARVESTING

The main work tasks of harvesting are firstly the felling of trees followed by cross-cutting the felled trees into sections by a worker referred to as a Chainsaw Operator. These workers are followed by a group of predominantly female Debarkers who are responsible for removing the bark from the trees with the aid of an axe. Lastly, these logs which have been 'debarked' are then positioned onto a 'rack' or 'stack' by a group of workers referred to as Stackers in preparation for removal from the area. The focus of the present investigation was on the physical demands being placed on the Chainsaw Operators and the Stackers, tasks which are traditionally performed by black males within the South African forestry industry.

A range of difficult working conditions characterizes all of the tasks under assessment. The terrain is often steep, uneven and covered with forest debris, the environmental conditions harsh and the work itself is physically demanding (Lilley *et al.*, 2002). Furthermore, the tools of the trade are sharp, heavy and dangerous if not used and maintained properly (Parker *et al.*, 1999). Falling trees and loose branches add to the hazardous nature of the work. Work sites are usually remote and isolated, and facilities often inadequate or non-existent (Apud, 1983). As a generalisation it also tends to have a low status and is a poorly paid occupation particularly in developing countries (Apud *et al.*, 1989). Associated with these factors are the issues of poor productivity and high costs; if forestry workers are exposed to so many negative factors, the work force cannot be stable and productive, and the likelihood of injuries and fatalities increases. It is therefore essential that efforts are made to draw on ergonomics principles to improve this negative scenario.

FATALITIES AND INJURIES IN HARVESTING

In Sweden, an industrialised nation, it is reported that there are 13.6 fatalities per 100 000 workers per year in harvesting (Thelin, 2002). In contrast to other industries in Sweden, trends indicate that fatalities are on the increase within the forestry industry of that country. Other developed nations reveal even more alarming statistics; New Zealand figures suggest 121 deaths per 100 000 workers per year (Feyer *et al.*, 2000) while Australia had 396 deaths per 100 000 workers per year (Driscoll *et al.*, 1995).

Within South African forestry, larger corporations have incorporated a voluntary Accident Reporting System (ARS) similar to that observed in New Zealand. The principle of the ARS is that when an accident occurs a report should be filled in by the contractor and sent to a central recording body. The information is summarised and analysed quarterly, then disseminated. A more comprehensive report is produced annually which contains information on accident trends, accident type, severity and frequency, problem areas are identified and research is targeted towards those areas. Although this manner of accident reporting has purportedly been successful in New Zealand (Sullman *et al.*, 1999), South African reports show a remarkably low accident frequency compared to industrialised nations. For example, in 2003, nine deaths were reported from approximately 31 749 workers involved in harvesting and silviculture (ARS, 2003); this is in stark contrast to New Zealand, Australia and Sweden. Either work practices are "better" in South African forestry or, a more likely explanation is that there is considerable under reporting by contractors or an inaccuracy with respect to completion of forms when an accident does occur.

Analyses of occupational accident risks, or accident frequencies, in South African forestry by Manyuchi *et al.* (2003) found that 10% of their sample had had at least one accident in their forestry working careers. Most indicated that incorrect working technique was responsible for their injuries, while poor working environment (mainly the environmental conditions), equipment failure and inadequate use of personal protective equipment (PPE) were other reasons cited for accidents during work. The tasks associated with the highest accident frequency were chainsaw operations, debarking, stacking and truck and tractor driving.

Overall there are limited scientific studies which have investigated injuries within the South African forestry with the Manyuchi *et al.* (2003) report being one of the few which has made an attempt to determine the extent of the problem. Manyuchi *et al.* (2003) who conducted their investigation on harvesters in Kwazulu-Natal identified that the most common musculoskeletal problem among manual harvesters was backache (See Table I). The workers attributed this to the nature of the tasks performed as well as the equipment utilised; this supports a report by the ILO (1991) which stated that musculoskeletal complaints in forestry mainly affect the lower back because of the demanding nature of the work and unfavourable working postures. However, although only a preliminary investigation, the figures reported by Manyuchi *et al.* (2003) suggests that, like the submission by the ARS (2003), there is still a low incidence of injuries within the South African harvesting workforce, with most of the sample reporting no injuries. It is worth noting that Pransky *et al.* (1999) maintain that the accurate reporting of work-related injuries plays a key role in workplace safety.

Table I: Types of occupational ailments among harvesters.
(Adapted from Manyuchi *et al.*, 2003)

	Percent (%) workers	
Complaint	**Yes**	**No**
Back problems	15.8	84.2
Sight problems	1.1	98.9
Hearing problems	0.5	99.5
Injury to fingers	0.5	99.5

After further analyses, Manyuchi and colleagues found that back problems could be more prevalent than their study revealed; the study found that many workers tend to leave forestry after only a few years, possibly due to injury. Of the sample assessed, 59% of the workers who had back problems had less than 5 years of working experience in forestry, followed by 14% and 27% who had between 5 – 10 years and 10 – 20 years respectively. These authors contend that the results could indicate that back problems are more prevalent than their study indicated because workers with back problems tend to leave forest harvesting and therefore would not be adequately represented in their investigation. This is in accordance with reports from the ILO (1991) who state that early retirement among forestry workers is common and is predominantly due to back problems. Therefore, the extent of injuries within the

South African forestry may in fact not be known, again emphasising the need to obtain accurate accident and injury statistics to ensure that ergonomic efforts are being targeted in the right areas.

OCCUPATIONAL HAZARDS

In forestry there are numerous factors rendering difficult working conditions with which harvesters need to contend. These encompass the material and natural risks, as well as the prevailing environmental conditions.

Material risks in forest harvesting include falling trees and loose branches which are a direct result of forestry operations themselves. Even small trees and branches on the ground can be extremely dangerous and cause serious injury. The handling of trees during felling, cross-cutting, debarking, stacking and transporting is risky, and the forces involved may lead to serious injuries (ILO, 1991). Natural risks incorporate different types of topography, dense harvests and adverse working conditions. These conditions all place extra demands on the body increasing the biomechanical and physiological costs of the tasks. Additionally, these conditions exacerbate the risk of slips, trips and falls and consequential injuries. Bentley *et al.* (2002) report that in New Zealand, 17.5% of all lost time injuries were a result of slips, trips and falls.

Furthermore as forestry is an outdoor occupation, workers are exposed to the prevailing climatic conditions. Temperatures and environmental conditions vary substantially from area to area and between the seasons. South Africa has a fairly temperate climate although extreme cold and extreme heat are often experienced. The forest operation investigated in this study is generally one of the hotter areas of the country especially during the summer months when the study was conducted. Heat load, including temperature, air velocity, humidity and radiant heat, influence a worker's physiological and psychological behaviour (Ayoub and Mital, 1989), and the Wet Bulb Globe Temperature (WBGT) index is one of the most commonly used indices for determining this environmental impact on heat gain (Pascoe *et al.*, 1994). This index combines ordinary air temperature (T_A), temperature affected by wind and humidity, the convective-evaporative wet bulb cooling (T_{NW}) and, temperature affected by radiant heat from the sun (T_G). The index involves a simple weighting of temperature and is calculated as follows:

$$WBGT\ (^0C) = 0.7 \times T_{NW} + 0.2 \times T_G + 0.1 \times T_A$$

The Occupational Health and Safety Association (OHSA) provide WBGT guidelines, seen in Table II, for work of different intensities. In this table it is clear that the higher the metabolic cost of work, the lower the recommended working WBGT. Wind velocity also impacts the recommended WBGT limits reflecting the complex nature of temperature regulation. What the WBGT index and these recommendations do not take into account however, is the impact of clothing and protective gear on the thermal load. These will increase the thermal load and should be considered before making any recommendations.

Table II: Recommendations of OSHA committee for heat stress threshold values for WBGT.
(From Haymes and Wells, 1986)

WORKLOAD	Low Air Velocity $< 1.53\ m.s^{-1}$	High Air Velocity $> 1.53\ m.s^{-1}$
Light $<837\ kJ.h^{-1}$	30.0	32.2
Moderate $841\text{-}1256\ kJ.h^{-1}$	27.8	30.6
Heavy $> 1256\ kJ.h^{-1}$	26.1	28.9

PHYSICAL WORKLOADS

International studies emphasise that the major contributor to injury is the constant exposure of forestry workers to excessive physical stress (Kukkonen-Harjula and Rauramaa, 1984; Hagen *et al.*, 1993; Lilley *et al.*, 2002). Despite extensive efforts, mainly in the form of engineering advances to reduce the amount of manual effort required in harvesting work, there are still high elements of manual and motor-manual labour (Wästerlund *et al.*, 2004). Mechanical trends are most evident in Industrially Advanced Countries (IACs) where the motor-manual cutter is, in some areas being replaced by the mechanical harvester, and timber being transported by a forwarder (Parker *et al.*, 1999). This mechanisation, although known to contribute to other injuries, has reduced the physical strain of harvesting, but the high costs involved make this mechanisation unattainable for even some developed nations (Parker *et al.*, 1999). In South Africa, mechanisation is still in its infant stages with further mechanised operations not likely to be introduced in the foreseeable future. Hence the high prevalence of manual and motor-manual labour is, and will continue to be of major concern, emphasising the importance of keeping forestry task demands within the capacity of the indigenous South African work force (Scott and Christie, 2004).

Most harvesters also select to 'work-to-task' which means that they adopt a fast working pace in order to complete the task as soon as possible enabling them to go home earlier. These workers therefore seldom take rest periods during their shift. Although the perception is that work completed rapidly will maximize short-term productivity, the long-term effects are chronic fatigue resulting in injuries and decreased productivity. Panter-Brick (2003) argues that under nourished workers, typical of workers in developing countries, cannot sustain this intensity of effort over time.

CHAINSAW OPERATOR

Work Procedure

Felling and cross-cutting constitute motor-manual tasks, i.e. tasks done by a worker manually, but with the aid of a chainsaw (Parker *et al.*, 1999). The chainsaw is the single most dangerous tool in forestry, with the Chainsaw Operator recognised as the most exposed worker in forestry (Parker and Kirk, 1993). It is therefore both physically taxing work and dangerous, contributing to a high injury incidence. According to Parker *et al.* (1999) in the past large and heavy chainsaws were used because the trees were larger than they are today. In their study, which investigated the impact of chainsaw mass on physiological cost, it was expectedly found that there was increased cardiovascular strain with increasing chainsaw mass; the chainsaws under investigation weighed 9.5, 8.2 and 7.7 kg (Parker *et al.*, 1999). Today, most chainsaws weigh in the region of 7 kg.

The Chainsaw Operator fells ‘x’ number of trees per work shift, and then cross-cuts these fallen trees; the quantity varies depending primarily on tree type and area, amongst other factors. The normal working procedure is to work for a period (30-45 minutes) and then take a ‘rest’ for up to 15 minutes to refuel or sharpen the chain and/or to perform repair work to the chainsaw (Apud *et al.*, 1989). The task of the Chainsaw Operator is therefore of an intense, but intermittent nature. However, according to Ashby *et al.* (2002), Chainsaw Operators are involved in other physical activities, the most notable additional task being walking. Shown in Figure 3 are the various cognitive and physical tasks which these authors found comprised a typical workday for a New Zealand feller.

In New Zealand, at the start of the day, an initial assessment of the conditions relating to the environment, the type and growth of the trees and any potential risks is carried out (Ashby *et al.*, 2002). These authors state that the planning of the order and method for felling trees is dependent on this initial assessment. Shown in Figure 3 is the example that, if for instance the feller does not prepare properly (see plan 1 in Figure 3), it can increase the risk of injuries due to for example, the absence of personal protective equipment, malfunctioning equipment and fatigue or heat stress. Accordingly, these authors emphasise that poor assessments of wind direction and speed or the weight distribution of a tree (plan 3) can increase the risk of the feller being struck by a falling tree being felled. In addition, there is considerable room for error, referred to as unintentional active failure by the feller, which may be due to poor judgement (Ashby *et al.*, 2002). Major contributors to felling accidents include felling trees with a ‘hang-up’ in them (felled trees caught up in nearby trees), poor felling technique and working too close to other fellers, within two tree lengths (Peters, 1991).

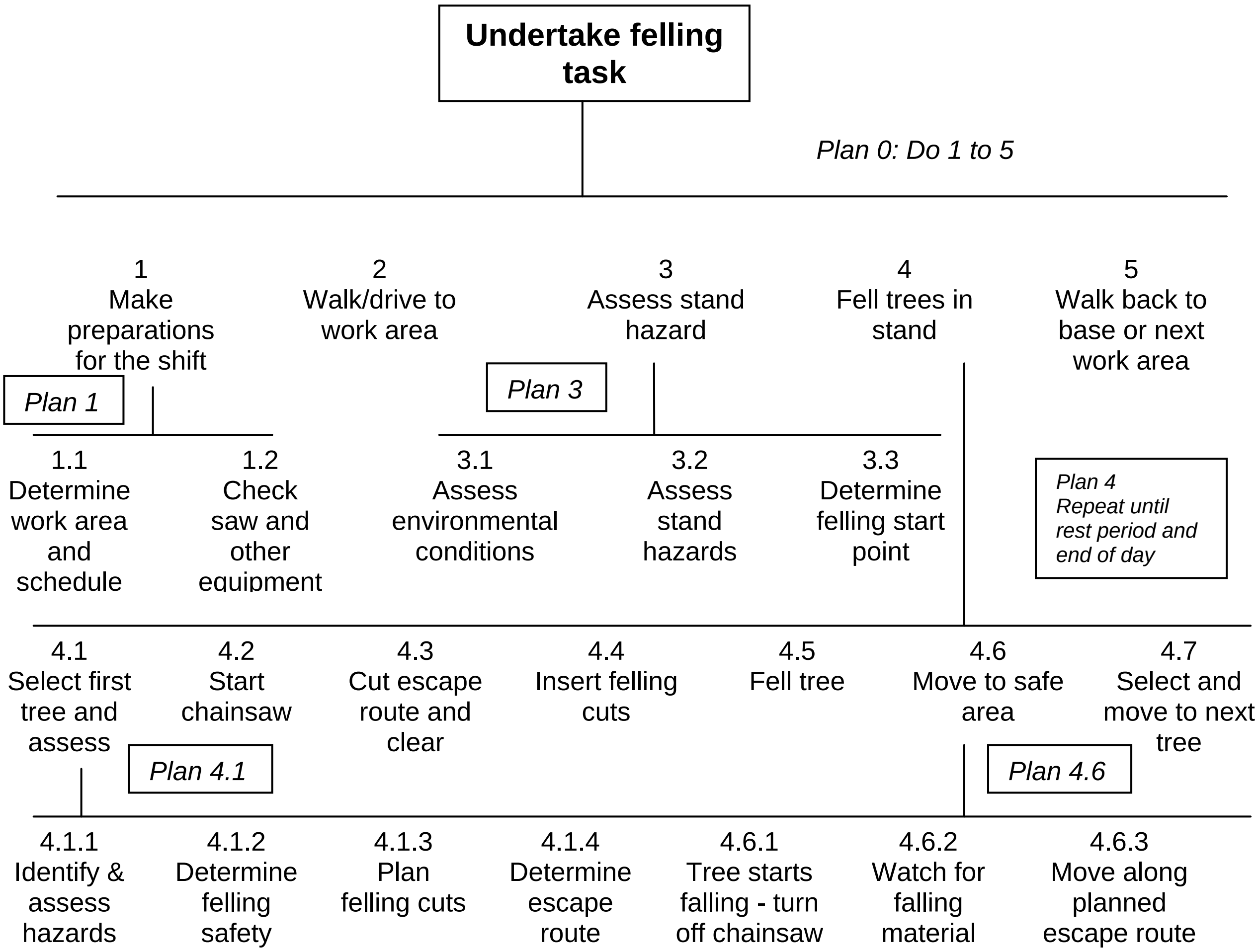


Figure 3: Hierarchical task analysis of a New Zealand feller during a typical work day.
(Adapted from Ashby *et al.*, 2002)

Although it is well accepted that felling is a difficult and dangerous procedure which requires adequate tools, training and experience (Axelsson, 1998), death by falling trees is still the most common cause of fatalities in harvesting. Recognising this risk, larger forestry corporations ensure that workers have properly maintained chainsaws and are adequately trained in safety procedures. Additionally, a number of countries have established minimum standards of training required by Chainsaw Operators to ensure proper work organisation crucial for safety and ultimately, productivity. However, whether this type of practice is evident with smaller contracting operations in South Africa, is questionable. As a generalisation, the training provided by contractors is known to be sub-optimal or even non-existent (Manyuchi *et al.*, 2003; Tam *et al.*, 2003), even though there are industry standards and guidelines such as the Forestry Engineering South Africa (FESA) Harvesting Code of Practice and the Chainsaw Operator's Manual (Manyuchi *et al.*, 2003).

Other risks to the Chainsaw Operator include vibration and noise. Occupational vibration exposure is typically considered in two categories: segmental and whole-body. The greatest health concern in segmental vibration is the occurrence of hand-arm vibration syndrome (HAVS) among users of powered hand tools, including chainsaws. Rummer (1998) found that forest workers perceived vibration to be one of the most uncomfortable aspects of their work, and Manyuchi *et al.* (2003) attribute finger problems experienced by Chainsaw Operators to the existence of vibration-induced disturbance of blood circulation resulting in numbness. Furthermore, hearing defects due to the continuous exposure to the noise of the chainsaw are common among these workers (McFarlane, 1989). This can be attributed to the high noise levels (above 85 dB) that these workers are exposed to for long periods of time (Manyuchi *et al.*, 2003).

Working Postures

The posture adopted by a Chainsaw Operator is awkward, with a predominance of trunk flexion. Besides the mass of the chainsaw ($\approx$ 7 kg) the head, arms and trunk (HAT), which constitutes almost 75% body mass, has to be lifted or statically held by the worker. This places excessive strain on the spine and the musculature of the upper limbs and trunk. Mazzoni *et al.* (1998) found that Chainsaw Operators bend their trunks an average of 7.3 times per minute, and sustain a stooped position for 42.2% of the time. Mazzoni *et al.* (1998) also reported that felling showed a compressive force of 5708 N on L_5/S_1. McGill (1997) noted that the repeated application of a submaximal load, or application of a sustained load over a long duration, leads to a slow decrease of the tissue failure tolerance; described as "creep deformation", this may lead to joint laxity resulting in an increased risk of local injury. Ergonomics literature has linked static work postures and forward bending as risk factors for lower back pain (Magora 1970; Marras *et al.*, 1995; Marras, 2000).

Hagen *et al.* (1998) found that neck and shoulder disorders were significantly elevated among machine operators due to the working posture adopted, but that back problems were still the most prevalent injury. Mazzoni *et al.* (1998), who reported that adopting awkward working postures while using a chainsaw is a major risk factor for lower back pain (LBP), support this. In 1992 Nagase and associates, studying 206 Chainsaw Operators in Japan, found that many years of using a chainsaw increased the risk of lower back pain, while Axelsson (2000) reported similar lower back concerns in the Swedish forestry. Back pain is also the most common complaint among South African foresters (Manyuchi *et al.*, 2003).

Energy Cost

As early as the 1950s and 1960s it was established that the energy cost of felling and cross-cutting constituted a “heavy” to “unduly heavy” task (Karvonen, 1958; Kaminisky, 1960; Karvonen *et al.*, 1961). Kaminsky (1960) reported energy cost values of 4.9 $kcal.min^{-1}$ and 4.1 $kcal.min^{-1}$ for felling and cross-cutting respectively, while Fibiger and Henderson (1984) argue that it was impossible for fellers to maintain the required constant high level of energy expenditure over an entire work shift. Working with Chilean forestry workers, Apud (1983) reported a mean heart rate and oxygen uptake (VO_2) of 109 $bt.min^{-1}$ and 1.36 $L.min^{-1}$ respectively over the course of a Chainsaw Operator’s shift. Overall, Chilean Chainsaw Operators were found to expend 3 729 kcal during the working day. Earlier, in 1967 Durnin and Passmore reviewed energy expenditure studies conducted on forestry workers. An adaptation of their findings, reproduced by Apud *et al.* (1989), is shown in Table III. Noteworthy, are the excessive demands placed on Chainsaw Operators; felling and cross-cutting reportedly costs in the region of 8-9 $kcal.min^{-1}$, which is similar to the findings of Kukkonen-Harjula and Rauramaa (1984) who reported VO_2 values of 1.8 $L.min^{-1}$ during felling, which equates to 8.6 $kcal.min^{-1}$. These findings are much higher than the earlier findings of Kaminsky (1960), although Apud *et al.* (1989) do caution that considerable differences in energy expenditure have been found for similar types of forestry work and these authors contend that this needs to be investigated in more detail, highlighting the importance of the present study.

Fibiger and Henderson (1984) found that the high energy cost of felling was a physiological strain likely to contribute to chronic fatigue, while a study by Lilley *et al.* (2002) highlighted the potential impact of fatigue due to physical workloads; according to Lilley *et al.* (2002), those forestry workers who reported high levels of fatigue were also more likely to report having had a near-miss injury event in the past 12 months. Machine operators also experience high levels of mental fatigue, with associated mental function deteriorating progressively during the shift (Kirk and Sullman, 2001). Lilley *et al.* (2002) maintain that at this stage workers are more hazardous to others and themselves.

Table III: Energy Expenditure of chainsaw operations.
(Adapted from Apud *et al.*, 1989)

TYPE OF WORK	ENERGY EXPENDITURE ($kcal.min^{-1}$)
Felling and Trimming	
Felling	8.6
Trimming	8.4
Work with a saw	
Sharpening saw	3.2
Carrying power saw	6.5
Cross-cutting by hand	8.6
Horizontal sawing by hand	7.2
Vertical sawing power saw	4.3
Horizontal sawing power saw	5.4

Noteworthy from the table is the fact that the other sub-tasks of the Chainsaw Operator reveal a significant reduction in energy cost. Sharpening the saw costs in the region of 3.2 $kcal.min^{-1}$, while carrying the chainsaw reportedly results in an energy expenditure of 6.5 $kcal.min^{-1}$. Although these sub-tasks are of a short duration, they do provide some respite from the excessive demands of felling and cross-cutting. The goal of ergonomics should be to capitalise on these ‘recovery’ periods by ensuring workers do not rush them in order to continue with the main tasks of felling and cross-cutting. Adequate fluid and fuel replacement could also be provided at these times to ensure workers are adequately hydrated with optimal blood glucose levels.

STACKER

Work Procedure

The task of the Stacker is to assemble the cut and stripped log lengths into piles for collection by mechanical devices. Once the area has been felled, and the trees cross-cut and debarked, the Stackers collect and position the logs onto stacks. The logs vary in length depending on aspects such as the area and type of wood. Manoeuvring the logs is primarily performed by pulling, dragging and even ‘flipping’ them with the aid of a ‘mechanical claw’. This is followed by lifting the logs onto the stacks which vary in height, ranging from approximately 250 mm to 1000 mm, depending on the required number of logs to be stacked. Similar to the Chainsaw Operators, Stackers are also required to stack ‘x’ number of logs per shift dependent on various factors. The main sub-task is that of ‘housekeeping’ which is done immediately prior to the start of a new stack. The Stacker clears wood and debris from an area and assembles the base of the stack on which to pile approximately 80 logs. It could be argued that this ‘preparatory’ work also provides some respite from the heavy demands of their main tasks of pulling, dragging and lifting logs.

Working Postures

Although the literature on working postures and physiological strain during stacking is virtually non-existent, as with Chainsaw Operators, the most common complaint among Stackers is back pain (ILO, 1991). Stacking of logs, ranging in mass from 10 kg to over 120 kg, demands forward bending to secure the logs and then pulling, dragging and lifting the logs to place them on the stack. This exerts considerable strain on the lower back (Manyuchi *et al.*, 2003), as well as the musculature of the upper body.

With respect to the lifting of logs, load mass in general is probably the most researched area in manual materials handling. As load increases, the stresses on the musculoskeletal and cardiovascular systems are amplified hastening the onset of fatigue. There is no universally acceptable load as it is dependent on other task characteristics such as frequency, distance and duration of lift. With stacking, the task is not exclusively lifting, so at times the frequency of lift may be high, whereas at other times the predominant task may be ‘dragging’ the logs into position. Another factor to consider is the height of the stack which will also influence the maximum acceptable load that can be lifted. NIOSH set the ‘recommended weight limit’ (RWL) for a standard lift under ideal conditions at 23 kg. Any excess of this mass will result in the compressive forces on the spine exceeding the ‘safe’ limit of 3400 N (Waters *et al.*, 1993). Charteris and Scott (1990) with the programme liftRISK have extended the weight range to 42 kg although emphasising that this needs to be considered with other task characteristics as well as indigenous worker capabilities. Although some logs may be within these recommended loads, in all probability the majority of logs lifted by Stackers will be of a considerably higher mass. Furthermore, there is no feasible manner in which the mass of the logs can be changed and as such, ergonomists need to work within these constraints recognising the balance between reducing the physical demands placed on workers and the needs of the company.

Although Manyuchi *et al.* (2003) does not report a high incidence of shoulder injuries with South African forestry workers, it is highly likely that these injuries are either not reported by Stackers, or like Chainsaw Operators, these workers are retiring early. As such, these injuries are in all likelihood not being identified (ILO, 1991). Pulling these timber logs places the arm in abduction, extension and rotation, which is a ‘unnatural’ shoulder position, and will therefore place excessive strain on the relatively gracile muscles of the rotator cuff. According to The Compensation Commissioner’s Guidelines (2004) on managing work-related-upper-limb-disorders (WRULDs), many employees do not recognise their own symptoms of WRULDs. Highlighted in these guidelines is the fact that many workers will continue to work regardless of upper body symptoms and may not report problems for fear of losing their job, a situation typical in developing countries where jobs are scarce.

Energy Cost

The table adapted from Durnin and Passmore (1967) by Apud *et al.* (1989) showing the physiological cost of the Stackers’ job is shown in Table IV. According to the studies summarised by Durnin and Passmore (1967), carrying and dragging logs places high physiological demands on workers, and carries an energy cost greater than 12 kcal.min^{-1}. This is greater than the demands placed on Chainsaw Operators evident in Table III.

Table IV: Energy expenditure of stacking.
(Adapted from Apud *et al.*, 1989)

TYPE OF WORK	ENERGY EXPENDITURE (kcal.min^{-1})
Preparing the logs for removal	
Carrying logs	12.1
Dragging logs	12.1

Durnin and Passmore (1967) did not report on the energy cost of piling logs because, according to Apud (1983), the errors of estimation are large if the work is carried out under different conditions. Apud (1983) measured a mean VO_2 of 1.42 L.min^{-1} during stacking (lifting) which theoretically implies an energy cost of 6.8 kcal.min^{-1} which is lower than the sub-tasks of dragging and carrying logs. However, this author strongly recommends the need to conduct ergonomic assessments under different harvesting conditions. He contends that factors such as terrain, tree type and environmental conditions will all influence the energy cost of stacking significantly, emphasising the need to test workers under a range of conditions.

It is highly probable that, due to the limited research on the demands placed on Stackers, the actual costs are not known. Although not reporting on Stackers, Sanders and McCormick (1993) reported that the metabolic cost of lifting objects off the floor, as done in stacking, is greater than lifting from ‘ideal’ heights; this is attributed to the additional effort of lowering and raising the body acknowledging HAT which has to be lifted in addition to the external load.

ASSESSMENT OF THE PHYSICAL DEMANDS OF FORESTRY WORK

Information on ergonomics research is mainly derived from experiments conducted in laboratories which, according to Forsman *et al.* (2002), do not fully reflect all aspects of the industrial environment. Furthermore, replicating complex forestry operations within a laboratory setting would be difficult, if not impossible, and as such most of the limited ergonomics research within forestry has been conducted within the actual field of work. Although experiments cannot be as rigorously controlled in the field (Oborne, 1995; Winkel and Westgaard, 1997), Zalk (2001) emphasised that field research is essential to gain information on worker responses under actual working conditions. Although the benefits of laboratory research are acknowledged, such as the rigorous control of all extraneous factors which may impact the results of the actual experiment, it is contended that due to the inability to simulate the forestry tasks and environmental conditions of the present study a field investigation was both practical and plausible.

Bao and Shanavaz (1989) and Scott and Renz (2006) emphasise that ergonomists must make their solutions applicable to the ‘real’ world, acknowledging that ergonomics is an applied science. The main advantages of *in situ* investigations are that the workers themselves are being tested. Oborne (1995) contends that volunteer subjects are often inexperienced and unreliable. However, caution must be given to the psychophysical factors influencing the workers’ responses, as these may not be typical of a ‘normal’ working day. To overcome this, it is imperative that an adequate familiarization period to the researchers, protocol and equipment be given so that workers feel comfortable with all aspects of the experimental procedures before the experiment begins (Scott and Christie, 2004).

WORKING POSTURES

Working posture is defined as the body’s configuration while performing a task (Ayoub and Mital, 1989). Working postures impose differential stressors on the musculoskeletal system (Stuebbe *et al.*, 2002), and affect the physiological responses (Pheasant, 1996). Extremes of trunk inclination, stooping, squatting, carrying and overhead work, all postures evident in harvesting tasks, are unnatural postures deviating from the normal anatomical alignment. Work-related-musculoskeletal disorders may result from such tasks and in particular from prolonged static postures of which carrying a chainsaw is an example, or biomechanical loading from external loads such as lifting logs.

The methods available for measuring working postures and biomechanical loads include direct measurements, observations, interviews, diaries and questionnaires (Capodaglio *et al.*, 1997). Electromyography (EMG) recording, goniometers and accelerometers are all examples of direct measures. These methods are quantifiable, but are restricted to a limited number of body regions, and some of these devices may hinder 'normal' work practices. Observation methods strike a balance between the high cost of direct measurements and the low subjectivity and validity of questionnaires, diaries and interviews (Wiktorin *et al.*, 1993; Kilbom, 1994; Capodaglio *et al.*, 1997). Biomechanical modelling using digital imaging and analyses of bodily alignment with software packages can assist in estimating the compressive forces on various joints to provide some indication of biomechanical loading. Capodaglio *et al.* (1997) has attested to the accuracy of such analyses, and in this study digital imaging in combination with measurements of trunk acceleration was utilised in order to assess working postures and biomechanical loads.

ENERGY EXPENDITURE (EE)

Due to the costs involved and the difficulty of obtaining valid physiological data in remote and often environmentally extreme areas while trying not to interfere with work tasks, limited research has been conducted on the energy cost of forestry workers (Apud *et al.*, 1989; Scott and Christie, 2004). Accordingly, the main purpose of the present project was to establish the metabolic cost associated with the harvesting tasks of chainsaw operations and stacking.

The techniques available to directly assess energy expenditure, such as direct and indirect calorimetery are well known (McArdle *et al.* 2001). Both methods depend on the principle that all energy utilised by the body is ultimately degraded into heat (Eston and Reilly, 2001). While direct calorimetry may be more accurate, it is technically difficult and extremely costly. As such, it is well accepted that since the energy provided by food can only be used because of oxidations utilising oxygen, measurement of steady-state oxygen uptake by the body through open-circuit spirometry provides an accurate estimation of energy expenditure (McArdle *et al.*, 1996; Eston and Reilly, 2001).

During open-circuit spirometry an analysis of the difference in composition between inhaled and exhaled air reflects the body's constant release of energy (McArdle *et al.*, 1996). Modern ergospirometers are portable, weigh very little (less than 1.0 kg) and attach to the individual's trunk which facilitates easy use within a field setting. However, as the measurement of oxygen uptake *in situ* has proved problematic for several practical reasons, regression models have been established so that direct measures are not necessary. For example, Garg *et al.* (1978) argued that if the metabolic cost of sub-tasks were assessed, then totalling these could establish the net metabolic cost of the activity, although other researchers (Taboun and Dutta, 1989) have not confirmed this assumption. These latter authors argue that this approach does not consider other aspects of the overall job such as small periods of housekeeping or walking between tasks. Another problem is that this equipment is costly and only one subject can be attached at any given time. While the use of this method in a laboratory or field setting is well suited for assessing energy expenditure of specific activities over a short duration, it is not suitable for measuring energy expenditure over long periods and especially in remote areas and on a large sample such as the present study, hence other methods have been employed. The use of various commercially available electronic activity monitors and heart rate monitors can provide an estimation of the metabolic cost of different tasks. Compared to the difficulties associated with indirect calorimetry, this equipment is inexpensive and several researchers have attested to their validity (Haskell *et al.*, 1992; Strath *et al.*, 2001; Keytel *et al.*, 2005).

Of the methods available, the most common method used to predict energy expenditure is heart rate recording. This is based primarily on the strong association between increasing heart rate and increasing energy expenditure during large muscle, dynamic exercise (Haskell *et al.*, 1992). Ceesay *et al.* (1989) found that the within-person correlation between heart rate and oxygen uptake during increasing exercise intensity on a treadmill or cycle ergometer frequently exceeds 0.95.

However, the limitations in using heart rate to predict energy expenditure include the slope of the relationship between heart rate and oxygen uptake, which varies from individual to individual, and between upper and lower body activities and the ratio of dynamic and static contractions (Maas *et al.*, 1989; Haskell *et al.*, 1992). Consideration should also be given to the fact that heart rate is influenced by other factors such as emotional status, posture and environmental conditions. Therefore, recording heart rate only for the estimation of the metabolic cost of a physically demanding task has not generally been accepted as an accurate method, although Kirk and Sullman (2001) showed that heart rate indices provided an effective means of determining the physiological strain of forest harvesters. To improve the accuracy of estimating oxygen uptake from heart rates recorded *in situ* during a wide range of activities, individualised heart rate-oxygen uptake regressions are used (Haskell *et al.*, 1992; Strath *et al.*, 2001; Strath *et al.*, 2002; Keytel *et al.*, 2005). From these recent studies it was evident that establishing individualised heart rate-oxygen uptake regressions is the most reliable indirect measure of energy expenditure. In order to achieve this each worker needs to perform a progressive, submaximal test with at least three workloads, achieving a range of heart rates similar to that which was recorded in the field (Scott and Christie, 2004). The individual nature of the heart rate/VO_2 relationship makes it necessary to establish a regression equation for heart rate and VO_2 for each subject at several levels of intensity, while recognising that factors other than oxygen uptake, such as ambient temperature, food intake, body posture, and muscle groups active may influence heart rate (Barbara *et al.*, 2000).

In order to establish a setting as close to the natural working ambience as possible the submaximal test should preferably be done during or after the work shift on the same day of recording heart rate while working (Apud, 1983; Lambert *et al.*, 1994; Scott and Christie, 2004). Heart rate measures taken in the field can then be converted to VO_2 by means of individual regression equations (Lambert *et al.*, 1994). Apud (1983) calibrated forestry workers on a cycle ergometer, and before applying the heart rate method, simultaneous measures of heart rate and VO_2 were carried out during different forestry activities. Following this, heart rate was converted into VO_2 using each individual regression equation. The results revealed no significant difference between the estimated VO_2 and the actual VO_2 measured in the field, although in other studies it has been found that the predictive values tend to overestimate actual measures of VO_2 between 10% and 20% (Nielsen and Meyer, 1987; Scott and Christie, 2004). However, as Scott and Christie (2004) argue, this is not necessarily a weakness as the overestimation may provide a safe index for workers in IDCs who tend to be over taxed during work. Although it has been suggested that this relationship be established in an activity representative of the task under investigation, many have argued that it does not make a significant difference (Apud, 1983; McArdle *et al.*, 1996). This need to individually calibrate subjects was acknowledged in the present study.

Additionally, the accuracy of estimating energy expenditure is further improved when heart rates and body movements are analysed simultaneously during work (Haskell *et al.*, 1992; Strath *et al.*, 2001; Strath *et al.*, 2002). There are numerous motion sensors available including pedometers which measure distance walked (Washburn *et al.*, 1980), motion sensors which count the number of times a limb or the trunk moves and accelerometers which monitor the acceleration of the body during an activity (Meijer *et al.*, 1989). Similar to heart rate monitors, used in isolation these monitors do not provide meaningful information about the energy demands of tasks, but when used in combination with heart rate monitoring they have been shown to provide an accurate reflection of the energy cost of an activity.

ACCEPTABLE LEVELS OF PHYSIOLOGICAL COST

Most of the physiological limits for manual work are related to heart rate responses, oxygen consumption (VO_2) and energy expenditure.

HEART RATE RESPONSES

Although the literature on physiological work limits is inadequate, Kilbom (1995) argues that if heart rates are below 90 $bt.min^{-1}$, the strain on the cardiovascular system is “light”. Heart rates, ranging from 90-110 $bt.min^{-1}$ indicate a “moderate” strain, while those between 150-170 $bt.min^{-1}$ suggest “extremely heavy” strain is being placed on a worker (Kilbom, 1995). These responses are average heart rate responses over extended work periods so at times, heart rate may be high (for example 150 $bt.min^{-1}$), while at other times it may be as low as 85 $bt.min^{-1}$. However earlier, Åstrand and Rodahl (1986) suggested that heart rates ranging between 110 $bt.min^{-1}$ and 130 $bt.min^{-1}$ are the upper limit for continuous work, while more recently Kumar *et al.* (2000) argued that acceptable, rather than the upper limit for continuous work, is a heart rate range of 104 $bt.min^{-1}$ to 114 $bt.min^{-1}$.

OXYGEN CONSUMPTION AND ENERGY EXPENDITURE

The most widely accepted limit for oxygen consumption during extended work is that it should not exceed 33% of the worker's maximum oxygen uptake (Waters *et al.*, 1993; Dempsey, 1998; Christie and Scott, 2005). Wu and Wang (2002) extend this further by providing recommendations for shifts varying in length, specifically 28.5% $VO_{2\ max}$ for 12-hour shifts, 31% for 10-hour shifts, 34% for 8-hour shifts, and 43.5% for 4-hour shifts.

Mital *et al.* (1993) proposed that there are two problems associated with physiological design criteria based on relative exercise intensity. Firstly, specifying the upper limit of VO_2 as a percentage of oxygen uptake which can be sustained without undue fatigue, and secondly deciding on what kind of oxygen uptake test should be used to express this percentage. This has proved to be problematic in that the recommendation of 33% $VO_{2\ max}$ for extended work has been predicted using values obtained by running workers on a treadmill or cycling workers on a cycle ergometer (McArdle *et al.*, 2001; Bales *et al.*, 2001; Christie and Scott, 2005). This brings into account the concept of specificity which argues that the best measures are those that are obtained when testing subjects in their chosen exercise mode (McArdle *et al.*, 2001), for example testing runners on a treadmill and cyclists on a cycle ergometer. This implies that someone trained in manual work should be tested during an activity which closely simulates the predominant activity during work. More specifically, this is related to the total muscle mass activated during a maximum oxygen uptake test. In general, $VO_{2\ max}$ tests aim to maximize the muscle mass used, which is the reason for the popularity of the treadmill and cycling ergometer protocols, although arm-crank and all-extremity tests are not uncommon (Reybrouck *et al.*, 1975; Glaser *et al.*, 1980; Louden *et al.*, 1998). It has been found that $VO_{2\ max}$ values obtained during arm cranking exercise and all-extremity protocols are 68% and 60% respectively of those measured during treadmill running (Reybrouck *et al.*, 1975;

McArdle *et al.*, 2001). Furthermore, Kumar (1984) found lifting to be more physiologically demanding than cycling for every workload. Recently Christie and Scott (2005) found that although most physiological responses were higher during lifting than during running, VO_2 was significantly lower during lifting. The accuracy of this measure is important for making recommendations for work as a measure done on a treadmill for example, may result in a worker being taxed beyond what they are capable for if their mode of work is completely different.

Absolute values of oxygen consumption and energy expenditure recommended for manual work can be seen in Table V.

Table V: Five-level classification of physical activity based on intensity of effort.
(Adapted from McArdle *et al.*, 2001)

LEVEL	ENERGY EXPENDITURE			
	MEN			
	$kcal.min^{-1}$	$L.min^{-1}$	$mlO_2.kg^{-1}.min^{-1}$	METS
LIGHT	2.0-4.9	0.40-0.99	6.1-15.2	1.6-3.9
MODERATE	5.0-7.4	1.00-1.49	15.3-22.9	4.0-5.9
HEAVY	7.5-9.9	1.50-1.99	23.0-30.6	6.0-7.9
VERY HEAVY	10.0-12.4	2.00-2.49	30.7-38.3	8.9-9.9
UNDULY HEAVY	>12.5	>2.50	>38.4	>10.0
	WOMEN			
LIGHT	1.5-3.4	0.30-0.69	5.4-12.5	1.2-2.7
MODERATE	3.5-5.4	0.70-1.09	12.6-19.8	2.8-4.3
HEAVY	5.5-7.4	1.10-1.49	19.9-27.1	4.4-5.9
VERY HEAVY	7.5-9.4	1.50-1.89	27.2-34.1	6.0-7.5
UNDULY HEAVY	>9.5	>1.90	>34.5	>7.6

kcal: kilocalories.
O_2: oxygen.
METS: metabolic equivalent.

It is evident in this table that “light work” reflects a VO_2 (energy expenditure) of up to three times the resting metabolic equivalent (MET), while “heavy work” is associated with responses eight times the resting value. The universal recommendation, in terms of energy expenditure, is that kilocalorie cost should not exceed 5 $kcal.min^{-1}$ for long duration work. This is approximately equivalent to 1 L of oxygen consumed per minute. This value however varies depending on the type of activity in question and in particular, the duration of the activity. Chainsaw operations and stacking are typically seen as placing “heavy” or “unduly heavy” demands on workers although, in general, the literature is equivocal on this concept.

PERCEPTIONS OF EFFORT

Assessing perceptions of effort during any work task is based on the premise that individuals combine feedback from the biomechanical and physiological stresses to provide a subjective evaluation of the task demands (Ayoub, 1992; Sanders and McCormick, 1993). The need to quantify subjective perceptions of effort resulted in the development of psychophysical rating scales such as Borg’s (1970) scale for Ratings of Perceived Exertion and Corlett and Bishop’s (1976) Body Discomfort scale (See Appendix B).

RATINGS OF PERCEIVED EXERTION (RPE)

Differential ratings of perceptual effort were used in the present study to identify perceived physical effort. More specifically, “Central” Ratings of Perceived Exertion (RPE), which focus on perceptions of central cardiorespiratory strain, and “Local” ratings which focus on effort perceptions of selected muscular groups, in this case the lower back, were utilised. In the 1960s Borg proposed that during physical effort, signals from the cardiorespiratory, muscular and central nervous systems are integrated into a ‘gestalt’ perception of exertion and that it therefore provided a good indicator of the degree of physical strain experienced.

The popularity of the RPE scale is that perception of strain has a close association with physiological measures, in particular heart rate. With respect to the relationship with oxygen uptake, Robertson (1982) found that work was perceived to be “light” corresponding to relative oxygen uptake values of less than 50% $VO_{2\ max}$, while “moderate” work corresponded to between 50% and 70% $VO_{2\ max}$. Oxygen uptake values greater than 70% $VO_{2\ max}$ were perceived to be “heavy” in nature. Numerous studies have however cautioned that the correlations between physiological and perceptual responses change depending on the type of activity (Robertson, 1982; Legg and Myles, 1985; MacKinnon, 1999). Aspects such as the intensity and duration of effort are therefore important factors to consider. Furthermore, Legg and Myles (1985) found that perceptual ratings increased significantly over the course of a shift without a corresponding increase in heart rate and VO_2.

Recognising the multifaceted nature of factors which could affect individual ratings, the validity of the Borg RPE scale is improved when the subject fully understands the concept through clear and detailed explanation. When the language of the worker is a language other than English, it is important that the conceptual basis of the scale be explained carefully in their own language. In the present study all the workers were Zulu speaking and as such the scale was translated into Zulu, with detailed explanation in Zulu before workers were asked for their responses (See Appendix B for example). Legg and Myles (1985) contend that if one has full co-operation from the subjects, and there is strict experimental control, this psychophysical approach is extremely effective.

BODY DISCOMFORT

This scale, developed by Corlett and Bishop in 1976, is a means of quantifying muscular discomfort experienced during prolonged work and is a potential means of predicting musculoskeletal injuries resulting from suboptimal working postures. A diagram of the anterior and posterior aspects of the human body is divided into 28 segments so that exact sites of discomfort can be identified (See Appendix B). In addition the intensity of discomfort (on a scale from 1 to 10 with 1 being “minimal discomfort”, and 10, “extreme discomfort”) experienced in each region is recorded. Sites and intensity of discomfort can be measured at any stage during the work shift, and if measured at regular time intervals will provide some understanding regarding the cumulative demands placed on the musculature of the body.

THE SOUTH AFRICAN CONTEXT

South Africa is an interesting mix of First and Third World influence and has one of the most extreme disparities of wealth in the world (Bradshaw and Steyn, 2001); a substantial portion of South Africans live below the poverty line while others are living in affluence. A recent technical report by Bradshaw and Steyn (2001) found that although the rich areas are further ahead in the epidemiological transition, the poor areas are also in the process of transition which adds to the burden of infectious diseases and malnutrition due to the rise in chronic diseases of lifestyle. This has been referred to as a 'double burden' to the health care system coping with both communicable diseases in the poorer population groups and now, an increased prevalence of non-communicable diseases in the same group.

The World Health Organisation states that the wealth of poor people is in their individual capabilities and their "assets", the most important being their health. Good health enables people to participate in the job market and is the key to productivity in a 'people dominated' working environment such as South Africa. Having a physically healthy, strong body is an asset, while a sick and weak body is a liability both to employee and employer. Unfortunately in South Africa, the latter health status is more common and as such many workers are being required to perform tasks for which they are not physically capable. In light of this, since 1994, the South African government has been committed to poverty reduction and improving the health needs of vulnerable groups.

A high level of unemployment and lack of education are the major contributing factors to the poor socio-economic status within South Africa. Many manual workers, who form the majority of South Africa's labour force, earn poor salaries and live in rural areas. Rural people constitute approximately 40% (16 million) of the total population of South Africa (statsSA, 2000); many have limited education and can only do manual work. Most of the rural individuals are Blacks who are historically disadvantaged; in Kwazulu-Natal, where the present research was conducted, most of the forest workers are Zulu and live in rural areas.

Rural unemployment is over 50% in most regions of South Africa, and over 60% of rural people have no tap water in or near their homes, while over 70% do not have electricity (statsSA, 2000). Inadequate housing and poor sanitation result in a high prevalence of disease (Christie, 2001). Average income earned by rural households is much less than that earned by urban households. Furthermore, there is the HIV/AIDS endemic which is particularly prevalent in the younger population of South Africa (Bourne *et al.*, 2002) resulting in the older group of South Africans having to work longer in the manual labour force. This in itself presents with a whole host of other problems associated with the ageing process and a progressive decrement in various aspects of physical work capacity.

NUTRITIONAL STATUS

Due to limited education and poor incomes there is suboptimal nutritional status among most of the manual labour force in South Africa. In 1984 Richter and co-workers reported that South African Blacks in the previous homeland of the Ciskei had a high prevalence of inadequate energy intake and their diets were deficient in most vitamins and minerals. This was attributed to the staple diet consisting predominantly of maize. Although it is acknowledged that this scenario is changing, a vast majority of manual labourers are still earning low salaries and are consuming inadequate calories to sustain the demands of physically taxing tasks (Christie, 2002). Charlton *et al.* (2001) investigating urban older blacks reported that mean energy intake was below the recommended daily allowance (RDA) for both men and women; 27% and 26% of men and women respectively had energy intakes less than 67% of the RDA. In an earlier study, these same researchers demonstrated that older coloured South Africans had energy intakes less than two-thirds the RDA (Charlton *et al.*, 1997).

Although not reporting on South African workers, Barac-Nieto (1987) found that healthy adult men are capable of a work effort equivalent to 32% $VO_{2\ max}$, and an endurance time of 8 hours. The required work effort increased to 40%, 50% and 80% $VO_{2\ max}$ for men showing mild, intermediate and severe under nutrition respectively. Furthermore, endurance time decreased to 6.5, 5 and 1.5 hours respectively for the same groups. This author concluded that work output was therefore reduced by 15%

in mildly under nourished workers, and by 35% and 78% for the intermediate and severely under nourished groups respectively. Spurr (1988) concurred that performance at work was severely compromised when workers were malnourished.

Limited research has examined the relationship between energy expenditure and energy intake in manual workers in South Africa (Christie, 2002). This is an important area for investigation, as Lambert *et al.* (1994), investigating South African sugar cane workers, reported that conscious efforts to enhance the nutrition of workers in this industry had made a significant contribution to an improved work output. However, due to the intense nature of the work, energy intake still did not meet energy cost. The sugar cane stackers assessed in their study had a mean energy intake of 5 281 kJ during the day, yet they expended 14 127 kJ, resulting in an average loss of 2% body mass. This emphasises the potential imbalance between energy intake and energy cost. On the other hand, in a similar project conducted in South America, Apud (1983) found that with Chilean forestry workers, daily energy intake was sufficient to meet the energy demands of work.

The major concern surrounds the fact that carbohydrate intake is insufficient to sustain physically demanding manual tasks. This macro-nutrient is essential to prevent low levels of liver and muscle glycogen (Goedecke *et al.*, 1999) which, when reduced, may decrease the ability to maintain the required effort. Numerous studies have shown that in particular, the depletion of muscle glycogen coincides with the onset of fatigue and most authors agree that consuming a high carbohydrate diet is essential for optimal performance (Bergstrom *et al.*, 1967; Brooks and Mercier, 1994; Burke, 2002).

The demand of physical work in an industrial context has much in common with the demands of endurance sports. Both types of activities influence the body in similar ways and ultimately challenge the body’s endogenous fuel stores. A considerable amount of literature has focused on optimising athletic performance, whereas little attention has been afforded to improving industrial worker performance from a nutritional perspective. Athletes are encouraged to consume a high CHO diet during training and are encouraged to consume fluid and fuel during the endurance activity.

Although substantial physical demands may be placed on industrial workers for long hours each day, these workers are not encouraged to alter their diet or in the case of IDCs, consume more total calories (Christie, 2002). Although optimising nutritional intake is a general health concern of a country, greater attention should to given to the many workers involved in physically taxing tasks which are so prevalent in IDCs. Without more concrete steps taken to address this problem the majority of workers will be unable to meet the energy requirements of their work.

WORKER CAPABILITIES

Any incompatibility between the demands of work and the capabilities of the human operator will result in ‘work inefficiency’ due to fatigue and injuries (Grandjean, 1986). This ultimately impacts on the productivity of the company and the industry as a whole. Any ergonomics investigation should consider characteristics innate to the task being performed and the capabilities of the workers executing these tasks. Nowhere is this more important than within developing countries where the physical capabilities of the workers are arguably the key factor in determining effectiveness at work.

AGE

As ageing progresses various decreases in peak functional capacity may limit an employee’s potential to engage in strenuous physical work (Shephard, 1988). According to this author, with self-paced work age-related decreases in muscle strength and endurance as well as anaerobic capabilities, may threaten the productivity of older workers. With increasing age, there is a progressive decline in the functional capacity of the cardiovascular system. Marti and Howard (1990) report a 9% decline in maximum oxygen uptake per decade from the age of 25 years. It is suggested that this age-related decline may be associated with the loss in muscle mass which usually occurs as people become older (Fleg and Lakatta, 1988; Noakes, 1992). These decrements are more pronounced in individuals who do not perform work of a physical nature, as this type of physical exertion assists in maintaining muscle mass and hence oxygen uptake. In the case of forestry workers who may have been performing these tasks for several years, much of this age associated decline in muscle mass may have been prevented, although the impact of malnutrition on lean body mass cannot be eliminated (Panter-Brick, 2003).

STRENGTH

An individual's capacity to perform mechanical work is determined by their ability to exert muscular strength (Mital and Kumar, 1998). Many manual tasks require muscle power for optimal execution while muscular strength is necessary to exert forces required to operate equipment and sustain external loading without inflicting injury. According to Mital and Kumar (1998) insufficient strength can lead to overloading of the muscle-tendon-joint system and likely to result in injury.

Work factors which influence human strength include posture, reach distance, arm and wrist orientation, speed of exertion and duration and frequency of exertions (Mital and Kumar, 1998). Assessing strength is particularly popular for tasks which require physical exertion (Kamon *et al*., 1982; Kumar, 1995). Most of the assessment criteria are utilised for design guidelines and screening procedures thereby ensuring that workers are physically capable of executing the required task or, more importantly, the task does not place undue strain on a worker. Due to the heavy loads and fast work pace adopted in forestry, strength is paramount to optimal performance.

MAXIMAL AEROBIC CAPACITY ($VO_{2\ max}$)

The maximum rate of oxygen use in the cells is referred to as maximum oxygen uptake or $VO_{2\ max}$. Assessing $VO_{2\ max}$ assists in establishing the relative level of exertion during manual work, expressed as a percent of maximum (Christie and Scott, 2005). Most of the research on the relationship between maximal capacity and performance has been conducted on sports people, and in particular runners (Noakes, 1992; St Clair Gibson *et al.*, 1999), whereas little research has been afforded to the maximal capacities of workers (Christie and Scott, 2005). These authors report that although there are several standardised running and cycling protocols to assess $VO_{2\ max}$, there is no established protocol for the assessment of manual work. Kell and Bhambhani (2003) report that most manual workers are tested on a treadmill or cycle ergometer. These authors argue that results of such tests must be questioned when consideration is given to the concept of specificity, as it is well accepted that the highest $VO_{2\ max}$ values are obtained when subjects perform the activity in which they are trained (McArdle *et al.*, 2001). This concept of specificity refers to the plastic changes which occur in response to training.

Traditionally $VO_{2\ max}$ tests have been used to assess physical training status and predict performance (Louden *et al.*, 1998). In the present study assessing VO_2 during a submaximal “test” was for the purpose of predicting the energy cost of working in the field. In ergonomics $VO_{2\ max}$ measures are sometimes used to make recommendations for work effort (Christie and Scott, 2005). Kurumatani *et al.* (1992) reported that compared to office workers, forestry workers had high aerobic capacities; this was ascribed to the high physical demands of the occupation. It has however been argued that $VO_{2\ max}$ is only one of the factors which should be used to predict performance. Other important factors include past performance, VO_2 responses during the activity, and improvements in present performance. Noakes (1998) goes as far as to say that measures of $VO_{2\ max}$ have virtually no role to play in the assessment of how well an individual will perform and that the measure of oxygen uptake during an activity holds more value.

HUMAN THERMOREGULATION

Felling, cross-cutting and stacking are all heat-generating tasks performed outdoors which implies exposure to the prevailing climatic conditions. This, and individual worker characteristics such as morphology and acclimatisation, will impact each worker’s thermoregulatory capabilities.

Since manual methods dominate wood harvesting in IDCs and productivity is considered to be low, it is has been suggested that a large number of forest workers regularly experience heat problems during their work (Wästerlund, 1998). Heat stress is defined as the body’s inability to dissipate excess heat to the environment (McArdle *et al.*, 1996). The extent of measures taken by the body through vasodilation, and increased heart rate and sweating, depends on the individual characteristics of age, sex, body composition and individual sensitivity. If these measures are insufficient the individual will suffer some sort of heat injury (McArdle *et al.*, 2001). The morphology of the individual also needs to be considered as larger workers have more metabolically active tissue than smaller workers, which suggests a higher metabolic rate and greater heat production at rest and during work.

The greatest impact on body heat generation is from the reactions of energy metabolism (Noakes, 1992). When muscles become active their heat contribution increases substantially. During prolonged, vigorous activity, the metabolic rate increase to 20-25 times above the basal level which can theoretically increase core temperature by 1^{0}C every five minutes (McArdle *et al.*, 2001). As such, any physically demanding manual task will result in the generation of excess body heat even in cold environments. Working with athletes, Noakes (1992) argues that the major physiological problem faced by athletes is the inability to lose excess heat generated by muscular contraction. Pascoe *et al.* (1994) reported that skeletal muscle contraction during exertion is responsible for 90% of the body's thermal load and points out that warmer outdoor conditions exacerbate this effect as heat is also absorbed by the body from the environment via solar radiation and from objects which are warmer than the body.

The body's major defence against excessive heat production is the evaporation of sweat. Sweat rate increases as the ambient temperature increases with a concomitant increase in energy expenditure (McArdle *et al.*, 2001; Noakes, 1992). In addition, high humidity levels, similar to those recorded in the area under investigation in this study, are known to hinder evaporative heat loss (Sutton, 1996). When humidity is high ambient vapour pressure approaches that of moist skin, and the vapour pressure gradient decreases resulting in less evaporative cooling (Pascoe *et al.*, 1994; McArdle *et al.*, 2001). According to Leski (1994), as long as humidity is low, relatively high environmental temperatures can be tolerated.

Haymes and Wells (1986) maintain that cardiovascular efficiency is the most important physiological variable when determining tolerance to strenuous activities in the heat. During physical work in hot environmental conditions, the circulatory system competes for the distribution of blood; competition is between the working muscles which require the delivery of oxygen and nutrients as well as the removal of wastes, and the cutaneous circulation for sweat production (Sawka and Wegner, 1988). The body adapts by reducing blood flow to other circulations which do not require more blood, for example the splanchnic circulation.

The major problem arises following prolonged physical exertion in hot environments when these competing demands are challenged. Nadel (1979) and Noakes (1992) contend that if faced with these competing demands, the body will favour blood flow to the working muscles, compromising evaporative heat loss from the skin. However, at this stage the body is likely to be dehydrated suggesting that the problem is now two-fold, dehydration coupled with heat gain due to a reduction in blood flow to the cutaneous circulation resulting in less heat loss. The body continuously attempts to protect the central cardiovascular function with a possible consequence being heat stress. It is generally acknowledged that sweat rates during endurance sporting events are about 1.0 to 1.2 $L.h^{-1}$ in temperate environmental conditions (Armstrong *et al.*, 1985). Indeed any physical activity in hot environments results in greater sweat losses than the equivalent activity in a cooler environment. Typically losses of 2–3% in body mass result in a decrement in physical performance (Burke, 2002) and arguably, cognitive performance (Cian *et al.*, 2001).

Hjelm and Frisk (1985) reported a body mass loss of 3.2% per working day if forest workers took in nothing per mouth during work. In Canada, Trites *et al.* (1993) reported body mass losses of 3.1% each day for planting workers, while Paterson (1997), reporting on forestry workers in New Zealand, found that Chainsaw Operators lost, on average, 1.2% body mass when on a voluntary drinking regime. Wästerlund and Chaseling (2001), comparing a hydration and dehydration protocol during forestry work, found that when on a dehydration scheme workers only had mild dehydration after the completion of work (mean body mass loss of 0.7 kg). During the fluid consumption trial, these same workers gained 0.7 kg. Although the level of dehydration was relatively mild when exposed to the dehydration scheme, the time taken to perform their work task was significantly increased when dehydrated highlighting the fact that even mild dehydration may negatively impact on work performance. In contrast, in 2004, Wästerlund and co-workers found no performance effects when workers where dehydrated.

The importance of hydration research lies in the fact that in forestry vigilance is paramount to safety; therefore any deterioration in cognitive function is highly likely to result in injuries and fatalities. It has been found that besides the health effects, heat stress causes fatigue and has a negative effect on performance, vigilance and productivity; hence concern about heat stress during forestry work is paramount. Few studies on forest work appear to have considered heat stress, and the ergonomics literature in forestry give only very broad recommendations on how to avoid heat stress; these include "restrict heavy work to early mornings and late afternoons" and "supply sufficient water" (Staudt, 1993; ILO, 1991). It is evident that more definitive guidelines are required. Vogt *et al.* (1983) found that workers naturally reduce their work pace in response to increased thermal stress to maintain their average heart rate. It is also well documented that maintaining a euhydrated state lowers working heart rate and rectal temperature during exercise in the heat (McLellan and Cheung, 2000).

While much concern is voiced about the effect of climatic conditions, the impact of extreme heat is exacerbated by the required clothing for forestry workers. Personal protective equipment in motor manual forest work is mandatory (ILO, 1991), yet due to heat accumulation and profuse sweating workers are reluctant to use them during warmer periods (Vayrynen and Ojanen, 1983; Pyke and Sutton, 1992). Abeysekera and Shahnavaz (1990) also reported that workers are hesitant to wear helmets for protection because of heat discomfort. Protective clothing and gear have implications for radiant heat exchange as it covers the skin, decreasing the surface area for natural exchange mechanisms. The barrier between skin and air hinders heat loss by trapping and insulating the layer of air around the body. In forestry, workers (particularly Chainsaw Operators) have a large portion of their body surface area covered by clothing and protective gear which could be argued, protects them from environmental radiation (Shephard, 1988), but are likely to interfere with evaporative and other heat loss processes (Cheung *et al.*, 2000). Convective heat loss is also negatively affected by clothing, limiting the cooling affect of wind.

The resultant situation is that although an item of protective equipment such as a helmet is effective for protection against impact, it is counter productive for thermal control. Despite some improvements in the design of protective head wear (Abeysekera and Shanavaz, 1988), thermal comfort is still thought to be of secondary importance to protection from impact (King *et al.*, 2002). Actively cooling the head with water or the inclusion of passive vents in the helmet are two separate approaches used to alleviate heat stress when wearing a helmet (Holland *et al.*, 2002). Research on cricketers within South Africa has shown that protective equipment (including a helmet) increases the thermal load of batsmen resulting in a significant rise in skin temperature (King *et al.*, 2002). These authors report an exacerbated thermal load when batting in the hot environmental conditions common in South Africa. As batting in cricket carries a substantially lower metabolic cost than all types of harvesting work, it can be argued that the protective gear will intensify the thermal load associated with both the activity and the protective gear. Nevertheless, while the impact on thermal load is important, safety is a far greater concern.

SUMMARY

As in all other industries the protection of workers is an ethical issue. This is particularly pertinent in forestry where unsafe working methods due to fatigue from physically taxing work is widespread. Even though extensive efforts have been made to improve the safety of the profession, it still has a negative image globally due to the high number of severe injuries and fatalities experienced. An immediate consequence for the forestry sector is the difficulties encountered in many countries to retain good workers and recruit suitable new ones. A less suitable and less proficient workforce results in lower productivity, higher costs and more accidents so creating a vicious circle (ILO, 1991). Nowhere is this more evident than within developing nations and it is argued that, by conducting sound ergonomics research and then implementing the most appropriate interventions for the local industry, both the well-being of the worker and the economic interests of the company will be accomplished.

CHAPTER III
METHOD

INTRODUCTION

The main purpose of this field-based research was to establish the physiological costs of chainsaw operations (felling and cross-cutting) and stacking within the South African forestry. However, acknowledging the importance of adopting a holistic approach when conducting any ‘human response’ investigation (Borg, 1970; Charteris *et al.*, 1976; Ayoub and Mital, 1989; Dempsey, 1998; Marras, 2000), further objectives were to assess working postures and perceptions of work effort.

A year prior to the main experimentation phase of this project visits to forestry plantations and discussions with forestry management, contractors, supervisors and workers in the Kwazulu-Natal forestry region were initiated. The prime objective being to establish an understanding of harvesting operations and then, following task observations, to establish the most appropriate protocol. During these visits, direct assessments of worker responses were conducted in order to obtain an understanding of the amount of physical stress being imposed during the execution of the required harvesting tasks. This was followed by several presentations to a wide spectrum of individuals involved in the major forestry corporations of South Africa. The purpose of these presentations was to create an understanding of ergonomics and to propose possible areas of research. The feasibility of our suggestions was then discussed with management and the appropriate method of assessment decided.

FIELD OBSERVATION

The four main tasks associated with manual harvesting, felling, cross-cutting, debarking and stacking, were observed in various areas in the Kwazulu-Natal region. The main purpose of these observations was to become familiar with the tasks which exhibit a wide range of manual materials handling including lifting, carrying, lowering, pushing and pulling, so as to establish the most appropriate research design.

Chainsaw Operator (Felling and Cross-cutting)

Figure 4 (A to D) highlights some of the many tasks undertaken by the Chainsaw Operator. These include the main tasks of felling (Figure 4 A) and cross-cutting (Figure 4 B) in addition to several sub-tasks such as preparation of the work area, walking between trees and logs (Figure 4 C) and maintaining the chainsaw (Figure 4 D). A large proportion of the work shift involved that of carrying and walking with the 7 kg chainsaw. Except when maintaining the chainsaw, this operator is never without this 7 kg load held in a predominantly static position with the upper body musculature. The task is extremely hazardous due to the ‘unprotected’ chainsaw, the uneven terrain and falling trees. Thus, simulating the types of tasks undertaken by this worker within a laboratory setting would be virtually impossible, necessitating field experimentation.

Figure 4: The Chainsaw Operator A: felling, B: cross-cutting, C: walking and D: performing maintenance work on the chainsaw.

Debarker

Following behind the Chainsaw Operator was a group of approximately 6 female Debarkers who were responsible for removing the bark from the trees with the aid of an axe. Although these workers formed part of the initial exploratory investigation, responses of these workers were not assessed as part of the main experiment. Responses of these workers are however reported on elsewhere (Christie and Scott, 2005).

Stacker

The Stackers, seen in Figure 5, followed the Debarkers and were required to move, by pulling/dragging, pushing and even tipping/flipping, the logs (2.5 m length) of varying mass (10 kg to 120 kg) to an area they had prepared.

Figure 5: **The Stacker A: pushing and B: pulling the log into position with the aid of a mechanical ‘claw’ and C: lifting and D: placing the log onto a ‘stack’.**

These workers then pushed, pulled and/or lifted the logs to construct the base of a 'stack' onto which they piled approximately 80 logs; hence there was extensive manipulation of these logs to get them to the stack and pile them into bundles. Referring to Figure 5, these workers were provided with a mechanical 'claw' to assist them in manoeuvring the logs into position. Once this stacking task has been completed in a particular section, the logs are mechanically removed from the area with the harvesting activities now complete.

PILOT RESEARCH

Following this observation period, extensive investigative trials, both *in situ* and within the laboratory, were conducted prior to the main experiment. The first pilot test involved the assessment of worker responses *in situ*. Female Debarkers were assessed in Kwambonambi, KwaZulu-Natal in the same area which was utilised for the main experiment. Additionally, in order to directly measure physiological responses during a work shift, 4 Chainsaw Operators and 4 Stackers were assessed while performing their required task. A portable ergospirometer, the $K4b^2$ (Cosmed®) was attached to each worker for the breath-by-breath assessment of physiological responses, specifically oxygen uptake, for the determination of the energy expenditure associated with the task demands. In addition, perceptual responses were assessed by means of the Rating of Perceived Exertion (RPE) scale and the Body Discomfort scale. "Central" and "Local" Ratings of Perceived Exertion were obtained at regular intervals during the work shift and Body Discomfort was obtained on completion of the shift.

Although it was accepted that the assessment of energy expenditure using open-circuit spirometry would be difficult within the actual field of work, the impact of the environmental factors, including the natural and material risks, on the equipment was not anticipated. The nature of the task meant that debris (particularly flying sawdust) resulting from the harvesting tasks interfered with the electronics of the portable ergospirometer. Furthermore, despite extensive habituation to the equipment, the workers complained because the mask hindered their vision while carrying out their required tasks. Based on these pilot findings and due to the problematic nature of assessing tasks *in situ* generally (Scott and Christie, 2004), other indirect methods of assessing energy cost were considered. This necessitated further laboratory-based pilot investigations which assisted in the design of a progressive, submaximal step test for the purpose of establishing individual worker heart rate/oxygen uptake (HR/VO_2) regressions for the estimation of energy expenditure from working heart rate responses. This need to individually calibrate workers, using a progressive test on the same day as the assessment of the specific physical activity has been well researched and accepted (Apud, 1983; Ceesay *et al.*, 1989; Lambert *et al.*, 1994; Strath *et al.*, 2001; Strath *et al.*, 2002; Scott and Christie, 2004; Keytel *et al.*, 2005).

Other pilot tests, conducted in the laboratory, assisted in establishing the protocol for the field 'laboratory' tests including anthropometrical testing and the method for the determination of percent body fat. In addition, the design and the administration of the questionnaires were tested on a small sample, and dietary recalls (24-hour) were conducted on several individuals in order to ascertain the efficacy of this method for determining the nutrient and caloric composition of the workers' diet.

Figure 6: Assessing O_2 uptake *in situ* with a portable ergospirometer, the $k4b^2$.

EXPERIMENTAL DESIGN

Experimentation was divided into four main phases. The first involved obtaining demographic data as well as anthropometric and 'reference' cardiovascular (heart rate and blood pressure) measurements on all workers. The second phase involved the assessment of the biomechanical (specifically working postures), physiological and perceptual responses of Chainsaw Operators and Stackers to task demands *in situ*. Included in this task assessment was the assessment of workers' fluid and fuel intake during working time. The third phase involved a re-test of these same workers under similar working conditions following the introduction of a nutritional supplement provided during work. This was done in order to determine the impact of this supplement on the workers' responses. During phases two and three, the main emphasis was on the energy cost of the selected tasks.

During the two work sessions the harvesters were required to go about their normal tasks, which for the Chainsaw Operator was to fell 280 trees and then to perform 2240 cross-cuts per day, while that of the Stacker was to stack 660 logs during the shift. Workers were able to set their own work pace and rest periods, and can either 'carry over' tasks for the next day, or leave the work area once the allotted task has been completed. The final output is determined by many factors including experience and skill, physical strength and health status, training and motivation, together with the quality of the wood and the environment.

The final phase included the assessment of habitual dietary intake and an analysis of health status and musculoskeletal injury history through the administration of questionnaires (Refer to Appendix C).

ETHICAL CONSIDERATIONS

INFORMED CONSENT

All subjects were informed of the nature of the study, approved by the Ethics Committee of Rhodes University, through a written and verbal explanation given by a Zulu interpreter. An informed consent (See Appendix A) was provided for the subjects to sign.

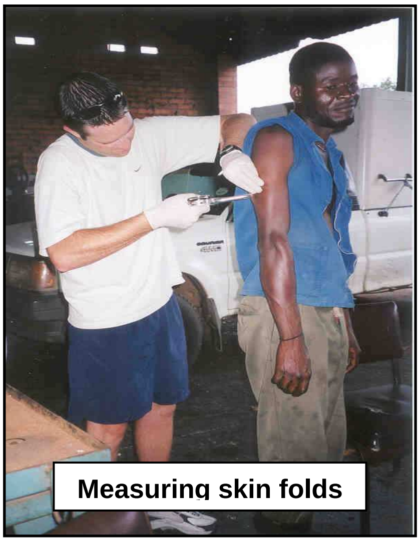
PRIVACY AND ANONYMITY OF RESULTS

A simple data coding system was used to ensure that any information obtained from the workers could not be traced to individual workers. The name field on the data sheets (Appendix B) was only for record purposes, and the workers were informed that any data obtained would be held on file for statistical analyses only.

INSTRUMENTATION AND TREATMENTS

ANTHROPOMETRIC PARAMETERS

Any investigation assessing the compatibility between task requirements and operator capabilities needs to include detailed analyses of worker characteristics. This is particularly pertinent with respect to the indigenous work force required to perform the tasks under investigation. Prior to each *in situ* investigation, a make-shift 'laboratory' was set up in the recreation halls at the workers' place of residence; these general information sessions were conducted in the afternoon prior to the field assessment of the workers and included assessments of morphological make-up and 'resting' cardiovascular function (Refer to Figure 7).



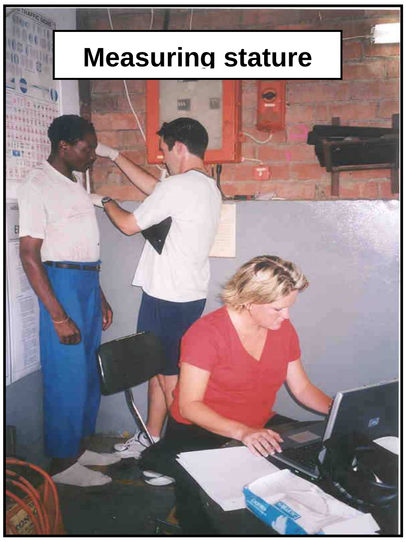


Figure 7: Make-shift 'laboratory' for pre-field testing.

Body Mass

The body mass of each worker was measured to the nearest 0.5 kg using a portable Seca scale. This measure was done with light clothing and with no shoes. Body mass was also measured at the work site immediately prior to, and on completion of the work shift in order to calculate fluid losses during work. These latter measures were done with full working gear including boots and helmets.

Stature

Stature of the forest workers was obtained using a tape measure which was taped to a wall. Workers were required to stand upright and barefoot with their heels against the wall and the head erect looking forward. Stature was measured from the floor to the vertex in the mid-sagittal plane (Refer to Figure 7).

Body Composition

According to the American College of Sports Medicine (ACSM) (2000), body composition determined from skin fold measures correlates well (r=0.70-0.90) with body composition determined by hydrostatic weighing, arguably the most accurate method. The principle behind this procedure is that the amount of subcutaneous fat is proportional to the total amount of body fat.

In the present project, the sum of the following seven skinfold sites was assessed: tricep, bicep, subscapular, abdomen, suprailiac, thigh and calf. All measurements were taken from the right side of the body with the skinfold calliper placed 10 mm away from the thumb and finger, perpendicular to the skinfold, and halfway between the crest and the base of the anatomical site. Duplicate measures were taken at each site and a retest conducted if duplicate measurements were not within a 3% error margin. Percent body fat was estimated using the equations of Durnin and Womersley (1974).

PHYSICAL PARAMETERS

Biomechanical Stressors

Biomechanical stressors associated with each task were estimated using the *Ergoweb 2D* biomechanical model. Digital photos were taken of the workers executing their harvesting tasks *in situ*, and at a later stage analyzed using the 2D model within a laboratory setting. The main purpose of these digital images was to obtain some tangible measure, albeit theoretical, of the kinematic responses associated with the different working postures.

Based on the sex of the workers, the working postures adopted and the mass of the load manipulated the *Ergoweb 2D* model estimates the low back spinal compressive and shear forces, and the required moments for the elbow, shoulder, L_5/S_1, hip, knee and ankle. The model then compares these estimates to standard values published by NIOSH (1991). Strength capabilities for given tasks are compared as percentiles to the static strength values for an industrial population.

The limitations of this model is that it applies only to two-dimensional activities in which the worker is exerting a symmetric lifting, pushing or pulling force using one or both hands, and does not consider the repetitive nature of the task or the total duration of exposure. Several assumptions are therefore made, such as minimal trunk rotation existed while performing the task, the task was of a short duration, the frequency of the task was low, and the postural position was not extreme. However, in the present study, due to the dynamic and repetitive nature of the tasks assessed in the field, it is evident that the theoretical results of the kinematic forces would therefore substantially underestimate the forces placed on the musculoskeletal system of these workers.

Body Acceleration

The RT3™ is a battery operated, 3-Axis, research-grade activity monitor which detects and records 3-Axis motion of the body; the equipment weighs 170g and the output measures are in mediolateral (x), anteroposterior (y) and vertical (z) dimensions. The RT3™ assessed changes in working posture due to trunk acceleration and was used in conjunction with the physical characteristics of the worker (age, sex, stature and mass), to compute the caloric energy required to complete the motion of their tasks.

The night before testing the age, sex, stature and mass of each subject was entered into the relevant accelerometer. On the day of testing, a RT3™ monitor was attached to the waist of each labourer before starting their daily shift and it was left on them for the duration of the work shift. Following the completion of work the RT3™ was removed from the worker and later that day connected to a PC via the RT3 Dock to transfer the data to the PC for independent analysis.

PHYSIOLOGICAL PARAMETERS

‘Reference’ Cardiovascular Responses

During the initial testing in the laboratory set up at the recreation hall, ‘reference’ measures of heart rate and blood pressure were obtained. These were done with a portable, automatic blood pressure unit which recorded heart rate and blood pressure. In accordance with the suggestion put forward by Scott and Christie (2004) the responses are termed ‘reference’ as it is very difficult to obtain true resting responses, despite detailed explanation and demonstration with these rural, mostly poorly educated workers who have never been exposed to such sophisticated testing devices. The unit consists of a cuff, which was secured around the left bicep of the worker, and a built-in sphygmomanometer. Once the cuff was secured, the unit was activated resulting in the expansion of the cuff to occlude the brachial artery. The pressure was automatically released and measures of diastolic and systolic pressure were displayed, together with heart rate.

Polar Heart Rate Monitor

Working heart rate was recorded using the Polar Accurex Plus and Polar Sports Tester Heart Rate Monitors (Polar Electro, Finland). The watch was worn on the subject’s wrist except when assessing the Chainsaw Operators when the attachment of the heart rate monitor was adjusted. Due to the interference of the chainsaw with the electronics of the heart rate monitor the watch was attached to the worker’s left scapula with adhesive tape.

The overall mean ‘working’ heart rates were the average of the heart rate values recorded over the entire working shift including rest periods and maintenance to equipment. Oxygen consumption was inferred from working heart rate using regressions from the step test performed following work.

On-line metabolic system ($K4b^2$)

A portable ergospirometer, the Cosmed® $k4b^2$ was utilised for the continuous assessment of ventilation and oxygen consumption during the step test conducted on completion of the work shift.

Calibration

Before each session, the $K4b^2$ was first calibrated using a Hans Rudolph 3 L syringe for volumetric calibration. The volume transducer on the $K4b^2$ was connected to the 3 L syringe and the calibration was initiated from the portable unit with six volume measurements and the average compared to the nominal value. The gas analyzers were calibrated using firstly ambient air and secondly a 16.10% O_2, 4.90% CO_2 and 79% N_2 mixture. The gas analysis tube was connected to the gas socket on the portable unit and pointed towards ambient air for the first measurement. The second measurement was performed with the gas mixture which channelled into the portable unit.

Determination of energy expenditure

In order to estimate VO_2 and hence energy expenditure from working heart rate, each worker performed a progressive, submaximal step test on the completion of their work shift during which the field assessment was conducted. During this progressive test, heart rate and VO_2 were recorded simultaneously via an on-line, portable ergospirometer. This equipment incorporates breath-by-breath analysis of numerous physiological responses, although for the purpose of this investigation the important variables were heart rate and VO_2 which were needed for the prediction of energy expenditure.

Each subject was required to wear a suitably sized facemask led to a portable unit containing oxygen and carbon dioxide analysers, as well as a sampling pump, UHF transmitter, barometric sensors and electronics. Powered by a battery, this portable unit was fixed to the subject's back via a harness. A receiver unit received the telemetrically transmitted data from the portable unit. These data were downloaded following the completion of their work session, and were exported to Excel™ (Microsoft Corporation).

The mode of testing selected, a stepping protocol, was based on the particular sample under investigation. Apud *et al.* (1989) who has studied forestry workers extensively attests to the accuracy of using standardised cycling or step up tests to predict VO_2 from heart rate during forestry work. The mode of testing is a 'natural' activity to the rural workers of the study and therefore required very little familiarisation, and was easy to administer on the large sample of workers in the field.

Figure 8: Progressive step test performed *in situ*.

During the step test (see Figure 8) the bench was set at a height of 350 mm. Each workload was 3 minutes in duration with step rate increments as follows: 82, 98, 114 and 130 steps.min^{-1}. If heart rate did not reach the highest recorded in the field, an additional workload was incorporated at 146 steps.min^{-1}.

Fluid Balance and Sweat Rate

Total water loss during an activity can be calculated by observing changes in body mass (BM). By assigning a density of 1.0 g.ml^{-1} to water, a simple method of estimating Sweat Loss (SL) is possible and is expressed as follows:

$$SL\ (L) = [BM\ before\ activity\ (kg) - BM\ after\ activity\ (kg)/g.ml^{-1}]$$

This provides an absolute sweat loss value and does not distinguish between losses from sensible and insensible perspiration.

The Relative Sweat Loss (SL_{REL}) was calculated by dividing absolute sweat loss by BM before the activity and multiplying by 100. Note that 1 kg is equal to 1 L.

$$SL_{REL}\ (\%BM) = [SL\ (L)/\ BM\ before\ (kg)] \times 100\ kg.L^{-1}$$

Absolute Rate of Sweat Loss (SL_{RATE}) was estimated by dividing the absolute quantity lost by the duration of the activity (in minutes) multiplied by 60 minutes as follows:

$$SL_{RATE}\ (L.h^{-1}) = [SL\ (L)/Duration\ of\ activity\ (minutes)] \times 60\ min.h^{-1}$$

Relative Rate of Sweat Loss ($SL_{RELRATE}$) was determined by dividing relative sweat loss by the duration of the activity and multiplying by 60 minutes as follows:

$$SL_{RELRATE}\ (\%BM.h^{-1}) = [SL_{REL}\ (\%BM)/duration\ of\ activity\ (min)] \times 60\ min.h^{-1}$$

Changes in body mass were calculated by weighing workers before the work shift and immediately on completion of their job. Workers were told to ingest fluid and food *ad libitum* during the work period, all of which was recorded by the investigator.

PSYCHOPHYSICAL PARAMETERS

To obtain an indication of each worker's personal perception of the work demands, the Rating of Perceived Exertion (RPE) scale and the Body Discomfort (BD) scale were utilised. While these ratings are personalised responses, the numeric ratings are quantifiable measures from valid rating scales. These scales assist in obtaining an overall assessment of the physical demands of the tasks under investigation and in locating sites of physical strain due to the imposed work load.

Ratings of Perceived Exertion

Borg (1970) was the first to propose the inclusion of the RPE Scale to compliment physiological responses during any movement activity; since then the validity of this scale as been comprehensively tested (Gamberale, 1985; Watt and Grove, 1993; Garcin *et al.*, 1998). The scale ranges from a value of 6, indicating almost no strain perceived, to 20 which is maximal perceived strain. The scale was translated into Zulu (Appendix B), the home language of the workers under investigation, and explained in detail by a Zulu interpreter who was the main assistant throughout the project. “Central” and “Local” (pertaining to the back) ratings were obtained at approximately 30 minute intervals, depending on work cycles, during the shift.

Body Discomfort Map and Scale

This scale utilises the perceptions of muscular discomfort experienced by workers and was developed by Corlett and Bishop in 1976. Although it originally consisted of only a posterior view of the body, it has been adapted to include an anterior view with 28 body parts identified overall (See Appendix B). Workers identified the area or site of discomfort and then rated the intensity of discomfort on a scale ranging from 1 (“minimal discomfort”) to 10 (“extreme discomfort”). Sites and intensity of discomfort were obtained and recorded on completion of the work shift.

ENVIRONMENTAL INSTRUMENTATION

Environmental conditions were measured throughout all testing periods; these included measures of ambient temperature and relative humidity. Additionally, the weather station at Kwambonambi provided detailed daily weather conditions. The parameters measured were ambient temperature (T_A), naturally aspirated wet bulb temperature (T_{NW}) and globe temperature (T_G). These three environmental temperatures were then used to calculate the WBGT index as follows:

$$\text{WBGT} (^{0}\text{C}) = 0.7 \times T_{NW} =+ 0.2 \times T_G + 0.1 \times T_A$$

QUESTIONNAIRES

To obtain information on the worker’s current health status and incidence of musculoskeletal disorders at present and in the preceding 12 months, a questionnaire was administered to each worker (Appendix C). This took the form of an interview session with a Zulu interpreter following work, in the recreation hall where they lived.

NUTRITIONAL ASSESSMENT

Assessment of energy intake during work

During *in situ* testing workers were requested to ingest fluid and food *ad libitum* and each investigator recorded this consumption during the working period. The balance between energy intake and energy expenditure while working was then assessed.

24-hour Dietary Recall Method

The 24-hour dietary recall method was selected as the primary technique to measure the habitual dietary intake, and the energy intake during work, of the forestry workers. One of the principal advantages of this method is its speed and ease of administration and the fact that literacy of the respondent is not required which in turn allows this method to be used across a wide range of populations (Nelson and Bingham, 1997). The interviewer administers and fills in the responses, which only require verbal answers from the recipient. This enabled the interview to be conducted in Zulu with each interview lasting approximately 20 minutes. Additionally, the immediacy of the recall period means that respondents are usually able to recall most of their dietary intake of the previous day. Thompson and Byers (1994) maintain that because the recalls take place after the food has been consumed, the assessment method does not interfere with dietary behaviour.

During the interview, the Nordic Co-operation Group of specific procedures for dietary recall (Cameron and Van Staveren, 1988) was utilised. These include conducting the interview in a quiet, relaxed atmosphere, not giving the respondent much prior warning of the interview and using dietary aids to assist in identifying portion sizes. During the interview the workers were requested to recall all beverages and food consumed during the previous 24-hour period; this information was written down on a data sheet broken down into seven daily intervals of pre-breakfast, breakfast, between breakfast and lunch, lunch, between lunch and dinner, dinner and after dinner (Appendix C). At the end of the interview, the interviewer summarised the items that had been eaten and checked with the worker that nothing had been omitted. The objective of the recall was to obtain information on the quantity and quality of the worker's current daily diet.

FoodFinder 3

Dietary intake and nutrient composition of the diets was assessed by utilising Food Composition Tables of the Nutritional Intervention Research Unit (NIRU) of the Medical Research Council (MRC) and the software programme *FoodFinder3* for Windows™ (Microsoft Corporation). Dietary data were entered into the programme for the assessment of dietary intake.

WORKER CHARACTERISTICS

Participants were recruited from the Kwambonambi harvesting area in Kwazulu-Natal. The main ethnic group represented was Zulu whose basic data are shown in Table VI. Fifty eight forestry workers involved in the harvesting tasks of felling, cross-cutting and stacking comprised the initial sample (29 Chainsaw Operators and 29 Stackers). Some participants, for various reasons, were not re-tested following the implementation of the nutritional supplement and thus the responses to this intervention were conducted on a sample of 44 workers (25 Chainsaw Operators and 19 Stackers).

Similar characteristics were observed for the Chainsaw Operators and Stackers, with the exception of years of experience; the Chainsaw Operators had a mean experience of 9.5 years, whereas the Stackers had 2.9 years work experience. This may be explained by the excessive demands placed on Stackers which was evident in the task analyses discussed later. All of the workers were of an ectomorphic build with a mean stature of 1714.6 mm and 1715.0 mm, and a mean body mass of 65.4 kg and 65.3 kg for the Chainsaw Operators and Stackers respectively. This slight build has previously been observed by research conducted on black workers in the Eastern Cape of South Africa (James, 2001; Todd, 2002; Christie and Scott, 2005).

Table VI: Characteristics of the workers investigated.

	CHAINSAW OPERATORS (n=29)			STACKERS (n=29)		
	Mean	**SD**	**CV**	**Mean**	**SD**	**CV**
Age (yr)	35.8	6.3	17.5	36.1	9.3	25.7
Work Experience (yr)	9.5	7.77	10.6	2.9	5.2	1.8
Stature (mm)	1714.6	66.1	3.9	1715.0	58.8	3.4
Body Mass (kg)	65.4	7.0	10.7	65.3	5.7	8.7
Body Mass Index	22.5	1.8	8.0	22.4	1.9	8.4
"Resting" HR ($bt.min^{-1}$)	81.7	13.4	16.4	74.8	13.7	18.3
"Resting" BP (mmHg)	136/87	15/11		139/87	16/12	
Sum of skinfolds (mm)	44.6	17.5	39.2	46.1	10.3	22.3
Body Fat (%)	8.9	3.9	43.8	8.8	2.4	27.3

SD: standard deviation.
CV: coefficient of variation (%).
HR: Heart Rate.
BP: Blood Pressure

EXPERIMENTAL PROCEDURES

The first of the four phases of the study involved obtaining demographic and anthropometric data on the workers. The second and third phases of the research, which involved the analyses of task demands in the field, were conducted during December 2003 and January 2004 respectively. The final investigation was carried out in May 2004. As forestry work is performed outdoors, the climatic conditions were an important determinant of the total physical workload placed on workers. It was therefore deemed necessary to report on the environmental conditions recorded during the period of experimentation in the field during December 2003 and January 2004. These are presented in Table VII. Ambient temperature is described as either T (^{0}C), which was the ambient temperature measured under controlled conditions in a Stephenson Screen, or as FT (^{0}C) which was the highest temperature recorded in the field (Field Temperature) during the working period without a protective screen for direct sunlight, but in a shaded area. In order to minimise the effect of substantial changes in temperature, any data obtained during field investigation were discarded if the mean temperature recorded for the duration of the work shift, measured by the weather station, dropped below 20^{0}C or increased above 30^{0}C.

Table VII: Summary of temperatures and relative humidity levels.

	DECEMBER 2003					JANUARY 2004				
DAY	**T (^{0}C)**	**FT (^{0}C)**	**MIN (^{0}C)**	**MAX (^{0}C)**	**H (%)**	**T (^{0}C)**	**FT (^{0}C)**	**MIN (^{0}C)**	**MAX (^{0}C)**	**H (%)**
1	23.3	29.6	18.7	27.3	80.5	30.0	38.4	23.2	34.9	73.8
2	25.0	31.3	20.8	28.6	76.4	28.7	37.1	23.3	32.2	75.1
3	22.8	30.0	20.4	23.5	76.6	29.4	37.1	23.2	34.3	71.8
4	22.8	22.8	16.6	25.3	81.4	27.0	35.5	24.4	30.1	82.0
5	25.1	34.0	20.5	27.9	80.1	22.2	28.0	21.2	23.1	86.3
6	24.9	32.2	22.4	27.3	79.5	22.2	30.2	19.6	26.1	86.0
7	28.2	41.8	22.3	35.2	74.0	27.0	36.4	20.7	32.2	69.0
8	23.3	30.5	21.1	24.4	76.7	27.1	38.0	23.1	30.3	74.9
9	21.0	29.3	19.1	22.0	84.4	26.3	33.6	23.6	30.0	75.8
10	26.6	35.5	19.3	33.4	84.5	26.2	34.0	22.2	28.1	82.1
11	23.9	30.2	22.3	25.5	73.8	23.1	27.0	22.0	24.6	88.0
MEAN	**24.3**	**31.6**	**20.3**	**27.3**	**78.9**	**26.3**	**34.1**	**22.4**	**29.6**	**78.6**
SD	**1.9**	**4.7**	**1.8**	**4.0**	**3. 7**	**2.7**	**4.0**	**1.4**	**3.8**	**6.5**

T: ambient temperature recorded at the weather station.
FT: highest temperature recorded in the field.
MIN and MAX: minimum and maximum recorded temperature at the weather station.
SD: standard deviation.

The mean temperature (T) during the testing in December 2003 was 24.3^{0}C, while the temperature recorded in the field (FT) was much higher, with a mean of 31.6^{0}C.

During the second testing period in January 2004, temperatures were marginally, but not statistically, higher with a mean T of 26.3^{0}C and a mean FT of 34.1^{0}C. Noteworthy are the high temperatures recorded in the field and how these differed substantially with those recorded at the weather station. Consideration therefore must be given to working temperatures experienced by labourers within the actual field of work.

Humidity levels were high during both testing periods with a mean humidity level of 78.9 and 78.6% during December and January respectively, but with a greater range in January (69.0% to 88.0%). Although ambient temperatures may not be considered excessively high, these temperatures in combination with the high levels of humidity, which is of major concern and which only once dropped marginally below 70.0% during the experimentation phase, will interfere with the body's ability to lose heat through evaporation of sweat from the skin. Although sweating is the most effective mechanism to lose body heat when moving outdoors, it is well known that high levels of humidity hinder this process (Nadel, 1979; Noakes, 1992; Pascoe *et al.*, 1994; McArdle *et al.*, 2001). Workers are therefore losing fluid from the body, which could result in dehydration and likewise, because evaporative sweat loss is hindered the cooling effect is reduced which could result in the development of some form of heat stress.

PHASE I: BASIC WORKER INFORMATION

During this phase, the project was firstly explained to the workers in Zulu and English. The night before *in situ* testing, which formed part of phases two and three, demographic, anthropometric and 'reference' cardiovascular data were obtained from the workers who were to be tested the following day. This was done in a make-shift 'laboratory' set up in the recreation hall were the workers lived. During this session the conceptual basis of the perceptual scales was explained in detail by a Zulu interpreter.

PHASE II: ASSESSMENT OF TASK DEMANDS *IN SITU*

Six workers were tested each day over a 2-week period. Before day break (04:00 am), when their work shift starts, these workers were taken aside. Body mass, in their working gear with shoes and helmets, was measured and recorded. Workers were then fitted with a polar heart rate monitor and an accelerometer and the RPE and Body Discomfort scales were again explained in Zulu.

Subjects were told that they should perform their tasks as they would normally and that they would be watched by a research assistant who would record any fluid or food intake; these research assistants were all either established researchers, or junior researchers reading for either an MSc or PhD at Rhodes University and who had the relevant experience. Workers were requested to return to the outdoor 'laboratory' on completion of their work shift in order to be weighed and to perform the progressive step test. As they went into the field to start their shift, the stopwatch on the heart rate monitor was started and the accelerometer initiated for recording.

Each research assistant was responsible for observing two, and in some instances three, workers who were working in close proximity. Detailed task analyses were done in order to determine specific work procedures. Heart rate was manually recorded at approximately 30 minutes intervals and at which time "Central" and "Local" Ratings of perceived effort were obtained. Each research assistant had either a Zulu interpreter assisting them, or in some instances the assistant was able to converse in Zulu. Fluid and food intake were recorded by the observers. On completion of the work shift, areas of body discomfort were identified and intensity of discomfort recorded. Following the work shift, body mass was measured and following a 30 minute recovery, the step test conducted.

PHASE III: SUPPLEMENTATION AND RE-ASSESSMENT *IN SITU*

Following the initial testing phase workers were provided with fluid and food replenishment during the work shift starting one week prior to re-testing *in situ* (Figure 9). This replenishment was continued for the duration of re-testing which was conducted 4 weeks post the initial investigation.

A

B

Figure 9: **A: The prepared fluid and food and, B: a worker consuming the replenishment.**

The supplementation consisted of 1 L morevite, 2 L water, 4 slices of bread: one sandwich with marmite and the other with peanut butter, and a piece of fruit. The nutrient composition of these replenishments is shown in Table VIII. The same testing procedures conducted *in situ* during phase two, was repeated in this phase.

Table VIII: **Nutrient composition and energy value of the replenishments.**

Foodstuff	Energy Value (kJ)	CHO (g)	Fat (g)	Protein (g)
Morevite* (1 L)	3038.0	172.1	2.1	12.1
1 Banana	108.8	6.6	0.1	0.3
1 Apple	66.9	4.3	0.1	0.1
4 Slices brown bread	1155.3	54.6	4.9	19.4
1 Tablespoon peanut butter	262.0	1.5	5.0	2.5
1 Teaspoon marmite	84.2	1.1	0.01	3.8

kJ: kilojoule
CHO: Carbohydrate.

* Morevite is a high energy food containing a high carbohydrate content which is easily converted in the body to energy. It is a South African product which is inexpensive and popular with rural individuals.

PHASE IV: HABITUAL DIETARY INTAKE AND QUESTIONNAIRES

Following the experimental procedures interviews were conducted with the assistance of Zulu interpreters. The interviews comprised two parts: the assessment of nutritional status and daily nutrient intake and the assessment of health status and musculoskeletal disorders. These interviews were conducted privately at the recreation halls.

STATISTICAL ANALYSES

All data were transferred to the STATISTICA (Version 6.0) statistical software programme. Descriptive statistical analyses were run on all relevant variables providing general information regarding the sample's responses. Simple linear regression equations were computed to predict oxygen uptake from working heart rate.

One-way ANOVAs were calculated to determine whether there were differences in responses during the course of the work shift. Related t-tests compared the physiological and perceptual responses pre- and post-intervention. Finally, Pearson product-moment correlations (r) were used to examine the relationship between working heart rate responses and corresponding RPE. The null hypotheses were rejected at a probability of $p<0.05$, providing a confidence level of 95%. This only allowed 5% chance of rejecting a true hypothesis (Type I error). The sample size of 58 limited the probability of a Type II error (failing to reject a false hypothesis).

CHAPTER IV
RESULTS AND DISCUSSION

INTRODUCTION

Although the discipline of ergonomics has made a substantial contribution to improving working situations it is still questioned whether this has been sufficient, or appropriate, considering the high incidence of musculoskeletal disorders still evident globally (Marras, 2000). Several authors argue that this is because ergonomics is largely a ‘laboratory-based’ science and that there is a need to take the research from the sterile environs of the laboratory to the ‘real world’ situation of the field in order to assess worker responses under authentic working conditions (Oborne, 1995; Zalk, 2001; Scott and Christie, 2004; Scott and Renz, 2006). With respect to ergonomics research in IDCs it may also be necessary to reach a compromise between scientific rigour and concern for the workers. This was recognized by Apud (1983) who, while acknowledging that research is needed to generate new knowledge, contended that in poorer nations the precision of the research process tends to be limited, particularly field-based IDC research. He attributes this to the fact that basic human needs including the provision of adequate water, food and housing are often not met, and if research is not seen by the workers to improve their lifestyle it is often considered unnecessary or even a nuisance. The present research in South Africa, and that done by Apud on Chilean forestry workers in the 1970s and 1980s is therefore ‘breaking new ground’ in the understanding of the demands placed on rural IDC forestry workers, by conducting *in situ* research in order to quantify worker responses while carrying out their manual tasks in the field. The research should take cognizance of the fact that establishing a good rapport with supervisors and workers is imperative for successful research outcomes as many extraneous factors independent of the work situation may influence work performance and the findings obtained (Scott and Renz, 2006).

IN SITU PILOT TESTING FINDINGS

Several pilot investigations were conducted in both the laboratory and the field in order to establish a sound understanding of the forestry industry in South Africa. However, the main pilot experiment was the *in situ* analyses of the responses of Chainsaw Operators and Stackers during a normal work shift. The primary objective was to obtain preliminary information on the profile of the workers in the same area where the main experimental phase was to be conducted. In addition, the physiological cost associated with chainsaw operations and stacking using direct physiological measures was assessed. Subsequent to this preliminary investigation, the method of assessing energy cost was modified for the main experiment because of the extreme environmental and working conditions such as dust, sawdust and sweat which interfered with the electronics of the equipment. Bales *et al.* (2001) in fact suggests that wearing ergospirometry equipment may lead to an overestimation of energy expenditure due to the discomfort experienced by the individual; discomfort experienced due to heat retention, perceived breathing restriction and the conscious effort of the individual to take extra precautions in working with the attached cords.

Detailed findings of the pilot test specific to chainsaw operations and stacking are reported on by Scott and Christie (2004). That study provided baseline data on 8 workers, 4 male Chainsaw Operators and 4 male Stackers, and is presented in Table IX. A noteworthy finding from this pilot investigation was the limited work experience of the Stackers. Overall the selected workers were relatively short and light, although body mass index was within the 'normal' range of 20 – 25 $kg.(m^2)^{-1}$.

This pilot study was conducted during the South African summer months; the mean ambient temperature during the experiment was 32^0C with a mean humidity level of 79%. The workers therefore started their shift at the break of day (04:00 – 04:30 am) to prevent exposure to the excessive midday heat. When the operators arrived at work they were fitted with Polar Heart Rate monitors, and the Rating of Perceived Exertion (RPE) scale was explained in both English and Zulu to each worker. Two workers were tested each day in random order using a portable online metabolic system, the $K4b^2$ (Cosmed®), with 8 workers being assessed over a four day period. The workers were informed that experimenters would be observing them throughout the work shift and that periodically they would be asked to rate their perceptions of effort.

Table IX: Basic data obtained from Chainsaw Operators and Stackers during the pilot investigation.
(Adapted from Scott and Christie, 2004)

	Chainsaw Operators (n=4)	**Stackers** (n=4)
Age (yr)	36	36
Experience (yr)	10	3
Stature (mm)	1700	1670
Mass (kg)	71	68
Ref HR ($bt.min^{-1}$)	79	77
BMI ($kg.(m^2)^{-1}$)	25	24
Blood Pressure (mmHg)	133/89	136/92

***Shaded area refers to the measures obtained on the Stackers**.*
Ref HR: '"Reference" heart rate.
BMI: Body Mass Index.

According to the categorization of workloads put forward by Sanders and McCormick (1993), preliminary physiological findings (Refer to Table X) indicated that the tasks performed by the Chainsaw Operators and Stackers placed "very heavy" to "unduly heavy" demands on these workers (Scott and Christie, 2004), with the energy cost responses well above the 'ideal' of 5 $kcal.min^{-1}$ acceptable for prolonged work shifts (Ayoub and Mital, 1989; Sanders and McCormick, 1993). The workers' perceptual responses of "Central" ratings of 12 and 13 for the Chainsaw Operators and Stackers respectively showed that these workers perceived their work to be "somewhat hard". However, most workers did not fully understand the conceptual basis of this scale; this was reflected in the fact that their ratings stayed very similar regardless of what they were doing and when questioned further most acknowledged that they did not have a thorough understanding of the concept. For the main experimental procedures the conceptual basis of the scale was explained in more detail with a Zulu interpreter trained in the use of the scale.

Table X: Physiological and perceptual responses to the task demands during pilot testing.
(Adapted from Scott and Christie, 2004)

Worker	Mean HR ($bt.min^{-1}$)	HiHR ($bt.min^{-1}$)	Mean VO_2 ($L.min^{-1}$)	Mean EE ($kJ.min^{-1}$)	Mean "Central" RPE
CO	135	167	1.78	35.75	12
St	137	182	1.92	38.55	13

Shaded area refers to the responses of the Stackers.
CO: Chainsaw operators.
St: Stackers.
HR: heart rate.
HiHR: highest maximum heart rate achieved by one worker.
VO_2: oxygen consumption.
EE: energy expended in kilojoules per minute.
RPE: ratings of perceived exertion.

Although the findings of all pilot investigations highlighted the need for a rigorous ergonomics investigation within the harvesting sector of South African forestry, they also assisted in identifying the difficulties associated with conducting a rigorously controlled experiment under such extreme circumstances. In addition the importance of establishing a good rapport with the ethnic supervisors and workers was emphasized, recognizing that these workers were interested in how this research would benefit them both immediately and in the long-term. An educational component to the whole process was therefore considered imperative, as was an interactive participatory involvement of all parties involved.

Overall the pilot test results confirmed the international findings that manual forestry work, specifically felling, cross-cutting and stacking are extremely physically taxing, overloading the musculoskeletal and cardiovascular systems of the workers (Kukkonen-Harjula and Rauramaa, 1984; Gaskin, 1990; Parker and Kirk, 1994; Parker *et al.*, 1999). Fortunately the preliminary findings led to the company acknowledging the need for further research and consequent funding of the much larger, more comprehensive investigation which in addition to the physiological assessments incorporated the analyses of working postures and more detailed analyses of the perceptual responses during work.

MAIN EXPERIMENTAL FINDINGS

The main experimental phases were completed during the South African summer months of December 2003 and January 2004. For ease of reference, worker characteristics likely to have an influence on performance at work will be discussed first. This will be followed by analyses of the working postures and workers' cardiac responses to the specific tasks carried out in the field, and their responses (physiological and perceptual) to the step test following work. Lastly, physiological and perceptual costs of the tasks will be discussed, plus the impact of the intervention strategy on fluid and energy balance.

WORKER CHARACTERISTICS

It is well documented that an individual's capacity to perform work is determined by the interaction of genetic, psycho-social and environmental factors (Smith, 2001). It is this nature-nurture interaction which results in substantial variability in human responses and poses a challenge to all human research. Ergonomics evaluations tend to focus on the 8h or 12h work shift and the responses of workers to task demands within the work setting. In developing nations however, it is important to take cognizance of the 24h cycle of the workers (Scott, 1993) and the associated socio-economic factors when considering that most of these labourers are from rural areas. The culmination of these elements is that many rural South African workers live on, or below the breadline and under nutrition or malnutrition are common.

Although the negative consequences associated with these poor lifestyle factors on the work capacity of forestry labourers appear obvious, it has not generally been considered. Hence one aspect of this study was to obtain an information base regarding the profile of workers likely to execute the required forestry tasks in order to provide some insight into their general condition. The author concedes however, that although this study provides some indication of worker capabilities within the South African forestry, this needs to be investigated further.

HEALTH AND NUTRITIONAL STATUS

Shown in Table XI are the findings obtained from the questionnaires relating to health status.

Table XI: Self-report of the health status of workers assessed.

Risk Factor	% CO (n=25)	% St (n=20)
Hypercholesterolemia	0	0
Diabetes	0	0
Smokers	17	13
Alcohol drinkers	50	30
Hypertension	0	0
Previous hypertension	28	0
Heart Disease	6	0

Shaded area refers to the data obtained from the Stackers.
Data presented as a percentage of the total workers assessed.
CO: Chainsaw Operators.
St: Stackers

Sparling *et al.* (1994) argued for a dose-response effect between increased physical activity levels in Black South African workers by virtue of their work, which is predominantly manual in nature, and a reduced incidence of coronary heart disease (CHD). Although this is confirmed by the findings shown in Table XI it is important to take cognizance that these findings were limited in that very few workers had in fact been tested for any of these conditions. The only risk factor most of the workers were aware of, or had been tested for, was hypertension, hence the incidence of hypercholesterolemia, diabetes and heart disease were either non existent or extremely low. The only way in which a true measure of these risk factors can be obtained, is by having these workers tested through proper medical screening. Monitoring employees' health is an important component of a comprehensive health and safety policy and which needs to be addressed in the forestry industry.

Contrary to anecdotal evidence and suggestions by supervisors and management, the amount of workers who smoked or consumed alcohol was surprisingly low. The supervisors, who were of the same ethnic origin as the workers, indicated that this was because the workers were afraid they would be ostracized and lose their job if they indicated that they did drink or smoke. Those who did drink alcohol said they had between 2 and 10 drinks of a homemade beer brew per day.

HABITUAL DIETARY INTAKE

The results of the 24-hour dietary recall method can be seen in Table XII. These results were compared with the mean recommended daily allowance (RDA) put forward by several authors (Brouns, 2002; Burke, 2002; Bean, 2003). According to them, males with a body mass of 65 kg should be consuming approximately 8 000.0 kJ per day; in the present investigation the Chainsaw Operators were ingesting only 49% of the RDA, while the Stackers had higher energy consumption (5346.0 kJ), but were still only ingesting 67% of the RDA.

Protein and fat intake were marginally below the recommended level and although carbohydrate intake was sufficient for sedentary individuals, for workers involved in heavy manual labour, this is unacceptably low. Research on athletes suggests that in order to sustain dynamic exercise performance a consumption of 8g of carbohydrate per kilogram body mass is necessary (Burke, 2002), which for a 65 kg individual, is 520g. The Chainsaw Operators and Stackers were only eating 110.9g and 186.8g of carbohydrate respectively per day. These stores are not sufficient to sustain work performance for even a few hours and is a likely contributor to low work capacity (Christie, 2002). The findings emphasize the urgency of intervention for these workers particularly with regard to carbohydrate intake. It is well known that a depletion of carbohydrate stores in the form of liver and muscle glycogen is a precursor for fatigue (Goedecke *et al.*, 1999). In fact, Loucks (2004) goes as far as to say that the limiting factor for physical performance is low energy intake, especially carbohydrate intake.

Table XII: Comparison between the recommended and actual dietary intake of the workers.

	PROTEIN (g)	FAT (g)	CHO (g)	TOTAL ENERGY (kJ)
RDA	65.0	30.0-80.0	100.0	8000.0
CHAINSAW OPERATORS	40.5	26.7	110.9	3949.1
STACKERS	56.2	23.1	186.8	5346.0

Shaded area refers to the data obtained from the Stackers.
RDA is the recommended daily allowance for sedentary individuals combining recommendations from several sources (Brouns, 2002; Burke, 2002; Bean, 2003).
CHO: carbohydrate.
kJ: kilojoules.

Although every attempt was made to rigorously control the recall method the author is of the opinion that the findings shown in Table XII are not an accurate representation of the 'normal' intake due to language and cultural differences which may have hindered the workers understanding of the information required. The workers assured the research team that they understood the principles, but this further illustrates the challenge of conducting work on rural, semi-educated and non-English speaking workers. Nevertheless, the findings do draw attention to the fact that these workers were not taking in sufficient nutrients for optimal health and well-being, let alone to sustain performance in a physically demanding job, and overall it is safe to assume that these workers were undernourished. O'Keefe *et al.* (1983) cautioned that undernourished Black South Africans had a predominance of respiratory disease which would compromise work efficiency. Beside the deleterious effect on work efficiency these authors also reported on the strong association between undernourishment and increased susceptibility to infection and mortality.

PREVALENCE OF INJURIES AND MUSCULOSKELETAL DISORDERS

Despite limited statistical evidence the occurrence of musculoskeletal problems would arguably be greater in forest harvesting, where manual work predominates, than in more mechanized operations. Furthermore, lower worker capacity as a direct result of socio-economic factors evident in South Africa would likely exacerbate this negative scenario. Despite this, evidence points to a surprisingly low incidence of MSDs in South African workers (Renz, 2004), and specifically forestry workers (Manyuchi *et al.*, 2003). This is apparent in Table XIII which demonstrates a low incidence of past and current injuries of the cohort of workers assessed. Also shown in this table was the level of absenteeism in the preceding 12-month period.

Injuries reported by the Chainsaw Operators were primarily cuts on the lower extremities from the chainsaw, or minor head injuries from falling branches. The Stackers reported significantly lower overall incidence of injuries with only two workers reporting that they had sustained an injury in the previous 12 months. These were the result of dropping logs on the lower extremities. The supervisor argued that the very low reporting of problems was probably due to the workers' perceptions that they would be seen to be 'complaining', and they feared for their jobs. This would be in agreement with the findings of Manyuchi *et al.* (2003) who reported that South African forestry workers did not report injuries or MSDs for fear of losing their jobs. As such, reliable statistics generally on South African workers' musculoskeletal health is severely lacking. This is despite the fact that it is well known that accurate reporting of work-related injuries assists in identifying unsafe areas and work practices, measures the impact of work-related problems on health, productivity and costs, and prioritizes accident prevention measures and assesses the effects of safety improvements (Pransky *et al.*, 1999). These authors state that under reporting of work-related conditions is not unique to developing countries and that it is a global concern. They also note that a recent study in the aerospace industry found that 69% of workers experienced low back pain, yet only 27% reported complaints to the medical department, and only 2.3% filed a workers' compensation claim (Jefferson and McGrath, 1996).

Table XIII: Prevalence of previous and current injuries.

	% CO (n=25)	**% St** (n=19)
Current MSD	6	0
MSD in preceding 12 months	22	9
Absenteeism in preceding 12 months	61	43

Shaded area refers to the responses of the Stackers.
Data presented as a percentage of the total workers assessed.
CO: Chainsaw Operators.
St: Stackers

With respect to absenteeism, the predominant reason for missing work among the workers assessed in this study was toothache. This interestingly was also the main reason for absenteeism amongst Chilean forestry workers (Apud, 1983), which this author attributed to poor diet, a factor which the present study would find a feasible explanation.

ANALYSES OF TASK DEMANDS

The present research adopted the universally accepted approach of integrated holism (Charteris *et al.*, 1976; Ayoub and Mital, 1989; Dempsey, 1998; Marras, 2000). While the main emphasis was on the physiological, in conjunction with the psychophysical responses of the workers, it was essential to consider the working postures which as Gallagher (2005) stated will have a decided influence on the metabolic demands of any manual labour. These were assessed using observational techniques, digital imaging and theoretical model analyses.

CHAINSAW OPERATIONS

Task Description

The Chainsaw Operators were the only workers assessed who were required to operate hand-held machinery, a chainsaw. The overall job demands were of an intermittent nature involving the two main tasks of ‘felling’ and ‘cross-cutting’, but which also required a great deal of walking from tree to tree, and periodic sitting while performing maintenance work on the chainsaw. The overall requirements of these operators, felling 280 trees and executing 2240 cross-cuts per shift, were met on a 'work-to-task' basis. The mean working period was 4h48min with felling constituting 31% of that total time, and cross-cutting 69% (Refer to Table XIV). These workers therefore spent a considerably larger proportion of their time sawing the tree trunks into 2.5 m logs as opposed to felling them.

Table XIV: Average duration of the two main sub-tasks of the Chainsaw Operators.

Worker	Felling (h.min)	Cross-cutting (h.min)	Total Time (h.min)
Chainsaw Operators	1.39 (0.48)	3.09 (0.78)	4.48 (1.16)

Data expressed as means (standard deviation)

There were no 'formal' rest breaks, and by virtue of the fact that they could go home once they had completed their allotted tasks, very few workers took voluntary rest breaks. The few who did, chose to take a short rest when changing over from felling to cross-cutting. This approach to work is predominantly seen in industries where productivity per time unit is rewarded, as it is in forestry, and is criticized for placing undue strain on workers, particularly undernourished workers (Panter-Brick, 2003). As the workers in this investigation were found to be undernourished, it is argued that this work method is not optimal for either worker well-being or the long-term company productivity, and may be a prime reason for the high turnover of staff in this industry within South Africa.

Felling

On arrival at the work site the Chainsaw Operators checked that their chainsaws were in working order before proceeding with the felling task. The operators worked within a 'rack' of trees, sawing at the base of the trees; the time taken to saw through the trunk of a single tree varied between 5 and 60 seconds depending on the size of the trunk. As a general rule each Chainsaw Operator worked with a 'Pusher' who assisted him in guiding the fall of the tree: this was referred to as 'directional felling'.

During the course of his work, the Chainsaw Operator was required to walk from tree to tree, carrying his chainsaw (7 kg), over uneven terrain negotiating debris and fallen trees. Each operator was also responsible for fuelling and maintaining his own chainsaw.

Cross-cutting

Once the required number of trees were felled, the same workers then cross-cut these trunks into 2.5m logs. While cross-cutting, the worker also removed branches (debranching) from the trunks by manipulating the chainsaw in order to saw off the branches from the trunk; this resulted in the operator having to adopt some awkward positions of the upper limbs. Both of these tasks were done in an *ad hoc* manner, with no clear pattern evident. This was unlike the hierarchical task analysis observed by Ashby *et al.* (2002) in the New Zealand forestry industry where Chainsaw Operators appear to follow a more organized pattern of felling and cross-cutting. Each trunk was cut into approximately 7 lengths, and the time taken to perform a single cross-cut varied between 7 and 20 seconds depending on the width of the trunk. Although there was greater task diversity as workers walk between fallen trees removing branches from the sides of trunks, as well as cross-cutting, the task did require more manipulation of the chainsaw as logs often lie at different levels and angles or beneath debris. This will place considerable strain on the musculoskeletal structures of the wrists and forearms predisposing these workers to upper limb disorders.

Working Postures

Felling

Four basic postures were adopted by these operators during this task; these included a “half-kneel”, “squat”, “flexed-stoop” and “stoop” posture (Refer to Figure 10). Analyses revealed awkward working postures with a predominance of trunk flexion. Activity counts measured with accelerometers support this as the predominant trunk motion during felling was in the sagittal plane; motion in this plane (y axis) demonstrated an average of 583.60 (±114.59) counts.min^{-1}. Motion in the mediolateral (x) and vertical (z) planes were less with a mean activity count of 560.16 (±114.88) counts.min^{-1} and 478.27 (±147.40) counts.min^{-1} respectively.

Trunk forward flexion was greatest when adopting the flexed-stoop posture (88^0), followed by the stooped (65^0) posture. Although adopting the half-kneel posture resulted in the least trunk flexion (46^0), according to the risk classification devised by Marras *et al.* (1995), all these postures and resultant forces on the lower back, fall within the 'high risk' category. In addition Marras (2000) has emphasized that MSDs tend to arise more from cumulative stress rather than from a once-off MMH event, and this task was generally carried out for over an hour and sometimes in excess of two hours per day for some workers; thus the cumulative strain is highly likely to lead musculoskeletal problems, particularly of the lumbar region of the spine.

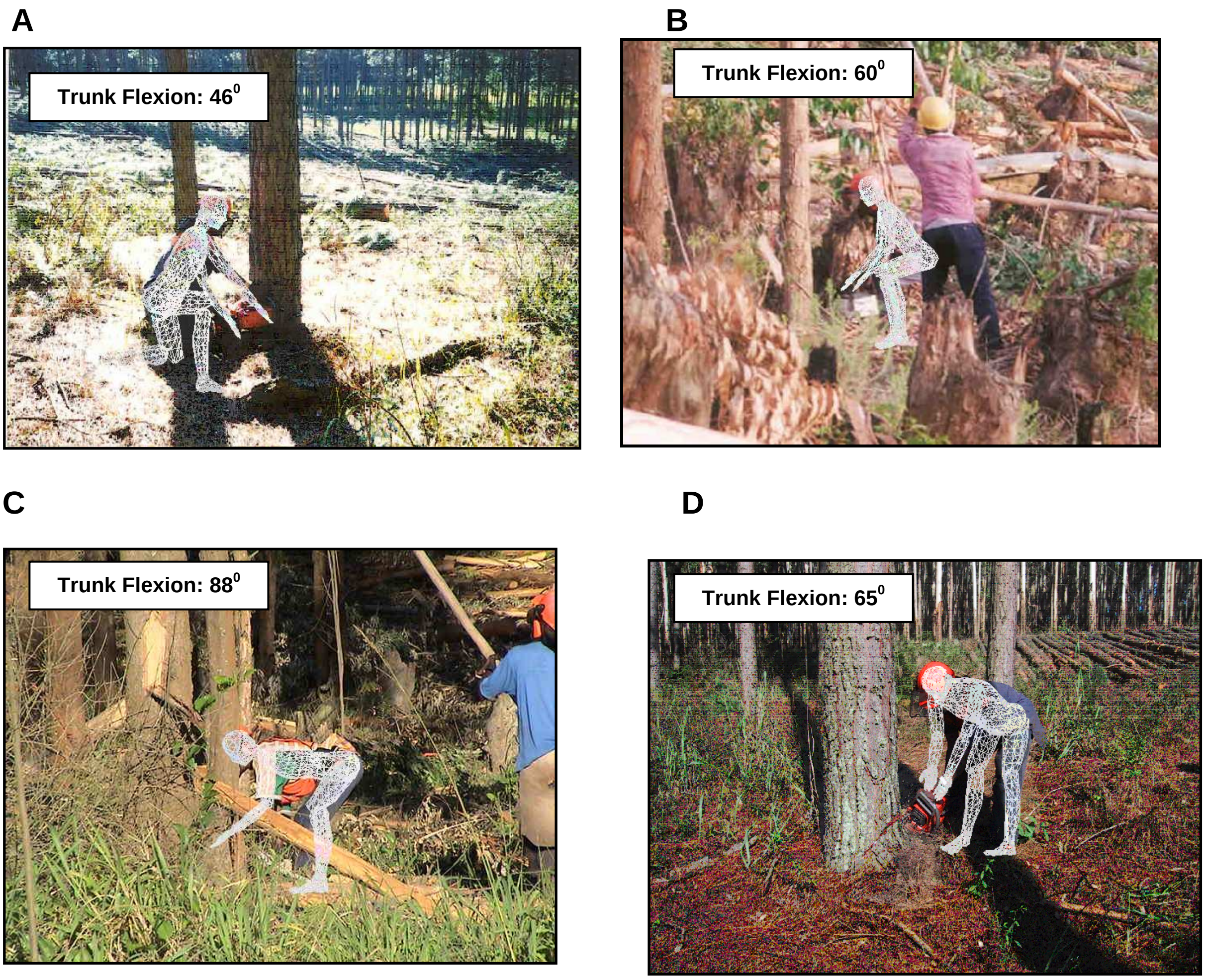


Figure 10: The four main working postures adopted by the Chainsaw Operator during felling; A: a half-kneel, B: a squat, C: a flexed-stoop and D: a stoop posture.

Due to the complex nature of musculoskeletal forces acting on the body as it adopts such a diversity of working postures, it is difficult to assess them directly. However, with the use of theoretical models, calculations of the moments and forces on the body induced by the combination of load and posture adopted can be estimated. In this project the *Ergoweb 2D* software package was used to obtain an estimation of low back compressive and shear forces. Due to the fact that this is based on a static two-dimensional assessment, it is important to note that it was not possible to estimate the additional forces generated by the sawing motion. Therefore, the forces shown in Table XV encompass only those associated with the working posture adopted while statically holding the 7 kg chainsaw and taking into consideration the counter action of the erector spinae muscles of the spine. These estimates would increase considerably when adding the transectional forces required to fell a tree, and would vary depending on hardness of timber and thickness of trunk. Furthermore, the strain placed on the quadriceps musculature particularly when adopting the squat posture, will contribute to the overall musculoskeletal strain experienced by these workers. Moreover, because this is a large muscle group, adopting this posture will raise the energy cost of the task considerably.

Table XV: Compressive and shear forces on L_5/S_1 during felling when adopting different working postures.

Posture	Trunk Angle (^{0})	Compressive Force (N)	Shearing Force (N)
“Half-kneel”	46	2394	166
“Squat”	60	2137	214
“Flexed-stoop”	88	2789	327
“Stoop”	65	2366	390

Due to the various postures adopted, the compression and shear forces vary substantially. The lowest compressive force was calculated when adopting the squat posture (2137 N), while the posture with the highest shearing force was the stoop posture (390 N). In contrast, the compressive forces were greatest when adopting the flexed-stoop posture (2789 N) where the flexing of the knees facilitated a greater amount of flexion in the trunk. Although these theoretical, static forces are moderate, it is essential to take cognizance of the transectional force required to cut through the tree trunk which were not measured, plus the effect of the vibration associated with using a motorized chainsaw. While it is commonly believed that excessive trunk flexion is a risk factor for lower back pain, no epidemiological studies have confirmed this and as such these forces should be interpreted with caution.

Cross-cutting

Working postures varied substantially during the cross-cutting sub-task so for ease of reference, the two most common postures adopted were analyzed. These include versions of “flexed-stoop” and “stoop”, similar to those adopted during felling (See Figures 10 and 11). Shown in Figure 11 is the extent of trunk flexion associated with these two postures with the more upright stance (Figure 11 A), associated with minimal knee flexion, the only posture adopted by the Chainsaw Operators which would not be considered ‘high risk’ according to the risk categorization of Marras *et al.* (1995). However, it should be noted that this posture was only possible when one tree trunk had fallen on top of another, as illustrated in Figure 11 A.

A **B**

Figure 11: Working postures adopted by the Chainsaw Operator during cross-cutting; A: a stoop and B: a flexed-stoop posture.

Table XVI reveals that the stoop posture resulted in nominally higher compressive and shear forces than the flexed-stoop posture. The compressive forces estimated for the cross-cutting sub-task were all lower than those for the felling component of the Chainsaw Operators job. This was due to a reduction in the extent of the stooping posture during cross-cutting. These reduced forces and the greater task diversity would predispose the Chainsaw Operator to a lower risk of musculoskeletal injury to the spine than during felling.

Table XVI: Compressive and shear forces on L_5/S_1 during cross-cutting when adopting different working postures.

Posture	Trunk Angle (^{0})	Compressive Force (N)	Shearing Force (N)
"Stoop"	23	2000	310
"Flexed-Stoop"	71	1837	303

STACKING

Task Description

Once the trees have been felled, cross-cut and debarked (the latter task by a team of female workers), the Stackers collect and position the logs into stacks of approximately 80–100 timber lengths. On arrival at the work site, these workers clear an area of debris and then assemble a stack frame or base on which to place the logs; this is repeated during the work shift as stack bundles are completed and new ones constructed. The workers collect logs by dragging or pulling them towards the stacking area, usually with the assistance of a 'mechanical claw' which helps to 'grip' the log (See Figure 12). Finally the logs are lifted and positioned on the stack. The methods of collecting and stacking the 2.5 m logs varies substantially and is often dependent on the experience of the worker, with the experienced workers demonstrating a more organized pattern of working. The average working time of the Stackers was 4h36 min.

Working Postures

During the stacking task, trunk movement was greatest in the anteroposterior plane (y axis) with a mean activity count of 796.85 (±165.99) counts.min^{-1}. Trunk movement in the mediolateral (x axis) and vertical (z axis) planes were 679.87 (±169.03) and 521.55 (±153.39) counts.min^{-1} respectively. The predominant trunk movement was therefore forward flexion. The high standard deviations reflect the intra- and inter-variability of the workers' movements depending on the demands of the situation.

Shown in Figure 12 are the two main methods employed to drag the logs towards the stack with the 'mechanical claw'; these were unimanual (A) or bimanual (B) techniques. Trunk excursions during the one-handed drag were considerably lower than those using the two-handed drag which forced the worker into a greater degree of forward flexion. Using one hand enabled the worker to adopt a more upright stance by lifting the one end of a log and dragging it into position. The degree of trunk flexion associated with the two-handed drag would, according to Marras *et al.* (1995), place the worker at a high risk for developing some form of lower back injury.

A

B

Figure 12: Stackers using A: a one-hand drag and B: a two-hand drag to manoeuvre the logs into position.

As the mass of the logs varied substantially in the field, a range of masses was selected to analyze the compressive and shear forces acting on L_5/S_1 while using these dragging methods. These are shown in Table XVII.

Table XVII: Compressive and shear forces on L_5/S_1 to collect timber using the two dragging techniques.

Log Mass	Action	Compressive Force (N)	Shearing Force (N)
10 kg	1 hand	1213	286
	2 hand	2924	333
60 kg	1 hand	3593	854
	2 hand	10794	996
120 kg	1 hand	5398	1308
	2 hand	18370	1526

Forces in red are above 'safe limits' (Ergoweb 2D biomechanical model).

Although neither the compressive or shear forces were excessive when pulling lighter logs (10 kg), these forces were exceptionally high when dragging 60 kg and 120 kg logs; as the mass of the logs increased so both compression and shear forces acting on the spine increased. Noteworthy from Table XVII is the fact that the compressive and shear forces on L_5/S_1 are consistently higher for the two-handed pull due to a greater forward stoop adopted by the workers. However, although the use of a one-handed pull may result in lower forces on the spine, those acting on the shoulder joint are increased significantly (Refer to Table XVIII). Acknowledging that Static models, such as the *Ergoweb 2D* model, tend to underestimate the compression on the spine, the finding that a compressive force of 18370 N was exerted when using two hands to drag the 120 kg load is excessive, and in reality would be exacerbated by the postures adopted by the workers when executing this aspect of the task. Thus the stacking of logs in excess of 100 kg is likely to result in severe trauma and should be cautioned against even though this type of maneuver and load mass is done intermittently.

The moments of force show that in contrast to the forces acting on the spine, the forces on all other joints were higher when using the one-, as opposed to the two-handed drag technique (Table XVIII). In particular, the moment of force in the shoulder and elbow joints when pulling the log with a single arm behind the worker, was excessive. The concomitant result is an increased likelihood of injury to the musculature in those areas due to placing the arm in abduction, extension and rotation. This awkward positioning of the arm is identified as an 'abnormal' posture for the shoulder to adopt (Compensation Commissioner's Guidelines, 2004), and any task requiring this action is a high risk task in need of intervention.

Table XVIII: Estimated joint moments during log dragging.

Log Mass	Action	Elbow	Shoulder	Hip	Knee	Ankle
10 kg	1 hand	16	33	55	60	109
	2 hand	1	31	66	9	55
60 kg	1 hand	42	91	106	50	81
	2 hand	1	72	77	7	44
120 kg	1 hand	104	227	131	29	15
	2 hand	1	168	199	2	18

Figures in red refer to less than 50% of the population which would be capable of producing the required moments of force. (Ergoweb 2D biomechanical model).

The sub-task of piling the logs onto the stack (Refer to Figure 13), is done by lifting and manoeuvring the logs in different ways. Once the log is on the stack, the workers push and manipulate them into position. Referring to Table XIX, the calculated forces for the heavier logs are substantially higher than acceptable forces proposed in the literature for lifting (Charteris and Scott, 1990; Waters *et al.*, 1993). Compressive forces in the lower spine were as high as 7552 N when lifting the 120 kg log onto the stack, while the shear forces for the same log mass was 1595 N. Recognizing the fact that often the movements to place the logs on the stack were more complex than just a pure lift, and that the software uses static models, these forces will in reality be much higher.

Most of the logs manoeuvred and positioned by these Stackers are in excess of the ‘recommended weight limit’ (RWL) of NIOSH (1993) which states that 23 kg is the maximum which can be lifted when all other conditions are ‘ideal’ (Waters *et al.*, 1993); indeed the majority of them were above the recommended maximum mass of lift (42 kg) suggested by South African researchers Charteris and Scott (1990) who recognized that loads of 23 kg and less are rarely seen within South African industries. Clearly the mass of most of the logs lifted by these Stackers are well above any ‘acceptable’ recommendation, placing these workers at considerable risk.

Figure 13: The act of stacking requires lifting and manoeuvring of the logs.

Table XIX: Compressive and shear forces acting on L_5/S_1 when positioning logs on the stack.

Log Mass	Compressive Force (N)	Shear Force (N)
10 kg	1692	348
60 kg	4432	1041
120 kg	7552	1595

Working postures have tended to be investigated predominantly from a biomechanical perspective (Bush-Joseph *et al.*, 1988; Adams *et al.*, 1994; Scott and Charteris, 2004). This is despite the suggestion by Garg and Herrin (1979) that the associated metabolic cost should not be neglected. The need to adopt a variety of approaches in any task analyses is illustrated by the fact that depending on the approach adopted, different ergonomic recommendations are put forward (Dempsey, 1998). For example with lifting, it is often argued that a squat lift is more biomechanically efficient than a stoop lift, yet the physiological literature suggests otherwise (Straker, 2003). While much of the literature has focused on the lifting action, the same principles will apply to the Chainsaw Operators where some adopted a squatting position to fell trees; this may tax the physiological systems more than workers who favour a more stooped posture, which is known to tax the musculoskeletal system more. Likewise, Stackers may favour different methods of lifting logs onto a stack. It is generally acknowledged that workers tend to prefer to 'protect' the musculoskeletal system at the cost of increased physiological responses (Straker, 2003), and in this study it was noted that the "half-kneel" and "squat" postures during felling were the preferred techniques highlighting the need to include an investigation of the physiological cost associated with this work.

Physiological responses

Heart rate responses during work

Due to the substantial variation in the duration of each work shift (3h10 min to 7h09 min) each worker's shift was divided into four quarters; with the Chainsaw Operators, the first two quarters represent the felling operations and the last two quarters, cross-cutting. Heart rate responses of the Chainsaw Operators and Stackers recorded over the entire duration of their work shift are shown in Table XX. The 'working heart' rates recorded from the Chainsaw Operators ranged from 85.1 bt.min^{-1} to 146.3 bt.min^{-1}, and on average they were working at 67% of their age-predicted maximum heart rate. These heart rates were significantly ($p<0.05$) higher during the last two quarters of the Chainsaw Operators' work shift compared to when the workers were felling down the trees. It is therefore reasonable to assume that a 'steady-state' was not achieved, indicating this job was physiologically taxing and not ideal for a sustained effort over a work shift.

In contrast working heart rates remained fairly stable over the course of the work shift for the Stackers, with no significant differences observed over time (Table XX). However, the range of cardiac responses was greater with the mean responses varying between 90.3 bt.min^{-1} and 164.4 bt.min^{-1}. On average, the Stackers were working at 64% of their age-predicted maximum heart rate. As mean responses remained fairly stable over time and from observations made while collecting data in the field, it was evident that these workers adjusted the intensity at which they worked so as not to over tax themselves for any length of time. In order to do this they tended to alternate between moving heavy logs and lighter logs, and between lifting on to a stack and clearing an area. This strategy of 'self pacing' is in keeping with the concept of 'body wisdom', first described by Cannon in 1922, whereby individuals recognize that continuing at an intense pace for too long will be counter-productive and will result in the premature onset of fatigue. Recently St Clair Gibson *et al.* (2003) found that athletes participating in repeated 'all-out' sprint efforts automatically reduced their pace with each subsequent sprint effort despite perceiving they were still working at the same intensity. These athletes were told to give a maximum effort during each trial and were convinced that they had in fact done this even when the results revealed otherwise. It is therefore contended that with the Stackers the same principle was probably applied whereby these workers subconsciously self paced themselves in anticipation of the required effort to sustain not only an entire shift, but also to enable them to return to work day after day. There is a greater probability of this with the more skilled workers who had experienced how physically taxing the work is and self regulated their work pace accordingly. The other key issue to consider in this demanding work ambience is that the workers are of differing nutritional and health integrity, and this will alter the intensity of effort according to their own individual capabilities. It is unfortunate that management may perceive this apparent 'drop off' in pace as 'laziness'.

According to Sanders and McCormick's (1993) classification, the responses in Table XX indicate "moderate" demands were placed on these workers. However, the range of responses suggests that the task demands varied substantially, and at times the physical demands experienced by these workers amounted to being "heavy", with one worker's heart rate reaching over 180 bt.min^{-1} indicating "excessive" demands.

Table XX: Cardiac responses of the Chainsaw Operators and Stackers for the duration of the work shift.

	First Quarter	Second Quarter	Third Quarter	Fourth Quarter
CO	120.6 (11.1)	118.9 (12.5)	125.8 (12.5)	127.4 (13.3)
ST	117.5 (11.4)	119.6 (15.2)	116.8 (15.3)	117.1 (12.9)

Shaded area refers to the response of the Stackers.
** Denotes a significant difference between felling and cross-cutting.*
CO: Chainsaw Operators.
ST: Stackers.
WHR: working heart rate.

When testing large groups heart rate monitoring provides one of the most efficient and economical means of quantifying work demands (Scott and Christie, 2004), and is often used for estimating energy expenditure (Keytel *et al.*, 2005). However, to improve the accuracy of using this measure to predict metabolic cost, individualized regression analyses based on the relationship between heart rate (HR) and oxygen uptake (VO_2) during a physical test is preferred (Strath *et al.*, 2001). Working heart rates can then be utilized to predict energy expenditure by applying a regression equation to the working heart rate measures. In the present study, after a 30 minute rest period following work, a step test protocol was employed to establish this HR/VO_2 relationship.

Responses to the step test

The physiological responses to the submaximal, progressive step test are presented in Table XXI. All the physiological responses increased significantly across the workloads during the step test for both sets of workers. The mean heart rate responses recorded during work for the Chainsaw Operators (123.3 $bt.min^{-1}$) and Stackers (117.6 $bt.min^{-1}$) were not significantly different from the mean responses measured during stepping (127.9 $bt.min^{-1}$ and 116.9 $bt.min^{-1}$ for the Chainsaw Operators and Stackers respectively). This suggests that workers were similarly taxed during both activities, which was imperative as the HR/VO_2 relationship measured during stepping was used to predict oxygen uptake from heart rate recorded during work. Several authors have noted that this relationship should be specific to each individual in order to yield the most valid results (Strath *et al.*, 2001; Haskell *et al.*, 1992).

Table XXI: Physiological responses recorded during the step test for the Chainsaw Operators and Stackers.

Variable	WL 1	WL 2	WL 3	WL 4	Mean
Heart Rate **(bt.min^{-1})**	114.6 (15.1)	123.5 (16.1)	131.7 (16.8)	141.7 (16.3)	127.9 (10.8)
	105.4 (11.1)	111.9 (11.2)	118.1 (10.6)	132.3 (12.2)	116.9 (14.9)
F_B **(br.min^{-1})**	20.0 (4.9)	24.3 (5.1)	28.3 (4.6)	34.1 (6.7)	26.7 (4.80)
	27.6 (3.2)	32.9 (6.2)	36.1 (5.7)	42.1 (8.1)	34.7 (5.3)
V_T **(L)**	0.70 (0.10)	1.20 (0.30)	1.50 (0.30)	1.70 (0.40)	1.28 (0.20)
	0.92 (0.15)	1.25 (0.23)	1.32 (0.21)	1.58 (0.31)	1.27 (0.20)
V_E **(L.min^{-1})**	14.0 (5.6)	29.16 (6.71)	42.48 (4.91)	57.97 (4.16)	35.90 (7.33)
	25.4 (4.7)	41.1 (5.8)	47.7 (6.9)	66.5 (4.2)	44.0 (6.9)
VO_2 **(ml.kg^{-1}.min^{-1})**	15.6 (3.9)	21.5 (3.4)	25.3 (4.0)	29.2 (4.9)	22.9 (6.5)
	18.3 (6.1)	21.1 (6.0)	23.8 (5.9)	30.1 (6.1)	24.0 (5.9)

Shaded areas are the responses of the Stackers.
n=58.
WL: workload.
Means with standard deviations in brackets.
Significant differences were observed between all workloads.

According to research conducted by Christie and Scott (2005) on South African foot soldiers, the ventilatory demands during workloads 1 and 2 place “nominal-to-heavy” demands on the workers, and during workloads 3 and 4, the demands increased to being “very heavy-to-excessive”. Further reiteration of the progressive demands of the step protocol was the 32% and 24% increase in oxygen uptake from the first to the last workload for the Chainsaw Operators and Stackers respectively. Yet, while heart rates tended to be lower for the Stackers than the Chainsaw Operators, the oxygen uptake responses were consistently higher for the Stackers, which reinforces the specificity of the HR/VO_2 relationship. Based on an estimated maximal oxygen consumption value of 40 $ml.kg^{-1}.min^{-1}$, which was obtained on South African soldiers of a similar ethnic origin (Christie and Scott, 2005), these workers, during the last workload were working at approximately 75% of $VO_{2\ max}$.

In an attempt to obtain a tangible measures of the workers' perceptions of these physical demands, both "Central" and "Local" RPE responses were recorded. Although "Central" ratings of perceived effort were higher than the "Local" ratings throughout the protocol for the Chainsaw Operators, these ratings were no different for the Stackers during the first three workloads (See Table XXII). It was only in the last workload that the Stackers perceived a greater cardiovascular strain rather than local muscular fatigue. The perceptual ratings increased progressively from 10 to 13 ("Central" RPE) and from 9 to 11 ("Local" RPE) for the Chainsaw Operators with a strong linear relationship (r=0.94) between heart rate and "Central" RPE which was to be expected due to the progressive nature of the test. The Stackers also demonstrated this linear relationship (r=0.89) although the relationship was not as close.

Table XXII: "Central" and "Local" ratings of perceived exertion recorded during the step test.

RPE	WL 1	WL 2	WL 3	WL 4	Mean
"Central"	10 (2.2)	11 (2.0)	13 (2.3)	13 (2.3)	12 (2.3)
	9 (1.1)	9 (2.1)	10 (2.0)	12 (2.1)	10 (2.4)
"Local"	9 (2.4)	11 (2.0)	10 (3.0)	11 (1.7)	10 (2.0)
	9 (1.4)	9 (2.0)	10 (2.6)	11 (2.0)	10 (2.2)

Shaded area refers to the responses of the Stackers.
WL: workload.

Regressions

As cardiac responses were the only direct physiological measure obtained in the field, based on the acknowledged relationship between heart rate and VO_2 individual regression equations were calculated from the data collected during the step test. The individual regression analyses revealed a mean r^2 of 0.59 (Chainsaw Operators) and 0.56 (Stackers) with a mean correlation of 0.75 (Chainsaw Operators) and 0.74 (Stackers) which is deemed to reflect a close relationship between heart rate and oxygen uptake where one could argue for a reliable predictive efficiency. However, a noteworthy finding was the low predictive efficiency evident with some individual workers. For example, the lowest individual r^2 was 0.22 (Appendix D) where only 22% of the variance in VO_2 can be explained by the variance in heart rate of that particular worker. At the other end of the spectrum the highest r^2 was 0.83, reflecting a large diversity within this group of rural workers. This was an unexpected finding considering that the protocol was of progressive intensity and is known to elicit tight individual relationships (Keytel *et al.*, 2005). However, the fact that these workers were undernourished and likely to be in poor health as a direct consequence, may explain this. Furthermore, various factors including ambient temperature and stress and dehydration (McArdle *et al.*, 2001) are known to affect the relationship between heart rate and VO_2. The step test was conducted following work when ambient temperature and humidity were considerably higher than they were during work. This in all probability also impacted on the association between heart rate and oxygen uptake. Furthermore, as the work was physically demanding and the workers were dehydrated and lacked energy (both shown later in the results section) these workers were clearly fatigued. This is despite the 30-minute recovery period provided before the initiation of the step test. It is highly probable that oxygen uptake had not recovered in a similar manner, thereby having an impact on the responses during stepping. This excess post-exercise oxygen consumption (EPOC) has been shown to occur following fatiguing activities (McArdle *et al.*, 2001).

Recently it has been contended that using prediction equations generated on large samples of individuals (group regression) may be useful to quantify energy demands on subsequent, similar samples particularly when individual testing is not possible (Scott and Christie, 2004). With respect to the group regression (Figure 14), which was derived from the mean heart rate and oxygen uptake responses achieved during each workload of stepping for all the workers, the r^2 was 0.24 (Chainsaw Operators) and 0.46 (Stackers) with a correlation coefficient of 0.42 (Chainsaw Operators) and 0.67 (Stackers), considerably lower than the mean individual values.

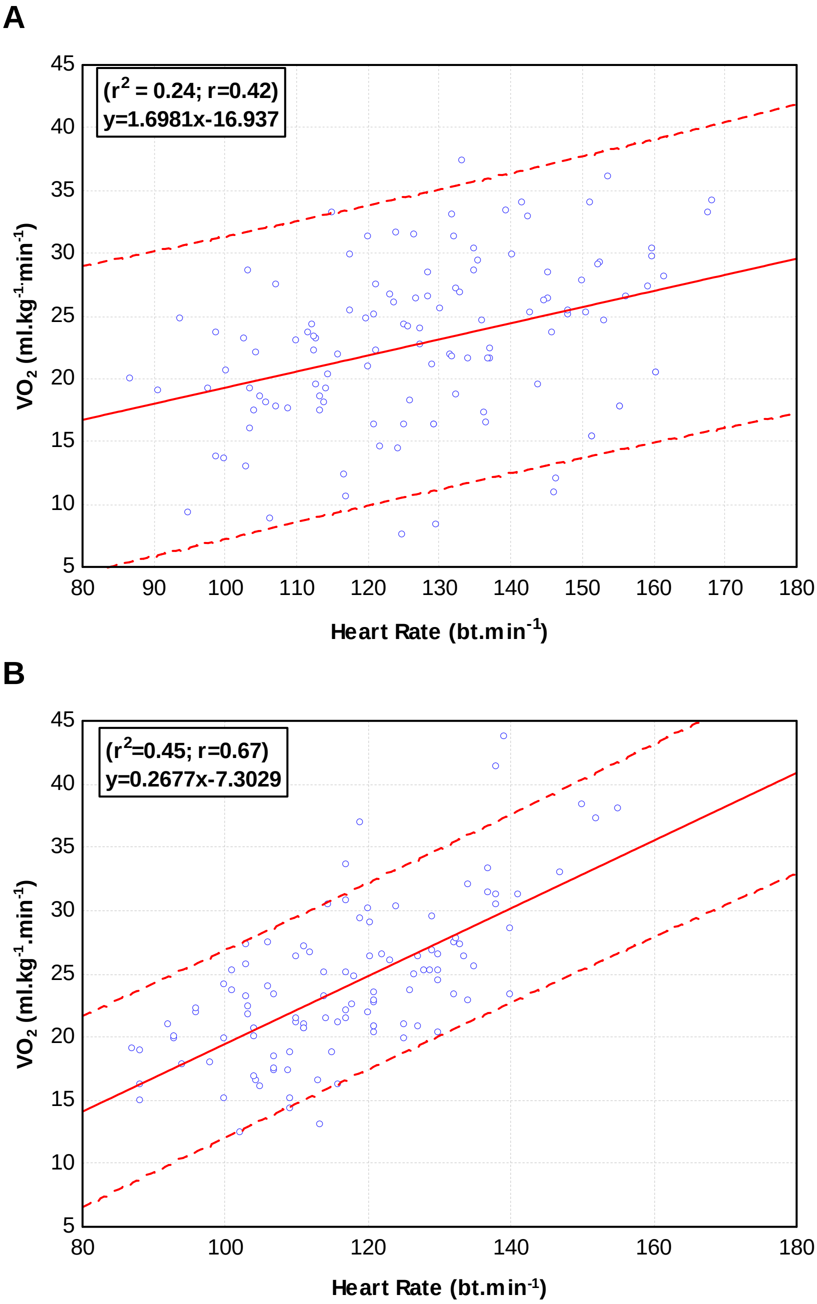


Figure 14: Group regression analyses determined for A: the Chainsaw Operators and, B: the Stackers.

Acknowledging the magnitude of differences in the health status of these workers, it is clear that individual regression analyses will reveal a closer relationship between heart rate and oxygen consumption than a group regression, supporting the literature that the within-person correlation between these two variables is highly variable (Haskell *et al.*, 1992; Scott and Christie, 2004; Keytel *et al.*, 2005). Hence although a group regression equation may be a more useful ‘generic’ prediction of the energy cost of a task, the establishment of a personalized equation will be more accurate in the prediction of the metabolic cost for each manual labourer. The individual regression values were used for the assessment of the physiological cost of work.

Predictive oxygen uptake and energy cost responses

Data from the regression equations and the energy cost predicted from body acceleration (accelerometers) were used to calculate the oxygen uptake and energy cost responses of the workers in the field. Table XXIII illustrates the differences in these predictive responses when using each of the three methods (individual HR/VO_2 regressions, group HR/VO_2 regressions and the accelerometer predictions). Also in this table is the combined measure of individual regressions and accelerometer predictions as suggested by Strath *et.al.* (2001).

All methods were significantly different from one another, except for the individual and group regression method with the Stackers where there was only a 0.33 $ml.kg^{-1}.min^{-1}$ difference between these two methods, suggesting that either method would be acceptable. This is in contrast to others who have argued for a greater predictive efficiency with the individual regression analysis (Strath *et al.*, 2001; Keytel *et al.*, 2005). Although there was a significant difference between these two predictions (individual and group regression) with the Chainsaw Operators, the difference was still only 1.38 $ml.kg^{-1}.min^{-1}$. Thus utilizing a single group regression, a suggestion put forward by Scott and Christie (2004), may be feasible when individual calibration is not possible. These authors do acknowledge that this equation would need to be specific to the working group to which it will be applied, but also contend that the simplicity of use would make it appropriate for companies in IDCs who may not have the sophisticated ergospirometry equipment available to perform individual calibrations.

Table XXIII: Oxygen uptake and energy expenditure responses utilising different methods.

Variable	Ind.Reg	Gr.Reg	Acc.	Ind.Reg/ Acc	Actual measures
VO_2 (ml.kg^{-1}.min^{-1})	20.9 (6.7)	22.3 (1.6)	11.6 (1.7)	16.3 (3.56)	26.2 (7.7)
	24.6 (6.5)	24.2$^+$ (3.6)	13.54 (2.66)	18.7 (4.14)	28.2 (8.9)
VO_2 (L.min^{-1})	1.37 (0.43)	1.46 (0.10)	0.76 (0.11)	1.07 (0.23)	1.78 (0.62)
	1.62 (0.45)	1.59$^+$ (0.23)	0.89 (0.17)	1.23 (0.29)	1.92 (0.57)
EE (kJ.min^{-1})	27.6 (8.6)	29.4 (2.1)	15.3 (2.3)	21.5 (4.7)	35.75 (9.81)
	32.6 (9.1)	31.9$^+$ (4.7)	17.8 (3.5)	25.2 (7.3)	38.6 (8.1)

Shaded areas refer to the responses of the Stackers.
Significant differences were found between all methods excluding where $^+$ denotes a non-significant different between the individual and group regression methods.
Ind.Reg: individual regression.
Gr.Reg: group regression.
Acc: accelerometer.
EE: energy expenditure.

The accelerometer predictions utilized body motion in the three anatomical planes and then applied a regression equation, which is built into the programme, as its predictive method; the output was in kilocalories which was then converted to kilojoules and oxygen uptake using the calculations shown in Appendix D. Compared to the individual and group regressions, predictions from the acceleration of the body were significantly lower. In fact, with both the Chainsaw Operators and Stackers this method predicted oxygen uptake 45% less than the individual regression method. It is therefore believed that this would not be reliable nor the most appropriate method to predict the energy cost of work particularly in developing countries where workers are often taxed to the limits of their physical capabilities already (Scott and Charteris, 2004).

Displayed in the final column of Table XXIII are the direct measures of oxygen uptake obtained in the field with the k4b^2 ergospirometer during pilot testing. Although these measures were obtained on different workers, they were workers executing the same tasks under similar, although nominally hotter, conditions. If comparisons are made between this direct measure of oxygen consumption and all the predictive measures, it is evident that the direct measure was substantially higher. However, this was to be expected considering that the mean heart rates during pilot testing were 135 bt.min^{-1} (Chainsaw Operators) and 137 bt.min^{-1} (Stackers), both substantially higher than the mean working heart rate of these workers which was approximately 120 bt.min^{-1}. Therefore a more reliable way of checking the accuracy of the prediction equation would be to substitute the pilot test mean heart rates into the group prediction equation. Substituting those heart rates in the equation resulted in a predicted VO_2 of 23.8 ml.kg^{-1}.min^{-1} and 29.4 ml.kg^{-1}.min^{-1} for the Chainsaw Operators and Stackers respectively. These predictions are similar to the actual measures of 26.2 ml.kg^{-1}.min^{-1} (Chainsaw Operators) and 28.2 ml.kg^{-1}.min^{-1} (Stackers). The predicted VO_2 of the Chainsaw Operators revealed an under prediction of 9%, whereas with the Stackers there was no difference. Although the literature argues for an over prediction when using calibration techniques this was not the case in the present study. This further emphasizes the need to conduct research on indigenous workers within their actual working environment as the findings obtained on others, possibly individuals not work-hardened and often students, in the sterile environs of the laboratory may yield completely different results questioning their applicability to rural IDC manual labourers working under extreme conditions.

Physiological cost of chainsaw operations and stacking

Once the energy cost for each individual had been established, the mean energy expenditure for both groups of workers was determined. As the workers all 'worked-to-task' the duration of each shift varied substantially, therefore each worker's shift was divided into four quarters and the responses are displayed across these four quarters (See Table XXIV).

With respect to the Chainsaw Operators, heart rate, oxygen uptake and energy cost remained stable during the first two quarters of their work shift, i.e. when felling.

These responses then increased significantly when the workers changed over to cross-cutting for the third and fourth quarters. This may be an indication of fatigue associated with ‘physiological drift’, or could suggest that cross-cutting is more physiologically demanding than felling. During cross-cutting these workers followed a fairly indiscriminate pattern with a considerable portion of their task constituting walking over uneven terrain interspersed with forward bending to perform cross-cuts or debranching. Furthermore, increases in ambient temperature over the work shift is likely to have increased the physiological responses, as these workers started felling at day break and once they were into the cross-cutting sub-task they were exposed to hotter conditions. According to McArdle *et al.* (2001), any increase in temperature causes about a 5% higher oxygen uptake than in a thermonetural environment, and is attributed to the thermogenic effect of elevated core temperature and the additional energy required for sweat gland activity and altered circulatory dynamics.

In contrast however, the physiological responses of the Stackers remained constant over time. This was an interesting finding considering that the Stackers started working later than the Chainsaw Operators and were thus exposed to more heat stress later in the day. As explained earlier however, these workers may have developed means to counteract a progressive build up by varying the intensity of effort expended over the entire work period. The range of oxygen uptake and energy expenditure responses imply that, according to Sanders and McCormick (1993), “moderate-to-heavy” demands were placed on these workers. These responses were also very similar to those of Apud (1983) investigating Chilean forestry workers. In his investigation, Chainsaw Operators and Stackers expended on average 6 to 7 $kcal.min^{-1}$ which was virtually the same as in this study. His findings were very different to those reported on for forestry workers from developed countries, which reiterates his emphasis on the importance of conducting research on indigenous workers in their actual working environments. What was dissimilar between his findings and the findings of the present investigation was that Chilean workers were not undernourished. The fact that the workers in this study were found to be undernourished would mean that there would in all likelihood be negative long-term consequences on work sustainability, thereby possibly explaining the high staff turnover. These workers may not have the required energy available to sustain this type of work effort over extended periods as the cumulative effect over many months or years will have a deleterious effect on the well-being of these workers.

Table XXIV: Energy cost of chainsaw operations and stacking for the four quarters of a work shift.

Variable	TIME				
	First Quarter	**Second Quarter**	**Third Quarter**	**Fourth Quarter**	**Entire Shift**
WHR ($bt.min^{-1}$)	120.7 (11.1)	118.9 (12.5)	125.8 (12.5)	127.4 (13.3)	123.3 (10.8)
	117.6 (11.4)	119.66 (15.23)	116.89 (15.30)	117.12 (12.95)	117.64 (12.95)
VO_2 ($ml.kg^{-1}.min^{-1}$)	19.9 (6.5)	18.8 (6.3)	21.8 (6.8)	22.9 (7.2)	20.9 (6.7)
	24.4 (6.2)	25.4 (7.4)	24.2 (7.3)	24.3 (6.0)	24.6 (6.5)
VO_2 ($L.min^{-1}$)	1.32 (0.43)	1.24 (0.41)	1.43 (0.43)	1.51 (0.47)	1.38 (0.39)
	1.61 (0.43)	1.68 (0.52)	1.58 (0.50)	1.60 (0.41)	1.59 (0.42)
EE ($kJ.min^{-1}$)	26.4 (8.6)	24.9 (8.2)	28.8 (8.6)	30.3 (9.4)	27.6 (8.6)
	32.4 (8.6)	33.8 (10.5)	31.9 (10.0)	32.1 (8.2)	32.6 (9.1)
EE ($kJ.h^{-1}$)	1585.8 (514.2)	1494.7 (490.6)	1727.5 518.1)	1818.9 (563.8)	1660.1 (469.4)
	1940.8 (516.0)	2025.9 (627.2)	1920.9 (602.5)	1924.1 (490.6)	1916.5 (509.1)
EE ($kcal.min^{-1}$)	6.31 (2.05)	5.95 (1.95)	6.88 (2.06)	7.24 (2.42)	6.61 (1.87)
	7.73 (2.05)	8.07 (2.50)	7.64 (2.39)	7.66 (1.95)	7.65 (2.03)
MET	5.70 (1.85)	5.41 (1.81)	6.24 (1.95)	6.54 (2.05)	5.79 (2.08)
	6.98 (1.77)	7.26 (2.11)	6.90 (2.08)	6.83 (1.77)	7.10 (1.76)

Shaded areas refer to the responses of the Stackers.
WHR: working heart rate.
VO_2: oxygen uptake.
EE: energy expenditure.
MET: metabolic equivalent.

According to Haymes and Wells (1986) who use the Occupational Health and Safety Association WBGT guidelines, the energy required to perform this type of work in the environmental conditions measured is unacceptable and should not be allowed. Recognizing that if energy cost is in excess of 1256.0 $kJ.h^{-1}$ then the demands being placed on workers are “heavy” and under such demanding workloads their recommendations are that ambient temperature should not exceed 28.9^{0}C; the field temperatures measured in this study were in excess of 30^0C and the mean energy cost was 1660.1 $kJ.h^{-1}$ and 1916.5 $kJ.h^{-1}$ for the Chainsaw Operators and Stackers respectively. Heat stress and dehydration are therefore likely consequences.

Relationship between energy expenditure and energy intake

With reference to the data obtained from the 24-hour dietary recall (presented on page 77) it is evident that the forestry workers participating in this project were undernourished and consequently had very limited energy stores to draw on once they were out in the field. In addition to assessing this 24-hour intake, the fluid and energy balance during work was calculated by monitoring liquid and solid intake during the work shift (See Table XXII and XXIII). Noteworthy was the labourers' reluctance to stop and drink or eat while they were working. It was clear that the workers were more concerned with completing their allotted task as fast as possible, with preference given to eat and drink on completion of their allotted work, thus enabling them to go home early. This reluctance to consume anything during work has previously been ascertained by Wigaeus Hjelm and Frisk (1985) investigating forestry workers in Vietnam.

Prior to the intervention, workers were consuming less than 500.0 ml of fluid during work which resulted in significant losses in body mass (Table XXV), they lost on average 1.9 kg (Chainsaw Operators) and 2.4 kg (Stackers) over the course of the work shift. Even though the Chainsaw Operators took in less fluid, their body mass losses were not as substantial as those of the Stackers. This is probably because the Stackers worked in hotter conditions as they came into the area later once the trees had already been felled. Consequently, the Stackers experienced greater sweat losses depicted in Table XXII. Insufficient replacement of excreted sweat associated with physically strenuous work and hot environmental conditions causes dehydration and adversely affects an individual's physiological condition (Sawka, 1992); and it is evident in Figure 15 that following work in the pre-intervention phase these workers were significantly dehydrated to the point of it being a critical health and safety issue. The Chainsaw Operators lost a mean of 2.8% body mass and the Stackers 3.6% body mass during their working shift.

Table XXV: Changes in hydration status following the implementation of proper fluid intake strategies.

	Pre BM (kg)	Post BM (kg)	BM Loss (kg)	Fluid intake (ml)	Sweat rate per hour ($L.h^{-1}$)
Pre-intervention	69.10	67.16**	1.94	230.0	0.47
	67.47	65.06**	2.41	413.0	0.64
Post-intervention	70.78	70.47	0.31*	1250.0*	0.27*
	66.36	65.66	0.70*	2000.0*	0.47*

Shaded areas refer to the values obtained for the Stackers.
BM refers to body mass.
** Denotes a significant difference (p<0.05) between the pre-and post-intervention.*
*** Denotes a significant (p<0.05) drop in body mass after work.*

Dehydration levels greater than a 2.0% loss in body mass have been shown in a number of studies to reduce work output as the decreased blood volume will lead to a drop in working capacity (Sawka, 1992; Below *et al.*, 1995; Fallowfield *et al.*, 1996). However, while this impact on physical performance is well known (Christie *et al.*, 2003), the impact on cognitive performance is not as well established. Some studies have found that dehydration (2.0% loss in body mass) results in a drop in performance levels for various cognitive abilities (Cian *et al.*, 2001). This is particularly concerning considering that forestry is innately dangerous and any deterioration in a worker's vigilance and concentration, particularly when handling machinery such as a chainsaw, is likely to result in accidents, and even fatalities.

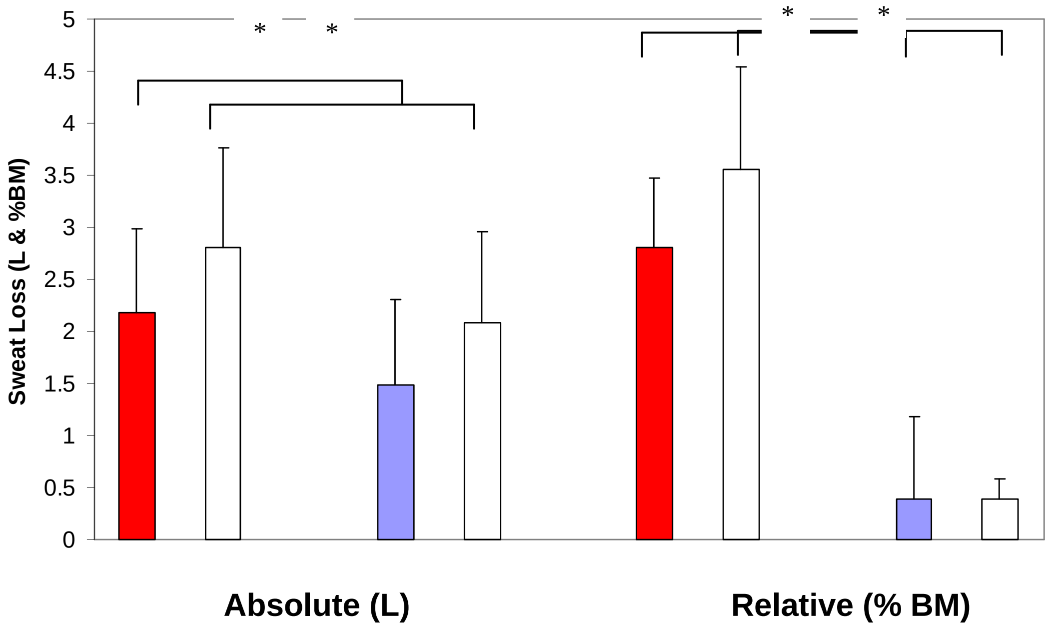


Figure 15: Estimated sweat losses, absolute (L) and relative (% BM) during work pre- and post-intervention.

Red: Pre-intervention.
Blue: Post-intervention.
Solid bars: Chainsaw Operators.
Striped bars: Stackers.

Due to the present unwillingness to stop and take in any replenishment, there was a significant imbalance between the overall energy demands of the tasks and the mean energy intake of the workers. The energy deficits were 8661.8 kJ and 8804.2 kJ for the Chainsaw Operators and Stackers respectively. These energy deficits are comparable to those of Lambert *et al.* (1994) who reported a deficit of 8846.0 kJ with sugar cane workers in South Africa. This diminished caloric intake, resulting in a substantial energy imbalance, is highly likely to negatively impact not only the work capacity of these workers, but also on their basic health status. It was therefore deemed imperative that the most critical intervention was not so much to focus on the task, where very little could be done without major changes in the entire forestry industry, but rather to address this unacceptable energy imbalance as well as the fluid imbalance.

Following the provision of fluid and solid supplies to the workers, the post-intervention data revealed promising changes. During the post-intervention stage workers were provided with 2000.0 ml of fresh, cool water which was delivered to them at regular intervals over their shift by the research team and/or supervisors. Fluid intake was thus significantly increased as part of the intervention strategy. However, although the Chainsaw Operators were provided with the same volume of fluid as the Stackers, they only took in a mean of 1250.0 $ml.shift^{-1}$; the difficulty of delivering water to these workers was the main reason for this as safety precautions prevent anyone from getting within two tree lengths of the Chainsaw Operators and these workers have established a pattern of working without breaks and with limited intake. Due to the environmental temperatures and the distance they would have to walk to get the warm, and sometimes hot, unfresh water they were reluctant to do it. Some method to ensure delivery of adequate cool water for these workers has been put forward and steps are being taken to introduce it as soon as possible.

Due to the intake of more fluid, body mass losses were significantly reduced in the post-intervention testing period (Table XXV) for both groups of workers, resulting in a significant reduction in dehydration levels. Workers lost only 0.4% body mass in this post-intervention phase. This would substantially reduce the likelihood of heat stress and its deleterious effect on work efficiency and worker well-being. Although dehydration levels greater than 2.0% would negatively impact both physical and cognitive performance, these post-intervention dehydration levels should according to Cian *et al.* (2001) have no negative consequences on performance.

Although energy expenditure was not statistically different following the provision of supplementation in the post-intervention stage, the relationship between the energy demands of the task and the energy intake of the workers was significantly improved (See Table XXVI). Energy intake during work increased by 3896.0 kJ and 4302.4 kJ for the Chainsaw Operators and Stackers respectively resulting in a 45% (Chainsaw Operators) and 53% (Stackers) improvement in the energy deficit. Despite this, there was still a discrepancy of over 4000.0 kJ, emphasizing the high energy level required to execute these tasks, and how essential fuel supplementation is for the workers.

Table XXVI: Relationship between the mean energy expenditure and energy intake of the workers pre-and post-intervention.

	Energy Cost ($kJ.shift^{-1}$)	Energy Intake (kJ)	Energy Deficit (kJ)
Pre-intervention	9481.2	819.4	8661.8
	8947.2	143.0	8804.2
Post-intervention	9450.4	4715.4*	4735.1*
	8892.1	4715.4*	4176.8*

Shaded areas refer to the values obtained for the Stackers.
** Denotes a significant difference between the pre-and post-intervention stages.*

Although these positive changes indicate that both liquid and solid replenishments are essential for these workers, it was necessary to take into consideration the costs involved. The significance of the provision of fresh, cool drinking water at regular intervals had the immediate affect of changing the hydration levels, demonstrating that making fluid available for the workers, which is a simple and cost-effective ergonomics intervention, will result in an immediate and essential improvement in the fluid balance of the workers. South Africa, and in particular Kwazulu-Natal, often experience hot environmental conditions and thus the provision of water is essential to prevent dehydration. In industries concerned with the cost of ergonomics interventions, providing cool water regularly is a good start to improving the overall working situation in many labour-intensive industries without significant cost to management.

Although management may argue that the costs involved with introducing a nutritional supplement may be too excessive, Morevite is inexpensive and has a high energy and nutritional value, and is something which the workers enjoy. Introducing a supplement like this would in any case far outweigh any menial cost by increasing worker output and reducing early onset fatigue; indicators which would decrease the risk of injury and associated workers compensation claims, all of which cost companies excessive amounts each year. An indirect benefit of taking replenishments to the workers is that they are 'forced' into taking a break, which in itself will provide some respite from their work demands.

Perceptual Responses

Olivier and Scott (1994) postulated that the biomechanical and physiological demands placed on the body during work will result in some degree of personalized psychophysical strain. In this investigation the use of psychophysical rating scales served to quantify the workers' perceptions of work effort.

Ratings of Perceived Exertion (RPE)

"Central" ratings of perceived effort are representative of the overall cardiovascular and respiratory strain perceived by individuals while executing their specific task. Table XXVII displays the mean responses over the four quarters of the working shift.

Table XXVII: "Central" and "Local" ratings of perceived exertion recorded during work.

		1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
"Central" RPE	Pre-intervention	10.0 (1.3)	10.3 (1.0)	11.4 (1.6)	11.6 (1.0)
"Central" RPE	Pre-intervention	10.5 (1.1)	11.6 (1.4)	11.6 (1.0)	12.2 (1.1)
"Central" RPE	Post-intervention	9.4 (1.0)	11.1 (1.6)	10.7 (1.3)	10.0 (1.8)
"Central" RPE	Post-intervention	9.4 (1.2)	11.0 (1.3)	10.9 (1.2)	9.9 (1.3)
"Local" RPE	Pre-intervention	9.6 (1.2)	10.2 (2.0)	10.1 (1.4)	10.0 (1.9)
"Local" RPE	Pre-intervention	10.6 (1.2)	10.2 (1.2)	10.5 (1.0)	10.6 (1.5)
"Local" RPE	Post-intervention	9.0 (1.4)	10.2 (1.6)	9.5 (1.0)	9.5 (1.6)
"Local" RPE	Post-intervention	9.9 (1.4)	10.2 (1.1)	9.9 (1.8)	10.0 (1.3)

Shaded area refers to the responses of the Stackers.

The observation prior to the intervention show that "Central" RPE increased marginally but steadily over the duration of the working day, from 10.0 to 11.6 with the Chainsaw Operators, and from 10.5 to 12.2 with the Stackers. Following the same trend as the working heart rates, there was a significant increase in central perceptions of effort between the first half and the last half of the Chainsaw Operators shift. On the other hand the responses of the Stackers increased significantly after the first quarter and then stabilized for the rest of the shift. All the workers perceived their work to be "fairly light" with regard to cardiovascular strain. Local ratings were generally lower than the central ratings and remained constant during the course of the working day. It would therefore appear that the workers perceived a greater cardiovascular strain than musculoskeletal strain over the pre-intervention period.

Following the implementation of the supplement all the "Central" ratings were significantly reduced, excluding the second quarter when the rating was elevated for the Chainsaw Operators. Overall, Local ratings were also lower post-intervention. As the general trend was for a lower perception of effort, it would seem reasonable to assume that the supplement, and corresponding short rest breaks, resulted in the workers perceiving that they were taking less strain even though their energy expenditure did not change. However, considering the scale range of 6-20, it could be argued that these changes were not sufficient considering the overall improvements in the severe energy and fluid imbalance observed during the pre-intervention stage. Nevertheless, the practical significance of these findings are profound; they include the prevention of heat stroke through adequate hydration and adequate rest periods, and the prevention of loss of lean body mass as a result of the improved energy balance; both of which will contribute to a significant improvement to the health and well-being of the workers.

Body Discomfort

Kroemer and Grandjean (1997) reported that the origin of musculoskeletal disorders lies with body discomfort. Axelsson and Eklund (2001) reiterate this contention saying that once body discomfort rises beyond a particular 'comfort threshold', productivity is compromised and the risk of accidents and injuries increases. This could be a likely explanation for the high accident rate generally seen in the forestry industry.

The body discomfort findings in this study revealed that the predominant area of discomfort experienced by the Chainsaw Operators was the lower back (See Figure 16) which is not unexpected when one considers the working posture analyses where a predominance of trunk flexion was evident. The second most dominant area of discomfort was felt in the knees. This discomfort was particularly evident during the felling of the trees where a squat posture, resulting in bent knees, or a half-kneel posture was often adopted. The discomfort felt in the wrists and forearms was in all probability associated with the manipulation of the chainsaw required by the upper limb musculature particularly during cross-cutting.

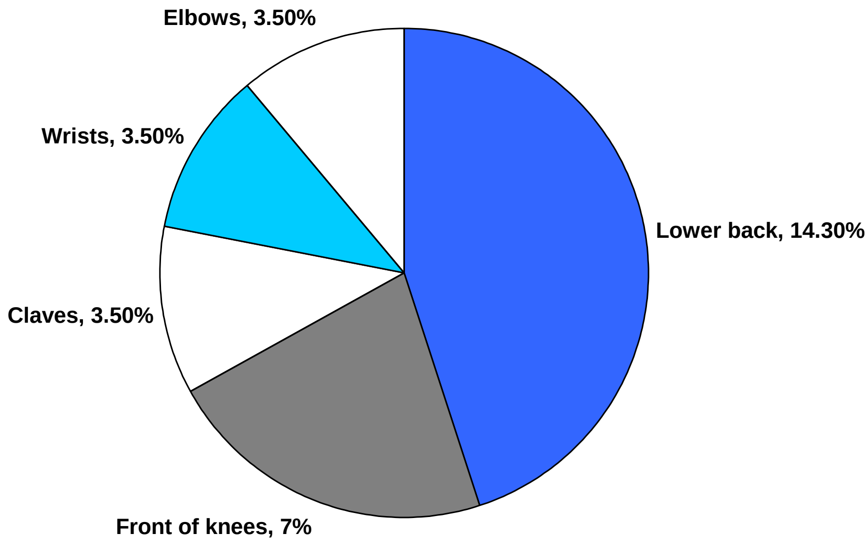


Figure 16: Areas of body discomfort for the Chainsaw Operators.

Only 41.4% of the Stacker indicated any discomfort during work. The areas with the most discomfort were the lower and upper back and the anterior shoulder musculature (Figure 17). This discomfort in the shoulder area is probably due to the dragging technique employed by the workers to manoeuver logs towards and onto a stack. Working posture analyses revealed high moments about the shoulder joint, and the musculoskeletal strain experienced as a result of this awkward posture is reflected in an elevated discomfort experienced by the workers in this area.

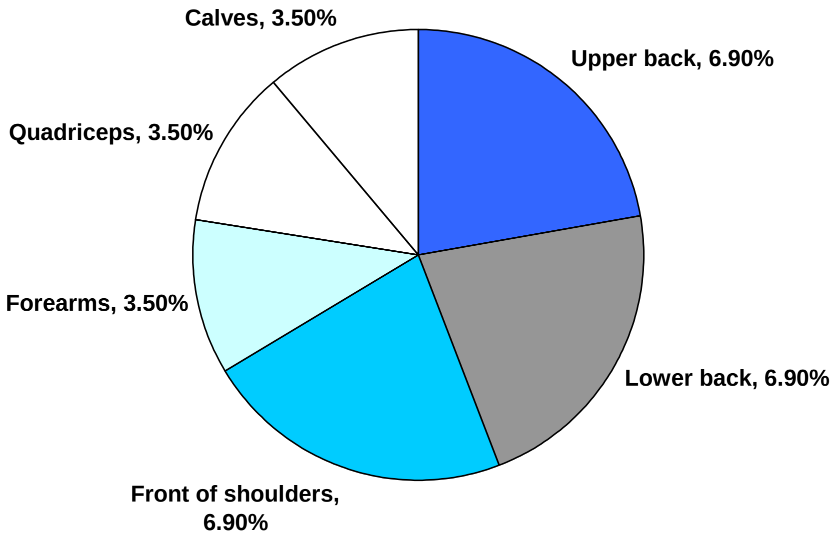


Figure 17: Areas of body discomfort for the Stackers.

SUMMARY

In conclusion, the results revealed poor working postures and high physiological demands during chainsaw operations and stacking. As a direct consequence of the taxing workloads and the lack of adequate fluid and energy intake during work, these workers were exhausted and severely dehydrated on completion of their work shift. It is essential that the forestry industry seriously considers altering the pattern of 'working-to-task' as this forces an intense work pace whereby harvesters are reluctant to take rest breaks. In addition, inadequate energy intake, both at work and at home means that these workers do not have the required energy to sustain these tasks on a long-term basis. The lack of appropriate levels of nutritional intake is an area of major concern as it is well recognized that in an undernourished state the body tends to resort to muscular proteins and skeletal minerals as energy sources, leaving the workers musculoskeletal system in a frail state, which will substantially increase the risk of injury.

Probably the most critical finding of the project was the quantification of the horrendous fluid and energy imbalance, resulting in a low work capacity for a physically demanding job. Hence the most important intervention was to address these imbalances by increasing the fluid and energy intake of these workers by introducing a regular supply of water and a nutritional supplement like Morevite at regular intervals over the work shift. These interventions implemented during work will also ‘force’ the harvesters to take regular rest breaks. The proposed interventions will enhance worker well-being and prolong the onset of fatigue, which will ultimately reduce the likelihood of injuries and potentially fatal accidents from occurring, which is the major concern currently facing the forestry industry at a global level. At the same time there is likely to be a marked improvement in worker efficiency resulting in increased productivity.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The forestry industry relies heavily on humans to sustain productivity, and due to the cost of increasing automation the need for humans to carry out these physically demanding tasks is not likely to change in the near future. In South Africa the physical demands placed on workers are exacerbated by the extreme poverty of the majority of workers which results in a negative spiral of poor nutrition, ill health and reduced work capacity (Scott, 1993). While the lack of ergonomics research on forestry workers is a global concern, it is a greater problem in IDCs where minimal ergonomics research has been directed and where reduced worker capacity, will reveal substantially different worker responses to similar tasks executed by workers in more affluent countries.

Furthermore, most ergonomics research has been confined to laboratory settings and although the value of laboratory research is universally acknowledged, the need to assess rural workers under actual working conditions is paramount in contributing to our understanding of the demands being placed on these workers. It is contented that the only way in which an accurate measure of the demands being placed on these workers can be obtained is by assessing their responses to specific tasks within the field of work where the workers themselves are active participants. The current research was therefore entirely field-based and assessed the physical workloads being imposed on South African forestry workers. The prime objective was to establish a basic data base of the workers and their responses before proposing interventions and reassessing the variety of tasks associated with harvesting in the forestry industry.

SUMMARY OF PROCEDURES

The physical workloads imposed on 58 male harvesters (Chainsaw Operators and Stackers) were assessed *in situ*. The experimentation was conducted in one of the main forestry regions in South Africa, Kwazulu-Natal. Demographic, anthropometric and resting cardiovascular data were obtained prior to the main experiment. These initial sessions provided an opportunity to explain the experimental procedures in detail to the workers with the assistance of a Zulu interpreter; Zulu being the 'mother tongue' of these workers.

For the experimental phase, 6 workers were assessed each day while going about their regular tasks. Prior to starting work, workers' were weighed in their normal working clothes including shoes and helmets; this measure was repeated on the completion of their work shift in order to establish hydration status. Workers were fitted with heart rate monitors and accelerometers and told to go about their 'normal' working day while being observed by a researcher who monitored their working patterns and took photos for digital imaging at a later stage. Heart rate was monitored and perceptual ratings ("Central" and "Local" Ratings of Perceived Exertion) obtained at regular intervals during the work shift. In addition, fluid and solid intake was carefully monitored and recorded by the researcher. Once workers had completed their allotted task, body discomfort ratings were obtained and workers were re-weighed. Following a 30 minute 'recovery' they participated in a progressive, submaximal step up test during which heart rate and oxygen uptake (using a portable ergospirometer) were continuously measured. This method was employed to predict oxygen uptake (energy expenditure) from working heart rate responses. In addition, energy expenditure was predicted from body motion in the three anatomical planes measured by the attached accelerometers.

Due to the unacceptable imbalance between caloric intake and output (discussed later), the intervention strategy was the implementation of a nutritional supplement and regular fluid intake during the work shift. In order to establish the efficacy of this intervention, these same workers were assessed during another typical working day several weeks later. The same pre-work, working and post-work measures were obtained and recorded. Following this test/re-test, workers completed various questionnaires during several interviews. These questionnaires related to the workers' nutritional status as well as their overall health and musculoskeletal integrity.

As this investigation took a holistic approach, the following specific variables were used in the analyses:

Physical variables:	working postures and trunk acceleration
Physiological variables:	heart rate, energy intake, level of dehydration, oxygen uptake and energy expenditure
Perceptual variables:	"Central" RPE, "Local" RPE and body discomfort

SUMMARY OF RESULTS

As the physiological domain was the prime focus in this investigation the quantification of energy expenditure during work was an important factor. Due to the difficulties of assessing oxygen uptake directly when testing in the field, which have been discussed in detail earlier, some basic yet reliable method is needed to predict the metabolic cost of physically taxing tasks particularly in developing countries which may not have the sophisticated, expensive equipment required to directly assess workers. This study, incorporated several methods of predicting energy cost during work and although the individual calibration technique was known to elicit the most accurate results (Strath *et al.*, 2001; Keytel *et al.,* 2005) other techniques were also included for consideration due to the variation in field application. Of the various techniques employed in this study, accelerometers were found to significantly under predict the energy cost, while the group regression was shown to most closely reflect individual calibration. This the author believes is an important finding as although it is acknowledged that it is advantageous to establish a regression equation for each individual and activity, in the absence of such a possibility it is argued that the group regression equations for the Chainsaw Operators (y=1.6981*-16.937) and Stackers (y=0.2677*-7.3029) will prove to be a useful *in situ* means of estimating energy expenditure when equipment and other constraints are evident. This is in accordance with the findings and recommendations put forward by Scott and Christie (2004).

The primary aim of any ergonomics investigation of a manual task is to establish compatibility between the physical demands of work and the physical capabilities of the worker (Scott, 2001). This study identified a disparity between the physical workloads imposed on harvesting workers and their capabilities. The nutritional assessment revealed that the workers were under nourished and it was proposed that as a direct consequence of this, health was compromised. These workers were consuming substantially less energy than the recommended daily allowance for sedentary individuals put forward by Brouns (2002), Burke, (2002) and Bean (2003). Total daily energy intake was virtually half the recommended levels with the Chainsaw Operators consuming 3949.1 kJ and the Stackers, 5346.0 kJ per day. Of particular concern was the low carbohydrate content of the diet which is an essential macro-nutrient for the performance of physically demanding activities conducted over extended durations (Christie, 2002). As these workers are required to perform the same arduous task every day, the daily normalisation or recovery of endogenous nutrient stores should be a priority. In particular, the carbohydrate content of the diet needs to be given attention as this is known to enhance performance (Brooks and Mercier, 1994) and should improve worker well-being.

The working postures adopted by the harvesters where highly variable and the analyses revealed a predominance of trunk forward flexion. This flexion varied between 46^0 and 88^0 in the analyses of the Chainsaw Operators during felling and cross-cutting. During felling the highest compression force was calculated for the flexed-stoop posture (2789 N), while during cross-cutting compression was highest in the lower spine when adopting the stoop posture (2000 N). With respect to the shearing forces during chainsaw operations, these ranged from 166 N to 303 N depending on the posture adopted. The cost of these awkward working postures was reiterated in the body discomfort findings where the predominant area of discomfort noted by the Chainsaw Operators following work was the lower back.

During stacking the workers used primarily two methods of dragging the logs towards the stack. These techniques were referred to as unimanual and bimanual. Trunk flexion ranged between 20^0 and 63^0 for the Stackers while dragging and piling the logs. The compression and shear forces acting on the lower back were consistently higher when utilising the bimanual method. The highest force calculated was when using this method to drag a log of 120 kg (Compression and shear force of 18370 N and 1526 N respectively). The only log mass considered ‘safe’ to manoeuvre using any technique, was the 10 kg log. However, this light log is rarely found in the field as most logs were 60 kg and heavier. The forces on the shoulder joint revealed that when using one hand, more strain was placed on the shoulder joint as opposed to using two hands. The posture adopted to drag the log using only one hand was deemed an ‘abnormal’ posture which is highly likely to lead to injury. The predominant area of discomfort felt by the workers was the back and the anterior aspect of the shoulder which reflects the findings of the theoretical analyses of these working postures.

Mean working heart rates were 123.3 bt.min^{-1} and 117.6 bt.min^{-1} for chainsaw operations and stacking respectively, with a mean highest heart rate of 146.3 bt.min^{-1} for a Chainsaw Operator and 164.4 bt.min^{-1} for a Stacker. The mean predicted oxygen uptake and energy cost responses were 20.9 ml.kg^{-1}.min^{-1} (27.6 kJ.min^{-1}) and 24.6 ml.kg^{-1}.min^{-1} (32.6 kJ.min^{-1}) for the Chainsaw Operators and Stackers respectively. These physiological responses increased significantly when the Chainsaw Operators changed over from felling to cross-cutting but remained constant over the course of the Stackers’ work shift. The physiological responses associated with harvesting work reveal that, according to Sanders and McCormick (1993), “moderate-to-heavy” demands were placed on these workers. As a direct result of the physically taxing nature of this work and because of the hot and humid conditions experienced by these workers in the field, sweat rates were high (0.47 L.h^{-1} and 0.64 L.h^{-1} for the Chainsaw Operators and Stackers respectively).

This negative scenario was exacerbated by the fact that the harvesters consumed very little fluid and food during their work shift. The Chainsaw Operators had a mean fluid intake of 230.0 ml and a mean energy intake of 819.4 kJ, while the Stackers consumed 143.0 ml fluid and 143.0 kJ of energy. These workers thus lost a significant amount of body weight: a mean of 1.9 kg for the Chainsaw Operators, and 2.4 kg for the Stackers, and were severely dehydrated. The Chainsaw Operators lost 2.8% of their body mass while the Stackers lost 3.6%. According to Cian *et al.* (2001)

the “critical” level of dehydration coinciding with deleterious performance effects is 2.0%. The levels of dehydration observed in this study therefore constitute a dangerous threat to not only working efficiency, but also life. In addition, the energy balance findings revealed a significant imbalance. When comparisons were made between the energy required to execute the tasks, and the energy intake of the workers during their shift, the energy deficits were over 8000.0 kJ for both groups of workers.

The primary intervention strategy, involving the delivery of water and food at regular intervals to these workers, resulted in a significant improvement in both hydration status and energy balance. The post-intervention results revealed that the Chainsaw Operators lost only 0.3 kg and the Stackers, 0.7 kg during work. For both groups, the mean level of dehydration was reduced to a 0.4% loss in body mass which should have no deleterious effects on work performance and should enhance the workers sense of well-being. In addition the energy deficits were reduced by half, to 4735.1 kJ (Chainsaw Operators) and 4176.8 kJ (Stackers), which would increase the energy levels of the workers which in turn is likely to improve work efficiency.

As a direct result of the physical workloads associated with harvesting and their menial lifestyle, it is highly probable that these workers were arriving each day at work with reduced energy stores from the previous day, as it is debatable whether these workers have in fact had an adequate recovery period after work, as many workers in South Africa have to walk far distances to get to work, and have to conduct physically demanding tasks at home. Some workers even take on second jobs to supplement their income; this highlights the complexity of conducting research with in an IDC setting such as South Africa and emphasises the importance of assessing the 24 hour cycle of the worker as suggested by Scott (1993).

STATISTICAL HYPOTHESES

The first hypothesis, 1 (a), focused on the physiological responses and the results force the rejection of the null hypothesis as physiological responses during chainsaw operations increased significantly between the first half and the second half of the work shift. However, it is tentatively retained for the Stackers as physiological responses remained constant across all time intervals.

Similarly with hypothesis 1 (b), significant differences were observed in “Central” RPE between the first quarter and the last two quarters of the work shift for the Chainsaw Operators and between the first quarter and the last three quarters for the Stackers. This hypothesis is therefore rejected. However, with “Local” Exertion, for both the Chainsaw Operators and Stackers, there was no significant change in these ratings over time. The hypothesis is therefore tentatively retained for the perceptions of musculoskeletal effort.

Hypothesis 2 (a) is rejected as the implementation of fluid and food significantly improved the fluid and energy balance of the workers. However, it is tentatively retained for the cardiovascular responses which were not significantly altered.

Hypothesis 2 (b) is rejected as the supplements, on the whole, resulted in significant changes in “Central” ratings. However, as the “Local” perceptions of effort for both groups of workers remained unchanged the hypothesis is tentatively accepted for these ratings.

CONCLUSIONS

Scott and Shanavaz (1997) emphasise the horrendous working conditions in developing countries, and this was very evident in the present study. Not only were the workers exposed to taxing manual labour, but they also had to contend with a range of difficult working conditions including uneven terrain, debris and falling trees, together with hot and humid environmental conditions. Although the workers started working at day break to prevent exposure to the excessive midday heat, mean field temperatures were still in excess of 30^0 and humidity levels in excess of 70%. Workers were provided with no formal rest breaks and as they were required to ‘work-to-task’, they were not motivated to take any rest, rather the emphasis was put on getting the job over as soon as possible. Overall therefore, fluid and energy consumption was virtually non existent. The workers also pushed themselves to complete their tasks rapidly so they could go home and sometimes take on an extra job to adequately take care of their families.

Although the introduction of technology would prevent workers from being exposed to these terrible conditions, it is unlikely to be introduced in a country like South Africa due to the costs involved. Another issue to consider when opting for the transfer of technology to IDCs is to take cognisance of the fact that most of the population are semi-literate and semi-skilled and are only able to do manual work to earn a menial wage to sustain a living. Introducing technology will eliminate many jobs which are desperately needed in South Africa where unemployment levels are high.

Due to the multifaceted nature of problems faced by employers and employees in IDCs, not least being the poor economies of these countries, some less costly recommendations were put forward to the forestry industry and specifically the contractors involved in this research project. In accordance with the strong recommendations of Kogi (1997) and Scott (2001), the main objective was to offer “low cost-no cost” interventions which would be appealing to the contractors, and beneficial to the workers. Nothing is more cost effective than supplying these workers with regular fresh, cool water which was the intervention introduced immediately, with immediate benefits. Supplying the workers with Morevite, an inexpensive nutritional supplement enjoyed by the workers, will significantly increase energy levels. In the follow up interview, the workers expressed their perceived benefit of these intervention strategies.

In addition, changes to work methods were recommended. It was suggested that more organised directional felling be initiated which would result in a less taxing pattern of cross-cutting which is apparently a recommended work practice, but one which the workers were not following. This is possibly due to the out sourcing of forestry operations to contractors which has, as a generalisation, been seen to be associated with a decline in safe work practices (Manyuchi *et al.*, 2003). Another recommendation discussed with all was the importance of all employers and employees, including the chief executive officers of the major international companies to the workers in the field, being involved in implementing ergonomics interventions and safe work practices. In fact, several workshops were held in various centres in South Africa to educate this broad spectrum of workers on the concept of ergonomics, explaining how ergonomics can contribute to improving the work situation. This macro-ergonomics approach considers the optimisation of organizational and work system design through consideration of the relevant personnel, technological and environmental variables, plus their interactions and interdependence. This approach is all encompassing and if addressed with the basic micro-ergonomics interventions proposed from this investigation, the benefits are likely to be more long-term.

A further suggestion was to initiate task rotation. In the case of the Chainsaw Operator it was suggested that he alternate with the 'Pusher' who was also a trained operator, this alternating of felling and cross-cutting with guiding and measuring would reduce both the musculoskeletal and cardiovascular strain placed on these operators. With respect to the Stackers it was suggested that they work in pairs and that any log weighing more than 60 kg should be lifted by two workers; the practicality of these suggestion were considered and discussed with management and workers. Both these basic interventions should go a far way in reducing the physical demands being placed on these workers.

These "low cost-no cost" interventions, initially focusing on a micro-ergonomics approach, are a good overall start to improving the working situation. However, within the forestry industry generally in South Africa, the issue of responsibility and accountability needs to be addressed as this is crucial in ensuring the rights of the workers are being protected. This is a clear example of the need for a macro-micro ergonomics approach recommended by Scott and Zink (2003).

RECOMMENDATIONS

In order for the discipline of ergonomics to make a meaningful contribution to both employers and employees within South African industries, considerable research needs to be directed towards obtaining a greater understanding of the physical workloads being imposed on rural, manual labourers and to link these findings with the capabilities of the indigenous work force. The following recommendations could assist in this process.

Industrial workers executing a variety of physically demanding tasks need to be assessed within their working environment. This quantification of worker responses to manual tasks needs to be done using a holistic approach including biomechanical, physiological and perceptual measures. This need to assess workers, and not student or other volunteers, was emphasised by a study conducted in South Africa by Scott and Renz (2006) whose results demonstrated very different responses for rural workers and urbanised students performing the same task.

As the general health of the workers will have a profound impact on the workers' well-being and capabilities, it is recommended that more research be afforded to establishing the nutritional and health status of South Africa's manual labour force.

In order to rigorously control the responses associated with the tasks, it is suggested that laboratory simulations be attempted. Although the task of felling may be impossible to simulate in a laboratory environment, the other sub-tasks associated with both chainsaw operations and stacking could be simulated in some way. This will enable objective measures to be obtained within the confines of a laboratory setting where all extraneous factors known to impact the findings can be controlled. This laboratory simulation will enable researchers to test the effectiveness of intervention strategies before implementing them in the field. However, a rigorous post-intervention assessment *in situ* is recommended to ascertain the overall effect of the intervention strategy in its industrial context.

The method of quantifying the energy cost of task demands within a field setting needs to be tested further. Although it is the author's opinion that the regression method is the most accurate indirect method of predicting energy cost it is argued that the use of a generic group regression for different working populations needs to be investigated further. This should be established in a laboratory setting prior to being applied in the field, and then reassessed to determine the efficacy of the proposed regression equations. Christie *et al.* (2005) recently demonstrated the applicability of a group regression method within a laboratory setting but acknowledge the importance of integrating field and laboratory research, which has been strongly recommended by Scott and Charteris (2004) and Scott and Renz (2006).

Some method of quantifying the impact of increased fluid and energy intake on productivity needs to be introduced to provide companies and contractors with the “cost benefit” associated with this type of intervention strategy. Thus a longitudinal investigation of the benefits, to workers and the company, associated with ergonomics intervention strategies needs to be conducted.

REFERENCES

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

Abeysekera JDA and Shahnavaz H (1990). Adaptation to discomfort in personal protective devices: an example with safety helmets. **Ergonomics,** 33 (2): 137-145.

Abeysekera JDA and Shanavaz H (1988). Ergonomics evaluation of modified industrial helmets for use in tropical environments. **Ergonomics,** 31 (9): 1317- 1329.

Accident Reporting System (2003). For the South African Forestry Industry.

Adams MA, McNally DS, Chinn H and Dolan P (1994). Posture and compressive strength of the spine. **Clinical Biomechanics,** 9: 5-14.

American College of Sports Medicine (ACSM) (2000). **Guidelines for Exercise Testing and Prescription.** Sixth Edition. Philadelphia: Lean and Febiger.

Apud E (1983). A human biological field study of Chilean forestry workers. **Doctoral dissertation.** London, Loughborough University.

Apud E, Bostrand L, Mobbs ID and Strehlke B (1989). **Guidelines on ergonomic study in forestry.** Geneva, ILO.

Armstrong LE, Costill DL and Fink WJ (1985). Influence of diuretic-induced dehydration on competitive running performance. **Medicine and Science in Sports and Exercise,** 17(4): 456-461.

Ashby L, Bentley T and Parker R (2002). Felling injuries: An exploratory analysis of logging tasks and safety. Centre for Human Factors and Ergonomics, 3 (3): Report ISSN 1174-1234.

Åstrand PO and Rodahl K (1986). **Textbook of Work Physiology – Physiological Bases of Exercise.** Third Edition. New York: McGraw-Hill.

Axelsson S-A (1998). The mechanization of logging operations in Sweden and its effect on occupational safety and health. **International Journal of Forest Engineering,** 9 (2): 25 – 31.

Axelsson JRC and Eklund JAE (2001). **Quality and Ergonomics in Concert.** In W Karwowski (ed). International Encyclopedia of Ergonomics and Human Factors. London: Taylor and Francis.

Ayoub MM (1992). Problems and solutions in manual materials handling: the state of the art. **Ergonomics,** 35 (7/8): 713-728.

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

Bales DW, Craig BN, Congleton JJ, Kerk CJ, Amendola AA, Gaines WG and Jenkins OC (2001). The influence of supporting the Oxylog instrument on estimated maximal aerobic capacity during a step test and heart rate in a lifting test. **Applied Ergonomics,** 32: 367-377.

Bao S and Shanavaz H (1989). The promises and problems of ergonomics application in the People's Republic of China. **Applied Ergonomics,** 20 (4): 287-292.

Barac-Neito M (1987). Physical work determinants and undernutrition. **World Review of Nutrition and Dietetics,** 49: 22-65.

Barbara M, Livingstone E, Robson PJ and Totton M (2000). Energy expenditure by heart rate in children: an evaluation of calibration techniques. **Medicine and Science in Sports and Exercise,** 32 (8): 1513-1519.

Bean A (2003). **The complete guide to Sports Nutrition: How to eat for maximum performance.** Fourth Edition. London: A and C Black Ltd.

Below PR, Mora-Rodriguez R, Gonzalex-Alonso J and Coyle EF(1995). Fluid and carbohydrate ingestion independently improve performance during 1 h of intense exercise. **Medicine and Science in Sports and Exercise,** 27 (2): 200-210.

Bentley TA, Parker RJ, Ashby L, Moore DJ, Tappin DC (2002). The role of New Zealand forest industry surveillance system in a strategic Ergonomics, Safety and Health Research Programme. **Applied Ergonomics,** 26: 395 – 403.

Bergstrom J, Hermansen E, Hultman E and Saltin B (1967). Diet muscle glycogen and physical performance. **Acta Physiologica Scandinavia,** 71: 140-150.

* Borg GAV (1970). Perceived exertion as an indicator of somatic stress. **Scandanavian Journal of Rehabilitative Medicine,** 2: 92-98. (See Borg, 1982).

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

Bourne LT, Lambert EV and Steyn K (2002). Where does the black population of South Africa stand on the nutrition transition? **Public Health Nutrition,** 5 (1A): 157-162.

Bradshaw D and Steyn K (2001). Poverty and Chronic Diseases in South Africa. Technical Report, ISBN: 1-919809-17-1.

Brooks GA and Mercier J (1994). Balance of carbohydrate and lipid utilization during exercise: the "crossover" concept. **American Physiological Society,** 76 (6): 2253-2261.

Brouns F (2002). **Essentials of Sports Nutrition.** Second Edition. Chichester: John Wiley and Sons, Ltd.

Burke L (2002). **The Complete Guide to food for Sports Performance – A guide to peak nutrition for your sport.** Fourth Edition. Australia: Allen and Unwin.

Bush-Joseph C, Schipplein O, Andersson GBJ and Andriachi TP (1988). Influence of dynamic factors on the lumbar spine moment in lifting. **Ergonomics,** 31: 211-216.

Cameron ME and Van Staveren WA (1988). **Manual on Methodology for Food Consumption Studies.** Oxford: Oxford University Press.

Cannon WB (1922). New evidence for sympathetic control of some internal secretion. **American Journal of Psychiatry,** 2: 15-30.

Capodaglio P, Capodaglio EM and Bazzini G (1997). A field methodology for ergonomic analysis in occupational manual materials handling. **Applied Ergonomics,** 28 (3): 203-208.

Ceesay SM, Prentice AM, Day KC, Murgatroyd PR, Goldberg GR, Scott W, and Spurr GB (1989). The use of heart rate monitoring in the estimation of energy expenditure: a validation study using indirect whole-body calorimetry. **British Journal of Nutrition,** 61 (2):175-86.

Charlton KE, Bourne LT, Steyn K and Laubsher JA (2001). Poor nutritional status in older black South Africans. **Asia Pacific Journal of Clinical Nutrition,** 10 (1): 31-38.

Charlton KE, Wolmarans P, Marais AD and Lombard CJ (1997). Macronutrient intake and cardiovascular risk factors in older South Africans. **East Africa Medical Journal,** 74 (8): 478-486.

Charteris J, Cooper LA and Bruce JR (1976). Human Kinetics: A Conceptual Model for Studying Human Movement. **Journal of Human Movement Studies,** 2: 233-238.

Charteris J and Scott PA (1990). Risk identification in manual materials handling operations: a prototype expert system which reveals task-operator mismatch. **Ergonomics SA,** 2 (2): 73-85.

Cheung SS, McLellan TM and Tenaglia S (2000). The thermophysiology of uncompensable heat stress: physiological manipulations and individual characteristics. **Sports Medicine,** 29 (5): 329-359.

Christie CJ (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 (1): 32-36.

Christie CJ (2002). Relationship between energy intake and energy expenditure during manual work in South Africa. **Proceedings of the Third International Cyberspace Conference on Ergonomics,** 15 September–15 October.

Christie CJ, Todd AI and Southworth S (2003). The impact of dehydration on heart rate responses and cognitive functioning. **Proceedings of the XVth Triennial Congress of the International Ergonomics Association**, 24-29 August, Seoul, South Korea.

Christie CJ and Scott PA (2005). Metabolic responses of South African soldiers during simulated marching with 16 combinations of speed and backpack load. **Military Medicine,** 170 (7): 619-22.

Christie CJ and Scott PA (2005). Physiological and perceptual responses of female debarkers during forestry work. **Proceedings of the Fourth International Cyberspace Conference on Ergonomics,** 1 September–1 October.

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

Christie CJ, Forbes MJ and Wolfe A (2005). Accuracy of using heart rate to predict oxygen consumption during moderate intensity lifting. **Proceedings of the Fourth International Cyberspace Conference on Ergonomics,** 1 September–1 October.

Cian C, Barraud PA, Melin B and Raphel C (2001). Effects of fluid ingesting on cognitive function after heat stress or exercise-induced dehydration. **International Journal of Psychophysiology,** 42: 243-251.

Corlett EN and Bishop RP (1976). A Technique for Assessing Postural Discomfort. Ergonomics, 19 (2): 175-182.

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

Driscoll TR, Ansari G, Harrison JE, Frommer MS and Ruck EA (1995). Traumatic Work-Related Fatalities in Forestry and Sawmill Workers in Australia. **Journal of Safety Research,** 26 (4): 221–233.

Durnin JVGA and Passmore R (1967). **"Energy, work and leisure".** London: William Heinemann.

Durnin JVGA 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.

Eston R and Reilly T (2001). **Kinanthropometry and exercise physiology laboratory manual: tests, procedures and data.** Second Edition. Routledge: London.

Fallowfield JL, Williams C, Booth J, Choo BH and Growns S (1996). Effect of water ingestion on endurance capacity during prolonged running. **Journal of Sports Science,** 14: 497-502.

Feyer A, Langley J, Howard M, Horsburgh S, Wright C, Alsop J and Cryer C (2000). The work-related fatal injury study: numbers, rates and trends of work-related fatal injuries in New Zealand 1985-1994. **New Zealand Medical Journal,** 114 (1124): 6-10.

Fibiger W and Henderson ME (1984). Physical work load in thinning pine plantations. **Australian Forestry Research,** 14:135-146.

Fleg JL and Lakatta EG (1988). Role of muscle loss in the age-associated reduction in $VO_{2\ max}$. **Journal of Applied Physiology,** 65 (3): 1147-1151.

Forsman M, Hansson G-A, Medbo L, Asterland P and Engström T (2002). A method for evaluation of manual work using synchronized recordings and physiological measurements. **Applied Ergonomics,** 533-540.

Gallagher S (2005). Physical limitations and musculoskeletal complaints associated with work in unusual or restricted postures: A literature review. **Journal of Safety Research,** 36 (1): 51-61.

Gamberale F (1985). The perception of exertion. **Ergonomics,** 28 (1): 299-308.

Garcin M, Vautier JF, Vandewallet H and Monod H (1998). Ratings of perceived exertion (RPE) as an index of aerobic endurance during local and general exercises. **Ergonomics,** 41 (8): 1105-1114.

Garg A, Chaffin DB and Herrin GD (1978). Prediction of metabolic rates for manual materials handling job. **American Industrial Hygiene Association Journal,** 39 (8): 661-674.

Garg A and Herrin GD (1979). Stoop or squat: a biomechanical and metabolic evaluation. **AIIE Transactions,** 11: 293-302.

Gaskin JE (1990). An ergonomic evaluation of two motor-manual delimbing techniques. **International Journal of Industrial Ergonomics,** 5: 211–218.

Glaser RM, Sawka MN, Brune MF and Wilde SW (1980). Physiological responses to maximal effort wheelchair and arm ergometry. **Journal of Applied Physiology,** 40 (6): 1060-1064.

Goedecke JH, Christie C, Wilson G, Dennis SC, Noakes TD, Hopkins WG and Lambert EV (1999). Metabolic adaptations to a high-fat diet in endurance cyclists. **Metabolism,** 48 (12): 1509-1517.

Golsse JM and Rickards J (1990). Woodlands equipment maintenance: An analysis of mechanical labor energy expenditure. **International Journal of Industrial Ergonomics,** 243-253.

Grandjean E (1986). **Fitting the task to the Man: An ergonomic approach.** Taylor and Francis. London and Philadelphia.

Hagen KB, 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.

Haines H and McAtamney L (1995). Undertaking an ergonomics study in industry. In JR Wilson and EN Corlett (eds): **Evaluation of Human Work – A Practical Ergonomics Methodology.** Second Edition. London: Taylor and Francis.

Haskell WL, Yee MC, Evans A and Irby PJ (1992). Simultaneous measurement of heart rate and body motion to quantitate physical activity. **Medicine and Science in Sports and Exercise,** 25 (1): 109-115.

Haymes EM and Wells CL (1986). **Environment and Human Performance**. Illinois: Human Kinetics Publishers, pp 1-40.

Hjelm E and Frisk C (1985). Physical strain on Vietnamese forest workers. Undersökningsrapport, 5: **Arbetarskyddsstyrelsen, Forskningsavdelningen, Solna.** (see Wästerlund *et al.*, 2004).

Holland EJ, Laing RM, Lemmon TL and Niven BE (2002). Helmet design to facilitate thermoneutrality during forest harvesting. **Ergonomics,** 45 (10): 699-716.

*ILO (1991). 'Occupational safety and health in forestry' Forestry and Wood Industries Committee, Second Session, Geneva, Report III. International Labour Organisation, Geneva. (See Wasterlund, 1998).

James JP (2001). Laboratory and occupation-simulating isokinetic and psychophysical responses of military personnel. **Unpublished MSc Thesis,** Department of Human Kinetics and Ergonomics, Rhodes University, Grahamstown, South Africa.

*Jefferson JR and McGrath PJ (1996). Back pain and peripheral joint pain in an industrial setting. **Archives of Physical Medicine and Rehabilitation,** 77: 385-390. (See Pransky *et al.*, 1999).

*Kaminsky G (1960). Arbeitsphysiologische Grundlagen fur die Gesaltung der Forstarbeit. **Holzwirtsch,** No 46, Hamburg. (See Apud, 1983).

Kamon E, Kiser D and Pytel JL (1982). Dynamic and static lifting capacity and muscular strength of steelmill workers. **American Industrial Hygiene Association Journal,** 43 (11): 853-857.

Karvonen MJ, Pekkarinen M, Metsälä, P and Rautanen Y (1961). Diet and serum cholesterol of lumberjacks. **British Journal of Nutrition**, 15: 157-164.

Karvonen MJ (1958). Use of competitive tests as a method of performance research. **Ergonomics,** 1: 137-150.

Kell RT and Bhambhami Y (2003). Cardiorespiratory and hemodynamic responses during repetitive incremental lifting and lowering in healthy males and females. **European Journal of Applied Physiology,** 90: 1-9.

Keytel LR, Goedecke JH, Noakes TD, Hiiloskorpi H, Laukkanen R, Van Der Merwe L and Lambert EV (2005). Prediction of energy expenditure from heart rate monitoring during submaximal exercise. **Journal of Sports Sciences,** 23 (3): 289-297.

Kilbom A (1994). Assessment of physical exposure in relation to work-related musculoskeletal disorders – what information can be obtained from systematic observations? **Scandinavian Journal of Work and Environmental Health,** 20: 30-45.

Kilbom A (1995). Measurement and assessment of dynamic work. In JR Wilson and EN Corlett (eds): **Evaluation of Human Work – A Practical Ergonomics Methodology.** Second Edition. London: Taylor and Francis.

King GA, Christie CJ and Todd AI (2002). Effect of protective gear on skin temperature responses and sweat loss during cricket batting activity. **South African Journal of Sports Medicine,** 9 (2): 30-35.

Kirk PM and Sullman MJ (2001). Heart rate strain in cable hauler choker setters in New Zealand logging operations. **Applied Ergonomics,** 32 (4): 389-398.

Kogi K (1997). Low-cost ergonomic solutions in small-scale industries in developing countries. **African Newsletter on Occupational Health and Safety,** 7 (2): 31-33.

Kroemer KHE and Grandjean E (1997). **Fitting the Task to the Human – A Textbook of Occupational Ergonomics.** Fifth Edition. London: Taylor and Francis.

Kukkonen-Harjula and Rauramaa R (1984). Oxygen consumption of lumberjacks in logging with a power-saw. **Ergonomics,** 27 (1): 59-65.

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

Kumar S (1995). Development of predictive equations for lifting strengths. **Applied Ergonomics,** 26 (5): 327-341.

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.

Kurumatani N, Yamaguchi B, Dejima M, Enomoto Y and Moriyama T (1992). Aerobic capacity of forestry workers and physical demands of forestry operations. **European Journal of Applied Physiology and Occupational Physiology,** 64 (6): 546-551.

Lambert MI, Cheevers EJ and Coopoo Y (1994). Relationship between energy expenditure and productivity of sugar cane cutters and stackers. **Occupational Medicine,** 44: 190-194.

Legg SJ and Myles WS (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.

Leski MJ (1994). Thermoregulation and safe exercise in the heat. In MB Mellion (ed): **Sports Medicine Secrets.** Boston: Mosby, pp 77-87.

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.

Loucks AB (2004). Energy balance and body composition in sports and exercise. **Journal of Sports Science,** 22 (1): 1-14.

Louden JK, Cagle PE, Figoni SF, Nau KL and Klein RM (1998). A submaximal all-extremity exercise test to predict maximal oxygen consumption. **Medicine and Science in Sports and Exercise,** 30: 1299-1303.

Maas S, Kok NLJ, Westra HG and Kemper HCG (1989). The validity of the use of heart rate in estimating oxygen consumption in static and in combined static/dynamic exercise. **Ergonomics,** 42 (5): 761-766.

MacKinnon SN (1999). Relating heart rate and rate of perceived exertion in two simulated occupational tasks. **Ergonomics,** 42 (5): 761-766.

Magora A (1970). Investigation of the relation between low back pain and occupation. **Industrial Medicine and Surgery,** 39 (12): 504-510.

Manyuchi KT, Pulkki RE and Ackerman P (2003). An analysis of occupational health and safety in forest harvesting in the South African forest industry. **Ergonomics SA,** 15 (1): 2-18.

Marras WS, Lavender SA, Leurgans SE, Fathallah FA, Ferguson SA, Allread WG and Rajula SL (1995). Biomechanical risk factors for occupationally related low back disorders. **Ergonomics,** 38 (2): 377-410.

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

Marti B and Howard H (1990). 'Long term effects of physical training on aerobic capacity: Controlled study of former elite athletes'. **Journal of Applied Physiology,** 69: 1451-1459.

Mazzoni CF, Marçal MA and Couto HA (1998). Occupational biomechanics intervention among chain saw operators in forestry activities to prevent low back pain. **North American Congress on Biomechanics, Canadian Society for Biomechanics – American Society of Biomechanics.** University of Waterloo, Waterloo, Ontario, Canada, August 14-18.

McArdle WD, Katch FI and Katch VL (1996). **Exercise Physiology – Energy, Nutrition and Human Performance**. Fourth Edition. Baltimore: William and Wilkins.

McArdle WD, Katch FI and Katch VL (2001). **Exercise Physiology – Energy, Nutrition and Human Performance**. Fifth Edition. Baltimore: William and Wilkins.

McFarlane S (1989). Noise and hearing loss in the logging industry. Logging Industry Research Association technical release No. 5. Rotorua, New Zealand, LIRA.

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

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

McLellan TM and Cheung SS (2000). Impact of fluid replacement on heat storage while wearing protective clothing. **Ergonomics,** 43 (12): 2020-2030.

Meijer GA, Westerterp KR, Koper H and Ten Hoor F (1989). Assessment of energy expenditure by recording heart rate and body acceleration. **Medicine and Science in Sports and Exercise,** 21 (3): 343-347.

Minister of Water Affairs and Forestry (1996). **Sustainable Forest Development in South Africa,** White Paper, March.

Mital A, Nicholson AS, Ayoub MM (1993). **A Guide to Manual Materials Handling.** London: Taylor and Francis.

Mital A and Kumar S (1998). Human muscle strength definitions, measurement and usage: Part I – Guidelines for the practitioner. International Journal of Industrial **Ergonomics,** 22: 101-121.

Nadel ER (1979). Control of sweating rate while exercising in the heat. **Medicine and Science in Sports,** 11 (1): 31-35.

*Nagase H, Nakamura H, Nohara S, Miura K and Ohnishi T (1992). Multivariate analysis on the relationship between subjective symptoms and risk factors for the development of symptoms including working conditions, life habits and physical status of forestry workers using chain saw. **Japanese Journal of Industrial Health,** 34 (6): 1-9. (See Mazzoni *et al.*, 1998).

Nelson M and Bingham SA (1997). Assessment of food consumption and nutrient intake. In: Margetss BM and Nelson M. **Design concepts in Nutritional Epidemiology.** Second Edition. Oxford: Oxford University Press.

Nielsen R and Meyer JP (1987). Evaluation of metabolism from heart rate in industrial work. **Ergonomics,** 30 (3): 563-572.

NIOSH, (1991). Revised NIOSH Equation**.** National Institute for Occupational Safety and Health. U.S.A.

Noakes TD (1998). Maximal oxygen uptake: “classical” versus “contemporary” viewpoints: a rebuttal. **Medicine and Science in Sports and Exercise,** 30 (9): 1381-1398.

Noakes TD (1992). **Lore of Running.** Fourth Edition. Cape Town: Oxford University Press.

Oborne DJ (1995). **Ergonomics at Work.** Third Edition. New York: John Wiley and Sons.

O’Keefe SJ, Thusi D and Epstein S (1983). The fat and the thin-a survey of nutritional status and disease patterns among urbanized Black South Africans. **South African Medical Journal,** 63 (18): 679-683.

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

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

Panter-Brick C (2003). Issues of Work Intensity, Pace, and Sustainability in Relation to Work Context and Nutritional Status. **American Journal of Human Biology,** 15: 498-513.

Parker R and Kirk P (1993). Felling and delimbing hazards, Report Vol 18, No. 22, Rotorua, Logging Industry Research Organisation.

Parker R and Kirk P (1994). Physiological workload of forestry work. LIRO Brief Report, 19 (4): 1-7.

Parker R, Sullman M, Kirk P and Ford D (1999). Chainsaw size for delimbing. **Ergonomics,** 42 (7): 897 – 903.

Pascoe DD, Shanley LA and Smith EV (1994). Clothing and Exercise, Part I: Biophysics of Heat Transfer between the individual clothing and the environment. **Sports Medicine,** 18 (1): 38-54.

Paterson T (1997). Effect of fluid intake on the physical and mental performance of forest workers. Project Report 66–1997, LIRO Limited, Rotorua.

*Peters PA (1991). Chainsaw felling accidents. **Transactions of the American Society of Agricultural Engineers,** 34: 2600-2608. (See Ashby *et al.*, 2002)

Pheasant S (1996). **Bodyspace – Anthropometry, Ergonomics and the Design of Work.** Second Edition. London: Taylor and Francis.

Pransky G, Snyder T, Dembe A and Himmelstein J (1999). Under-reporting of work-related disorders in the workplace: a case study and review of the literature. **Ergonomics,** 42 (1): 171-182.

Pyke FS and Sutton JR (1992). Environmental stress. In J Bloofield, PA Fricker and KD Fitch (eds): **Textbook of Science and Medicine in Sport.** Melbourne: Blackwell Scientific Press, pp 112-133.

Renz MC (2004). Laboratory investigation of a simulated industrial task pre- and post-ergonomics intervention. **Unpublished MSc Thesis,** Department of Human Kinetics and Ergonomics, Rhodes University, Grahamstown, South Africa.

Reybrouck T, Heigenhauser GF and Faulkner JA (1975). Limitations to maximum oxygen uptake in arms, leg and combined arm-leg ergometry. **Journal of Applied Physiology,** 38 (5): 774-779.

Richter MJ, Langenhoven ML, Du Plessis, JP, Ferreira JJ, Swanepoel AS and Jordaan PC (1984). Nutritional value of diets of blacks in Ciskei. **South African Medical Journal,** 65 (9): 338-345.

Robertson RJ (1982). Central signs of perceived exertion during dynamic exercise. **Medicine and Science in Sports and Exercise,** 14 (5): 390-396.

Sanders MS and McCormick EJ (1993). **Human Factors in Engineering and Design. Seventh Edition.** New York: McGraw-Hill.

Sawka MN and Wegner BC (1988). Physiological responses to acute exercise-heat stress. In: KP Pandolf, Sawka MN, Gonzalez RR (eds): **Human Performance at Environmental Extremes.** Indianapolis: Benchmark Press Inc., pp 199-226.

Sawka MN (1992). Physiological consequences of dehydration: exercise performance and thermoregulation. **Medicine and Science in Sports and Exercise,** 24 (6): 657-670.

Scott PA (1993). Ergonomic problems associated with industry in developing countries, with South Africa as a model. **Ergonomics SA,** 5 (1): 27-28.

Scott PA and Shanavaz H (1997). Ergonomics training in Industrially Developing Countries: Case studies from “Roving Seminars”. **Proceedings: 7th International Conference on Human-Computer Interaction,** 24-28 August, San Francisco, USA.

Scott PA (2001). The key to humanizing the work environment and improving productivity in IDCs. Keynote address. **Proceedings: Humanizing work and work environment. International Indian Society's Ergonomics Conference,** 11-14 December, Mumbai, India.

Scott PA (2003). Establishing an ergonomics ethos in SA Forestry. **Presentation at FESA Focus on Forest Engineering Conference,** 25-26 November, 2003, Badplaas, South Africa.

Scott PA and Zink K (2003). Micro? Macro? – you cant have one without the other. Proceedings: "Ergonomics in the Digital Age". **XVth Triennial Congress of the International Ergonomics Association,** 24-29 August, Seoul, South Korea.

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

Scott PA and Christie CJ (2004). A Preliminary field assessment of the energy expenditure of forestry workers in South Africa. **Proceedings: Human Factors and Ergonomics Society 48th Annual Meeting**, 20 – 24 September, New Orleans, USA.

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

Scott PA and Renz MC (2006). An example of a combined field and laboratory investigation for effective ergonomics. **Applied Ergonomics.** (in press).

Shephard RJ (1988). Heat. In A Dirix, HG Knuttgen and K Tittel (eds): **The Olympic Book of Sports Medicine.** London: Blackwell Scientific Publications, 153-161.

Smith JL (2001). Physical Work Capacity (PWC). In W Karwowski (ed): **International Encyclopedia of Ergonomics and Human Factors.** London: Taylor and Francis.

Sparling PB, Noakes TD, Steyn K, Jordaan E. Jooste P, Bourne L and Badenhorst C (1994). Level of physical activity and CHD risk factors in black South African men. **Medicine and Science in Sports and Exercise,** 26 (7): 896-902.

*Spurr GB (1988). Body size, physical work capacity, and productivity in hard work: is bigger better? In: Waterlow JC (ed.): **Linear growth retardation in less developed countries.** Nestle Nutrition Workshop Series, Vol 14. New York: Raven Press, pp 215-239. (see Panter-Brick, 2003).

statsSA (2000). www.statssa.gov.ac.za

Staudt FJ (1993). 'Ergonomics/labour' in Pancel L.(ed). **Tropical Forestry Handbook,** Vol 2 Chap 24, Springer, Berlin, 1485-1547.

St Clair Gibson A, Lambert MI, Hawley JA, Broomhead SA and Noakes TD (1999). Measurement of maximal oxygen uptake from two different laboratory protocols in runners and squash players. **Medicine and Science in Sports and Exercise.** 31 (8): 1226-1229.

St Clair Gibson A, Baden DA, Lambert MI, Lambert EV, Harley YX, Hampson D, Russell VA and Noakes TD (2003). The conscious perception of the sensation of fatigue. **Sports Medicine,** 33 (3): 167-176.

Straker L (2003). Evidence to support using squat, semi-squat and stoop techniques to lift low-lying object. **International Journal of Industrial Ergonomics,** 31: 149-160.

Strath SJ, Bassett DR, Swartz AM and Thompson DL (2001). Simultaneous heart rate-motion sensor technique to estimate energy expenditure. **Medicine and Science in Sports and Exercise,** 33 (12): 2118-2123.

Strath SJ, Bassett DR, Thompson DL and Swartz AM (2002). Validity of simultaneous heart rate-motion sensor technique for measuring energy expenditure. **Medicine and Science in Sports and Exercise,** 34 (5): 888-894.

Stuebbe P, Genaidy A, Karwowski W, Kwon YG and Alhemood A (2002). The relationships between biomechanical and postural stresses, musculoskeletal injury rates, and perceived body discomfort experienced by industrial workers: A field study. **International Journal of Occupational Safety and Ergonomics**, 8 (2): 259-280.

Sullman MJM, Kirk PM, Parker RJ and Gaskin JE (1999). New Zealand Logging Industry Accident Reporting Scheme: Focus for a Human Factors Research Programme. **Journal of Safety Research,** 30 (2): 123-131.

Sutton JR (1996). Physiological and clinical consequences of exercise in heat and humidity. In JR Sutton (ed): **Oxford Textbook of Sports Medicine**.

Taboun SM and Dutta SP (1989). Energy cost models for combined lifting and carrying tasks. **International Journal of Industrial Ergonomics,** 4 (1): 1–17.

Tam CM, Fung IWH, Yeung TCL and Tung KCF (2003). Relationship between construction safety signs and symbols recognition and characteristics of construction personnel. **Construction Management and Economics,** 21 (7): 743-753.

Tewari DD (2001). Sustainability of Commercial Forestry in a Changing Socioeconomic and Legal Environment: A Case Study of South Africa. **Africa Today,** (48.1): 51-74.

The Compensation Commissioner's Guidelines for Health Practitioners and Employers to manage work-related-upper-limb-disorders (2004). Compensation for Occupational Injuries and Diseases Act, 1993 (Act No 130 of 1993, as amended).

Thelin A (2002). Fatal accidents in Swedish farming and forestry, 1988 – 1997. **Safety Science,** 501 – 517.

Thompson FE and Byers T (1994). Dietary Assessment Resource Manual. **Journal of Nutrition,** 124: 2245S-2246S.

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.

Tortora GT and Grabowski SR (1996). **Principles of Anatomy and Physiology.** Eighth Edition. New York: Harper Collins College Publishers.

Trites DG, Robinson DG, Banister EW (1993). Cardiovascular and muscular strain during a tree planting season among British Columbia silviculture workers. **Ergonomics,** 36 (8): 935-949.

Vayrynen S and Ojanen K (1983). The protection of loggers' heads and eyes in forestry work. **Journal of Occupational Accidents,** (5): 81-88.

Vogt JJ, Libert JP, Candas V, Daull F and Mairiaux PH (1983). Heart rate and spontaneous work-rest cycles during exposure to heat. **Ergonomics,** (26): 1173-1185.

Wästerlund DS (1998). A review of heat stress research with application to forestry. **Applied Ergonomics,** 29 (3): 179-183.

Wästerlund D and Chaseling J (2001). Physiological and labour-productive effects of fluid consumption during forestry work. In: Staal Wästerlund D (ed): **Heat Stress in Forestry Work.** Acta Universitatis Agriculturae Sueciae, Silvestria 213. Swedish University of Agricultural Sciences, p 213. (see Wästerlund *et al.*, 2004).

Wästerlund DS, Chaseling J and Burström L (2004). The effect of fluid consumption on the forest workers' performance strategy. **Applied Ergonomics,** 35: 29-36.

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.

Watt B and Grove R (1993). Perceived Exertion: Antecedents and Applications. **Sports Medicine,** 15 (4): 225-241.

*Wigaeus Hjelm E and Frisk C (1985). Physical strain on Vietnamese forest workers. Undersökningsrapport 5, **Arbetarskyddsstyrelsen, Forskningsavdelningen, Solna** (See Wästerlund *et al.*, 2004).

*Wiktorin C, Karlqvist L, Winkel J and Stockholm MUSIC I Study Group (1993). Validity of self-reported exposures to work postures and manual material handling. **Scandinavian Journal of Work and Environmental Health,** 19: 208-214. (See Capodaglio *et al.*, 1997).

Winkel J and Westgaard RH (1997). A model for solving work related musculoskeletal problems in a profitable way. Applied **Ergonomics,** 27 (2): 71-77.

Wu H-C and Wang M-J (2002). Relationship between maximum acceptable work time and physical workload. **Ergonomics,** 45 (4): 280-289.

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

BIBLIOGRAPHY

Note: The following sources were consulted by the author during the conceptual growth of this dissertation. While not specifically cited, these works did play an important role in establishing the basis upon which this research was developed.

Basset DR and Howley ET (1997). Maximal oxygen uptake: “classical” vs. “contemporary” viewpoints. **Medicine and Science in Sports and Exercise,** 29: 591-603.

Bourne LT, Lambert EV and Steyn, K (2002). Where does the black population of South Africa stand on the nutrition transition? **Public Health Nutrition,** 5 (1A): 157-162.

Guild R, Ehrlich RI, Johnston JR and Ross MH (2001). SIMRAC Handbook of Occupational Health Practice in the South African Mining Industry. Braamfontein: The Safety in Mines Research Advisory Committee (SIMRAC).

Kay D and Marino EE (2000). Fluid ingestion and hyperthermia: Implications for performance, thermoregulation metabolism and the development of fatigue. **Journal of Sports Sciences,** 18: 71-82.

Louden JK, Cagle PE, Figoni SF, Nau KL and Klein RM (1998). A submaximal all-extremity exercise test to predict maximal oxygen consumption. **Medicine and Science in Sports and Exercise,** 30: 1299-1303.

Matter M, Sitfall T, Adams B, Myburgh K, Graves J, Jacobs P and Noakes TD (1987). The effects of iron and folate therapy on maximal exercise performance in iron and folate deficient marathon runners. **Clinical Science,** 72: 415-422.

Mital A (1999). Analysis of multiple activity manual materials handling tasks using A Guide to Manual Materials Handling. **Ergonomics,** 42: 246-257.

Ndaba N and O’Keefe SJ (1985). The nutritional status of black adults in rural districts of Natal Kwazulu. **South African Medical Journal,** 68 (8): 588-590.

Noakes TD, Myburgh KH and Schall R (1990). Peak treadmill running velocity during the $VO_{2\ max}$ test predicts running performance. **Journal of Sports Science,** 8: 35-45.

Pandolf KB (1975). Psychological and physiological factors influencing perceived exertion. **Perceptual and Motor Skills,** 40: 463-574.

Seedat YK, Mayet FGH, Latiff GH and Joubert G (1992). Risk factors and coronary heart disease in Durban blacks – the missing links. **South African Medical Journal,** (82): 251-256.

Seftel HC (1978). The rarity of coronary heart disease in South African blacks. **South African Medical Journal,** 54: 99-105.

St Clair Gibson A, Lambert MI and Noakes TD (2001). Neural control of force output during maximal and submaximal exercise. **Sports Medicine,** 31 (9): 637-650.

Steyn K, Fourie J and Bradshaw D (1992). The impact of chronic diseases of lifestyle and their major risk factors on mortality in South Africa. **South African Medical Journal,** 82: 227-231.

Steyn K, Jooste P and Bourne L (1991). Risk factors for coronary heart disease in the black population of the Cape Peninsula. **South African Medical Journal,** 79: 480-485.

Wang J, Bell JL and Grushecky ST (2003). Logging injuries for a 10-year period in Jilin Province of the People's Republic of China. **Journal of Safety Research,** 34: 273-279.

Wilson JR and Corlett EN (1995). **Evaluation of Human Work.** Second Edition. London: Taylor and Francis.

APPENDIX A: GENERAL INFORMATION

Equipment Checklist

Letter to Subject

Subject Consent Form

EQUIPMENT CHECKLIST

Stationary

Pens
Pencils
Paper
Clipboards
Calculators
Highlighters
Scissors
Paper Clips
Stapler
Plastic sleeves
Folders
Envelopes
Batteries for BP units
Batteries for accelerometers
Battery for metronome

Questionnaires

Health Status and musculoskeletal disorders questionnaire
24-hour dietary recall
Retrospective questionnaires

Data Sheets

Informed Consent
Letter to Subject
Subject data sheet
Physical capacity tests data sheet
Task Demands data sheet with body discomfort data sheet
Environmental
HR information sheets
Order of procedures

Anthropometrical/Body composition Equipment

Scale
Tape Measure (x4)
Skinfold calliper (x2)

Physiological Equipment

$K4b^2$
3L Syringe
Masks and head caps
Heart Rate monitors (4 accurex plus and 4 sports testers)
Polar interface
Accelerometers x 8
Accelerometer interface
Blood pressure monitors (x2)
Step
Hand Grip dynamometers (x2)
Chattilon Dynamometer

Perceptual Equipment

Rating of Perceived Exertion Scales
Body Discomfort Scales

Environmental Equipment

Whirling hydrometer
Automatic temperature unit
Ambient Temperature thermometer
Radiant Temperature thermometer
Humidity probe

General Equipment

Laptop x 2
Discs
Stopwatch (x4)
Response counters (x2)
Camera
Paper Towel
Milton
Gloves
Cotton Wool
2 x metronomes
Microphone
Fixomull tape

Software programmes (for specific equipment)

$K4b^2$
Polar
RT3
Food Finder

LETTER TO SUBJECT

Dear Participant

Thank you for participating in this project entitled:

A FIELD INVESTIGATION OF PHYSICAL WORKLOADS IMPOSED ON HARVESTERS IN SOUTH AFRICAN FORESTRY

The Department of Human Kinetics and Ergonomics at Rhodes University is interested in investigating the compatibility (or incompatibility) between worker capabilities and basic job requirements in the forestry. However, in order to do this, we need to have a better understanding of the type of work being done in the forestry and the types of demands being placed on workers. We also need to gain a better perceptive of worker capabilities. Therefore, this project serves to investigate forestry task demands and forestry worker abilities and the interaction between the two.

WHAT WILL BE REQUIRED

You will be required for two days; on one day you will be assessed outside your working environment, and the other day you will be assessed while you do a normal days work. After 4 weeks we will assess you again, but this time only while you are working. Prior to data collection all procedures will be explained to you verbally and then you will be required to sign a consent form acknowledging your willingness to participate in the study.

DAY ONE:
We will take the following measurements of you:

Stature	(how tall you are)
Mass	(how much you weigh)
Waist and hip circumference	(how big your waist and hips are)
Body Composition	(how much fat and muscle you have)
Blood Pressure	
"Resting" Heart Rate	

You will also be asked a few questions such as what is your age, whether you have any medical problems and whether you smoke.

DAY TWO:
When you arrive at work, we will weigh you to see what your body mass is. We will then place a heart rate monitor on you. This is a belt which is fitted around your chest and which transmits your heart rate to a watch which will be put on your wrist. We will also fit an accelerometer to your body, on the hip. This device will measure the movement of your body while you do your tasks.

We will then watch you working to look at the types of tasks you are doing. We will often look at the watch to see your heart rate responses and every 30 minutes we will show you a “Rating of Perceived Exertion” scale so we can determine how hard you feel you are working. This scale will be explained to you in detail before you start working. You will be asked some questions about your work requirements. After every hour we will ask you if you have any discomfort on your body and you will have to tell us how uncomfortable or sore it is. During your shift we will also assess what you eat and drink so we can measure your energy intake during your work period. At the end of the day we will remove the heart rate monitor and accelerometer and weigh you again to see if your body mass has changed.

Following your work shift and still at your work site, you will have to perform one physical test stepping up and down a step, 150 mm high. The speed of stepping up and down will be progressively increased every 3 minutes for 5 different stages. While you are doing the test, you will have a small machine on your back fitted into a harness, this is called a $K4b^2$. With this equipment you will need to wear a mask which will measure how much oxygen (air) you are consuming while you do the test. You will also wear a heart rate monitor fitted around your chest and you will be asked how hard you feel you are working during these tests. We will first ask you how hard you feel your heart and lungs are working (“Central” Rating of Perceived Exertion) and then we will ask you how hard you feel your legs are working (“Local” Rating of Perceived Exertion).

After this, for the next 4 weeks, you will be given a nutritional supplement every day at the same time during your work shift. It is very important that you consume this supplement. After this 4 week period, in January, we will return and assess you again while you are working to see how the nutritional supplement has helped you.

Thank you for your interest shown and for agreeing to participate in this research protocol. If you have any questions please feel free to ask me at anytime.

Yours Sincerely

CANDICE CHRISTIE
Department of Human Kinetics and Ergonomics
Rhodes University

SUBJECT CONSENT FORM

I,______________________________________ having been fully informed of the research project entitled:

A FIELD INVESTIGATION OF PHYSICAL WORKLOADS IMPOSED ON HARVESTERS IN SOUTH AFRICAN FORESTRY

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

I am fully aware of the procedures involved as well as the potential risks and benefits associated with my participation as explained to me verbally and in writing. In agreeing to participate in this research I waive any legal recourse against the researchers of Rhodes University, from any and all claims resulting from personal injuries sustained whilst partaking in the investigation. This waiver shall be binding upon my heirs and personal representatives. I realise 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 my consent and may withdraw from participation in the research at any time. I am aware that my anonymity will be protected at all times, and agree that all the information collected may be used and published for statistical or scientific purposes.

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

SUBJECT (OR LEGAL REPRESENTATIVE);

____________________	____________________	________________
(Print name)	(Signed)	(Date)

PERSON ADMINISTERING INFORMED CONSENT:

____________________	____________________	________________
(Print name)	(Signed)	(Date)

WITNESS:

____________________	____________________	________________
(Print name)	(Signed)	(Date)

APPENDIX B: DATA COLLECTION

Order of Procedures

Rating of Perceived Exertion Scale

Rating of Perceived Exertion Scale Explanation Sheet

Body Discomfort Map and Scale

Body Discomfort Scale Explanation Sheet

Data Collection Sheets

ORDER OF PROCEDURES

CHAINSAW OPERATORS AND STACKERS

Afternoon Testing: (Need an interpreter to assist especially with the questionnaires)

1. Explain the protocol
    - What is happening today (demographic and anthropometrical/ body composition data).

2. Collection of basic demographic data
    - Name, sex, age, number of years working
    - Anthropometrical data
    - Body composition
    - “Resting” cardiovascular responses
    - Questionnaire

3. Explanation of 24-hour dietary recall

4. Explanation of perceptual scales in detail with interpreter

5. Explanation of what is happening during the week.

- Six (6) will be tested each day
- You will only be tested on one day and then again on one day in JANUARY
- When you arrive at work we will measure your body mass
- Heart rate monitor and accelerometer will be attached to you
- You will work normally for the duration of your shift – you must not change what you normally do. We will watch you and ask to see the heart rate monitor when you refuel your chainsaw (in the case of the chainsaw operators) or every 30 minutes (in the case of the stackers). At this time you will also be asked how you are feeling (“Central” and “Local” Ratings of Perceived Exertion).
- Anything you eat or drink will be recorded
- You must let us know when you go to the toilet
- After the shift you will be asked to identify areas of body discomfort
- After the shift we will remove the heart rate monitor and accelerometer and measure body mass again
- The heart rate monitor will be reattached and you will rest for approximately 30 minutes before we do the submaximal test

6. Explain the submaximal protocol in detail showing the $k4b^2$, masks, step and metronome (get someone to demonstrate).

ORDER OF PROCEDURES

CHAINSAW OPERATORS AND STACKERS

Testing on site: (Need 2 or 3 interpreters)

NIGHT BEFORE: Load users into the accelerometers

1. Set up the environmental equipment
2. Measure body mass
3. Attach heart rate monitor
   - Intervals set to record every 60 seconds
   - Tight contact
   - Ensure reading
4. Attach accelerometers (must put USER PROFILE in the NIGHT BEFORE)
7. Start stop watch on heart rate monitor, accelerometer and on the stop watch and start work cycle
8. Monitor work cycle for the shift
   - WORKER PACED: Time, description of activity, reason for activity (includes food and fluid intake), heart rate
   - 30 MINUTE INTERVALS (or when re-fuelling): Heart Rate and “Central” and “Local” Ratings of Perceived Exertion
9. Body discomfort post-shift
10. Remove heart rate monitors
11. Measure body mass post-shift
12. Reattach heart rate monitor
13. Recover for 30 minutes
14. Perform submaximal step up test
15. Pack away equipment

RATING OF PERCEIVED EXERTION

(ISIKALI ESITSHENGISA UKUTHI USEBENZA KANGAKANANI)

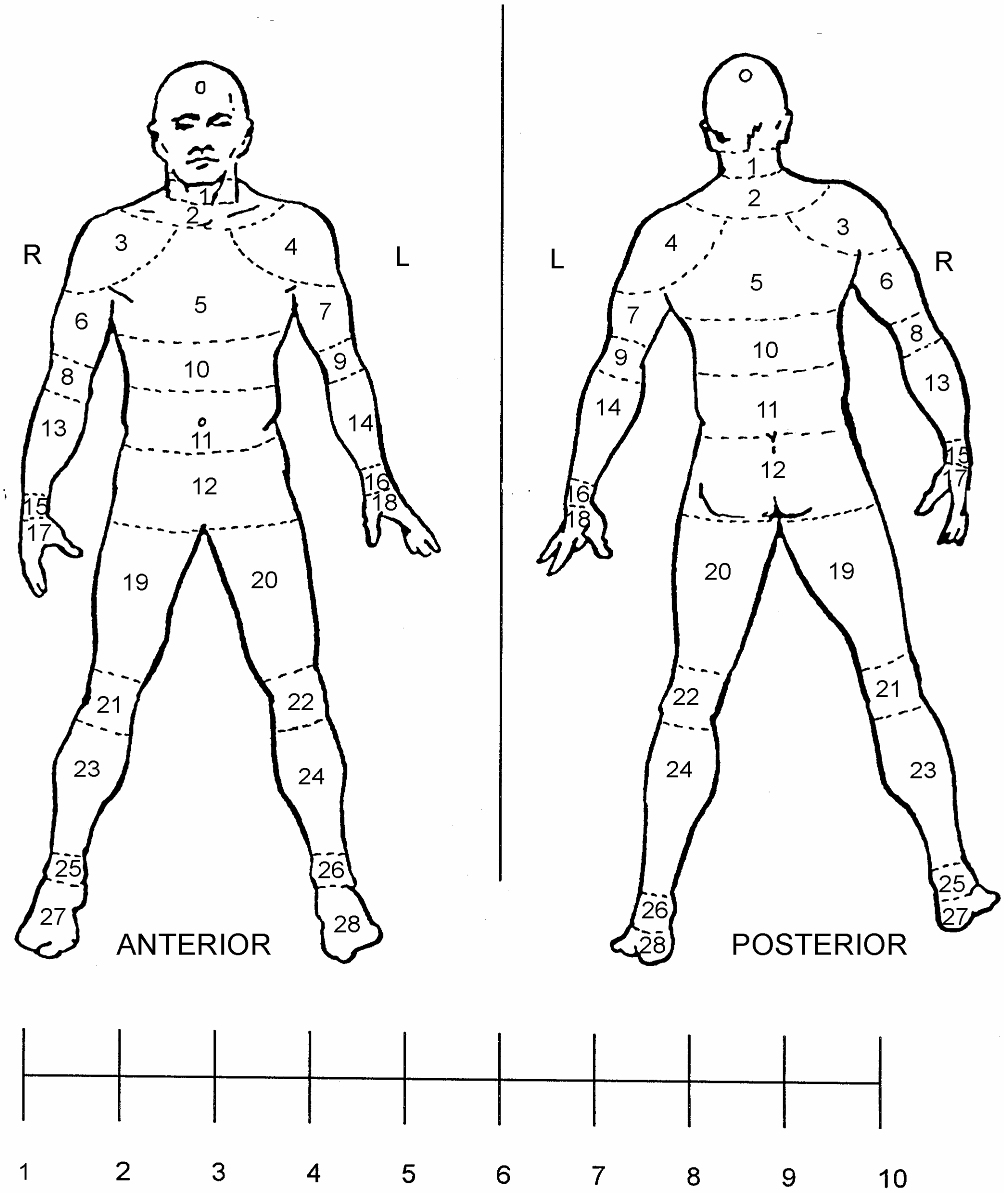
NUMERICAL	VERBAL
6	
7	KULULA KAKHULU
8	
9	KULULA
10	
11	KULULA KANCANE / KULULANA
12	
13	KUNZIMA KANCANE / KULIKHUNYANA
14	
15	KUNZIMA / KULIKHUNI
16	
17	KUNZIMA KAKHULU / KULIKHUNI KAKHULU
18	
19	KUNZIMA NGOKUSEZIGENI ELIPHEZULU / KULIKHUNI NGOKUSEZINGENI ELIPHAKEME

EXPLANATION OF RPE

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. Lena ibizwa ngokuthi I "Local RPE". Izimpendulo zakho zizobe zisitshela izinga osebenza ngalo, lokhu kuchaza ukuthi zizobe zehlukile kunezabanye abantu osebenza nabo.

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 MAP AND RATING SCALE



Minimum Intensity Maximum Intensity

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

EXPLANATION OF BODY DISCOMFORT

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.

SUBJECT DATA SHEET

GENERAL INFORMATION:

*Name:*______________________________________ *Code:*__________________

Task: (Tick) | Chainsaw operator | | Stacker | 2.5m | 5.0m | | Debarker |

*Date of birth*_____:/_____/19___ (Day/month/year) *Age*________ *years*______ *months*

Sex: (Tick) | Male | | Female |

Number of years working in forestry: _________years

Comments:____

ANTHROPOMETRIC DATA:

*Stature:*___________mm *Mass:* _____________kg

*Waist cirumference:*___________mm *Hip Circumference:*_________mm

BODY COMPOSITION:

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

Sum of Skinfolds:___________mm ***Fat:***___________% ***LBM:***___________%

RESTING CARDIOVASCULAR RESPONSES:

"Reference" Heart Rate: _____________bt.min^{-1}

"Resting" Blood Pressure: _________mmHg (Systolic) ________mmHg (Diastolic)

Identity clothing:______________**HRM:** *No:*______ *File:*_____ **Accelerometer**:

*No:*_____ **Subject Code:**_________

WORKER PACED: CHANGE IN ACTIVITY		**30 MINUTE INTERVALS (or when refuelling)**			
TIME	**DESCRIPTION OF ACTIVITY** (May stay consistent) **REASON FOR ACTIVITY** (Must include DETAILED description of food and fluid intake)	**HEART RATE** **($bt.min^{-1}$)**	**RATING OF PERCEIVED EXERTION** **"Central"**	**"Local"**	**COMMENTS**

Pre shift body mass:_______________ **kg**

Post shift body mass___________________ **kg**

Duration of work shift:__________________________

BODY DISCOMFORT

TIME	BODY DISCOMFORT (A = Anterior; P = Posterior) 1		2		3	
End of:	AREA	RATING	AREA	RATING	AREA	RATING
1st Hour						
2nd Hour						
3rd Hour						
4th Hour						

Comments:____

Name:________________________________

Code:_____________ **Type of work:**______________

Age:______________ **Stature:**____________mm **Mass:**____________kg

"Resting" Heart Rate:__________bt.min^{-1}

(NB: Set HR intervals at 5s)

TIME	**STEP RATE (bpm)**	**HR (bt.min^{-1})**	**VO_2 (ml.kg^{-1}.min^{-1})**	**RPE**		**COMMENTS**
				"Central"	**"Local"**	
0:00						
3:00	82					
6:00	98					
9:00	114					
12:00	130					
15:00	146					
18:00	162					
	178					

(bpm=beats per minute; HR=heart rate; VO_2=oxygen consumption; RPE=Ratings of perceived exertion; Local RPE refers to the legs)

COMMENTS:____

APPENDIX C: INTERVIEW AND QUESTIONNAIRE SHEETS

24-hour Dietary Recall Sheet

Health Status and incidence of Musculoskeletal Disorders Questionnaire

Retrospective Perceptual Questionnaire

DIETARY INTAKE: 24-HOUR RECALL METHOD

The 24-hour dietary recall method is a way of assessing your diet (what you eat and drink) over a 24-hour period (i.e. one day). You need to remember (recall) all the food and drink you have eaten or drunk in the 24-hours before (i.e. the day before filling in the attached sheet). You need to be as accurate as possible about how much you have eaten or drunk i.e. your portions (see attached form) and how you prepared your food or drink (preparation procedures).

The following are important:

1. The recall sheet (which is the next sheet) has three columns in which you need to indicate the time you ate or drank, a detailed description of what you ate or drank and how much of that you ate or drank (i.e. the portion size).
2. You need to tell us everything you have eaten or drunk the previous day from the moment you woke up until you went to sleep that evening.
3. You need to tell us when you ate the food (i.e. lunch, tea, after dinner) and give us an approximate time.
4. You need to tell us how much you ate or drank – see the portion size list which is attached – such as an apple which was the size of my fist, or a piece of cheese which was the size of my thumb, or a piece of meat the size of the palm of my hand or the size of my hand. These are approximations, but you need to be as accurate as possible.
5. You need to tell us how you prepared the food (i.e. the chicken was cooked in oil – then you need to tell us how much oil). Everything that has gone into the preparation of your food must be put down on the list and you must give us an idea of how much.

Other important considerations:

- If you eat a sandwich you must remember how much margarine/butter you used and what was on the sandwich.
- If you drink any liquid you must let us know how much; such as a coffee mug or a tea cup.
- If you put milk in coffee or tea you must indicate how much.
- Sugar added to food or drink must also be included.

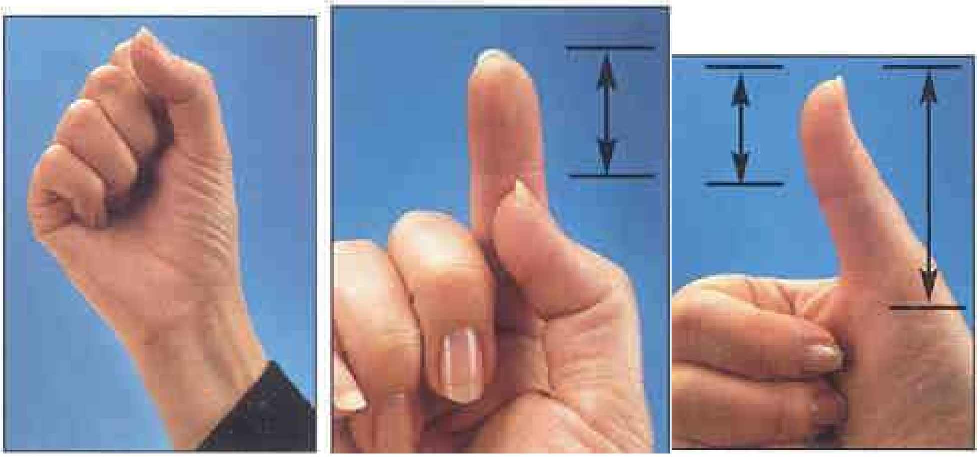
Name:______________________________ **Code:**___________ *(for office use)*

Today's Date:___________(Day/Month/Year) **Day of the week:**___________

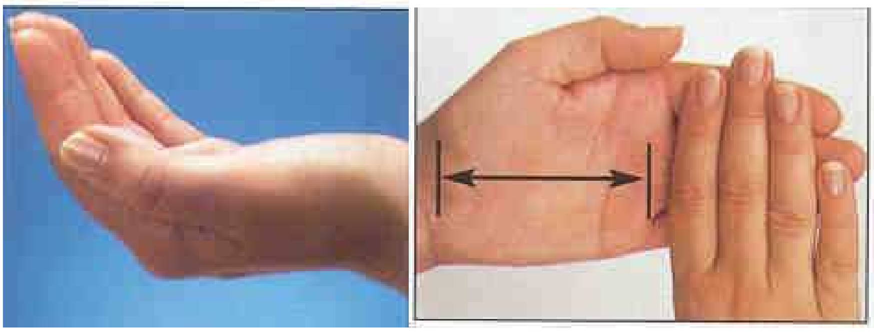
Is this a typical day? ☐ *(If not, give an example of a typical day after this record)*

Time	Type of food and/or drink and how you made it	Quantity	Eaten at Home (H) or at Work (W)
BEFORE BREAKFAST			
BREAKFAST			
MID-MORNING: Between breakfast and lunch			
LUNCH			
MID-AFTERNOON: Between lunch and dinner			
DINNER			
AFTER DINNER			

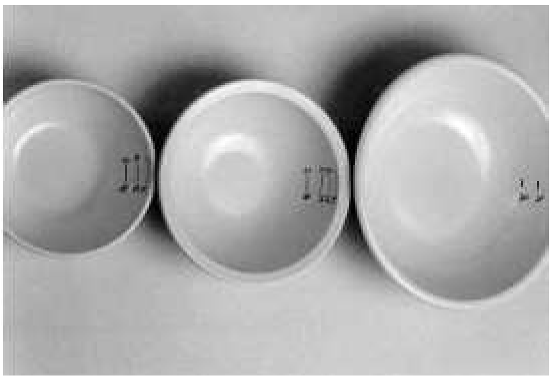
PORTION SIZES



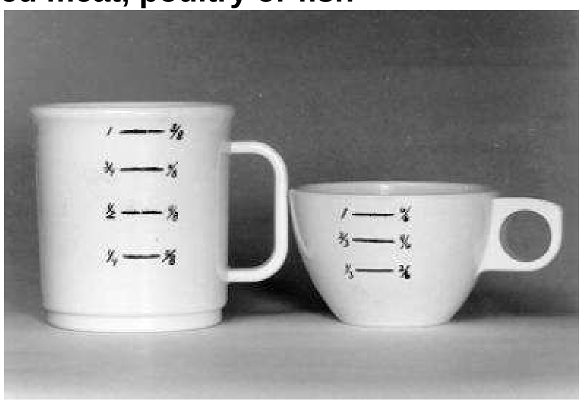
The size of your fist refers to a medium sized fruit or vegetable (i.e. apple, orange, potato), the size of your fingertip refers to one teaspoon (i.e. sugar, butter on bread), the size of your thumb refers to one tablespoon



Your cupped hand refers to approximately 45 g (i.e. a cupped hand of chopped vegetables or rice), the palm of your hand refers to a medium portion of cooked meat, poultry or fish



Small Medium Large



Mug Cup

Code:__________

HEALTH STATUS AND INCIDENCE OF MUSCULOSKELETAL DISORDERS

HEALTH STATUS

CHOLESTEROL

Have you had your cholesterol measured?

(If answered YES)

Have you been told you have high cholesterol?
If so, what is it?______________

Are you on medication for your cholesterol?

DIABETES

Have you been told you have diabetes?

(If answered YES)

Are you on medication for your diabetes?

SMOKING

Do you smoke?

(If answered YES)

Light daily smoker (1-14)

Heavy daily smoker (> 15)

(If answered NO)

Have you ever smoked (ex-smoker)?

Non-smoker *(i.e. Never smoked)*

ALCOHOL

Do you drink?

(If answered YES)

*What do you drink?*_________________________________

*Roughly how many drinks do you have per day?*_________

HYPERTENSION

Do you have high blood pressure?

(If answered YES)

Are you on medication for high blood pressure?

(If answered NO)

Have you ever been told you have high blood pressure?

HEART DISEASE

Do you have heart disease?

(If answered YES)

Are you on any medication for this condition?

COMMENTS:____

Do you have a family history (mother, father, brother, sister) of heart disease?

Do you have a family history of high cholesterol, high blood pressure, diabetes or heart disease?

COMMENTS:____

Do you have any other health problems? (Comment):__________________________

MUSCULOSKELETAL DISORDERS

Do you **currently** have any musculoskeletal injury?

(If answered YES)

To what area of the body? (Tick)

Upper Body	Torso	Lower Body

Did you get injured at work or because of your work?

*What is the specific injury?*__________________________________

Are you receiving treatment?

(If answered YES)

*What type of treatment?*___________________________________

Have you had any musculoskeletal injury in the **past 12 months**?

(If answered YES)

To what area of the body? (Tick)

Upper Body	Torso	Lower Body

Did you get injured at work or because of your work?

*To what area/s of the body?*________________________________

*How was the injury treated?*________________________________

COMMENTS:____
____
____
____

ABSEENTISM

Have you been absent from work during the last 12 months?

(If answered YES)

*For how long?*____

*What was the reason?*____

Code:__________

RETROSPECTIVE QUESTIONNAIRE

(Food and Fluid Intervention)

Please read the following questions and answer them as honestly as possible by marking the appropriate box with an X.

REGULAR FLUID (WATER) INTAKE

1. Did you enjoy getting fresh WATER to drink during your work shift?

YES	NO

*Please give a brief explanation to support your response:*__________________

____

____

2. Do you think getting fresh WATER helped you work more efficiently (better)?

YES	NO

3. Did the regular supply of WATER make you feel better?

YES	NO

4. Would you like to get fresh WATER on a regular basis?

YES	NO

MOREVITE

5. **Did you enjoy getting MOREVITE to drink during your work shift?**

YES	NO

*Please give a brief explanation to support your response:*___________________

____

____

6. **Do you think getting MOREVITE helped you work more efficiently (better)?**

YES	NO

7. **Did the MOREVITE make you feel better?**

YES	NO

8. **Would you like to get MOREVITE on a regular basis?**

YES	NO

SANDWICHES

9. **Did you enjoy getting SANDWICHES to eat during your work shift?**

YES	NO

*Please give a brief explanation to support your response:*________________

____

____

10. Do you think getting SANDWICHES helped you work more efficiently (better)?

YES	NO

11. Did the SANDWICHES make you feel better?

YES	NO

12. Would you like to get SANDWICHES on a regular basis?

YES	NO

FRUIT

13. Did you enjoy getting a FRUIT to eat during your work shift?

YES	NO

*Please give a brief explanation to support your response:*________________

____

____

14. Do you think getting FRUIT helped you work more efficiently (better)?

YES	NO

15. Did the FRUIT make you feel better?

YES	NO

16. Would you like to get FRUIT on a regular basis?

YES	NO

OVERALL

17. Indicate your preference from 1 – 4 (1=you liked this the most and 4=you liked this the least) in terms of the four different supplementations.

INTERVENTION	PREFERENCE (1- 4)	REASON
Water		
Morevite		
Sandwiches		
Fruit		

18. Did you feel better or less tired at the end of the working shift?

YES	NO

19. Did you feel better or less tired at the end of the working week?

YES	NO

APPENDIX D: SUMMARY REPORTS

Individual regressions and correlations

Physiological Formulae and Variables

Heart Rate Responses Printouts

K4b^2 Printout

Accelerometer Printout

Foodfinder3 Printout

Statistica Printout

Papers published by the author relating directly and indirectly to this research

INDIVIDUAL REGRESSIONS AND CORRELATIONS FOR THE CHAINSAW OPERATORS DURING STEPPING

WORKER	EQUATION	R	r^2
1	y=0.4498*-30.30	0.69	0.48
2	y=0.5453*-39.56	0.66	0.43
3	y=0.3066*-14.68	0.67	0.44
4	y=0.5673*-36.33	0.82	0.66
5	y=0.4929*-39.41	0.88	0.78
6	y=0.5223*-55.88	0.88	0.78
7	y=0.4787*-31.50	0.78	0.62
8	y=0.6359*-47.82	0.86	0.75
9	y=0.5948*-43.11	0.58	0.34
10	y=0.505*-37.85	0.86	0.73
11	y=0.4229*-18.77	0.86	0.73
12	y=0.5183*-53.29	0.91	0.83
13	y=0.3384*-18.76	0.69	0.47
14	y=0.5413*-52.98	0.85	0.73
15	y=0.6008*-75.90	0.64	0.41
16	y=0.6381*-61.90	0.70	0.49
17	y=0.5413*-52.98	0.85	0.73
18	y=0.5471*-67.45	0.60	0.37
19	y=0.8839*-81.04	0.80	0.64
20	y=0.6012*-58.01	0.62	0.82
21	y=0.3993*-32.45	0.73	0.54
22	y=0.1260*-7.07	0.64	0.41
23	y=0.5369*-26.31	0.66	0.44
24	y=0.3650*-19.91	0.73	0.53
25	y=0.2308*-14.77	0.78	0.60
26	y=0.2858*-17.65	0.67	0.45
27	y=0.3552*-18.43	0.82	0.67
28	y=0.1978*-3.94	0.68	0.46
29	y=0.3964*-25.64	0.88	0.77
MEAN		**0.75**	**0.59**

INDIVIDUAL REGRESSIONS AND CORRELATIONS FOR THE STACKERS DURING STEPPING

WORKER	EQUATION	R	r^2
1	y=0.5272*-45.94	0.76	0.58
2	y=0.3853*-23.02	0.86	0.74
3	y=0.4360*-28.86	0.86	0.73
4	y=0.3579*-31.48	0.47	0.22
5	y=0.4380*-31.77	0.81	0.66
6	y=0.5719*-44.45	0.67	0.44
7	y=0.4651*-28.79	0.86	0.75
8	y=0.6733*-63.54	0.78	0.61
9	y=0.4379*-30.82	0.80	0.64
10	y=0.4980*-25.90	0.85	0.72
12	y=0.3175*-21.02	0.85	0.72
13	y=0.5187*-40.13	0.79	0.63
14	y=0.4514*-24.36	0.34	0.12
15	y=0.6372*-50.82	0.52	0.27
16	y=0.5610*-38.02	0.82	0.66
17	y=0.5953*-46.08	0.87	0.75
18	y=0.5566*-48.20	0.77	0.59
19	y=0.5424*-41.31	0.69	0.48
20	y=0.4680*-22.81	0.62	0.38
21	y=0.6029*-50.63	0.69	0.48
22	y=0.5005*-39.51	0.88	0.77
23	y=0.5329*-47.75	0.77	0.59
24	y=0.5130*-39.95	0.80	0.65
25	y=0.3628*-13.80	0.64	0.41
27	y=0.5397*-30.86	0.72	0.52
28	y=0.3104*-12.55	0.71	0.50
29	y=0.6428*-39.81	0.66	0.44
30	y=0.6461*-43.93	0.74	0.55
32	y=0.4505*-24.90	0.81	0.66
MEAN		**0.74**	**0.56**

PHYSIOLOGICAL FORMULAE AND VARIABLES

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

HR_{max} = 220 – age (in years)

Breathing Frequency (F_B) in $br.min^{-1}$:

Amount of breaths per minute

Tidal Volume (V_T) in L:

The amount of air moved in and out of the lungs with each normal breath and which is approximately 0.5L at rest in a young, healthy adult.

Minute Ventilation (V_E) in $L.min^{-1}$:

The amount of air breathed in every minute; a function of breathing rate and tidal volume.

V_E = Breathing frequency x Tidal Volume

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

The amount of oxygen consumed by the body each minute.

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

Energy Expenditure (EE):

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

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

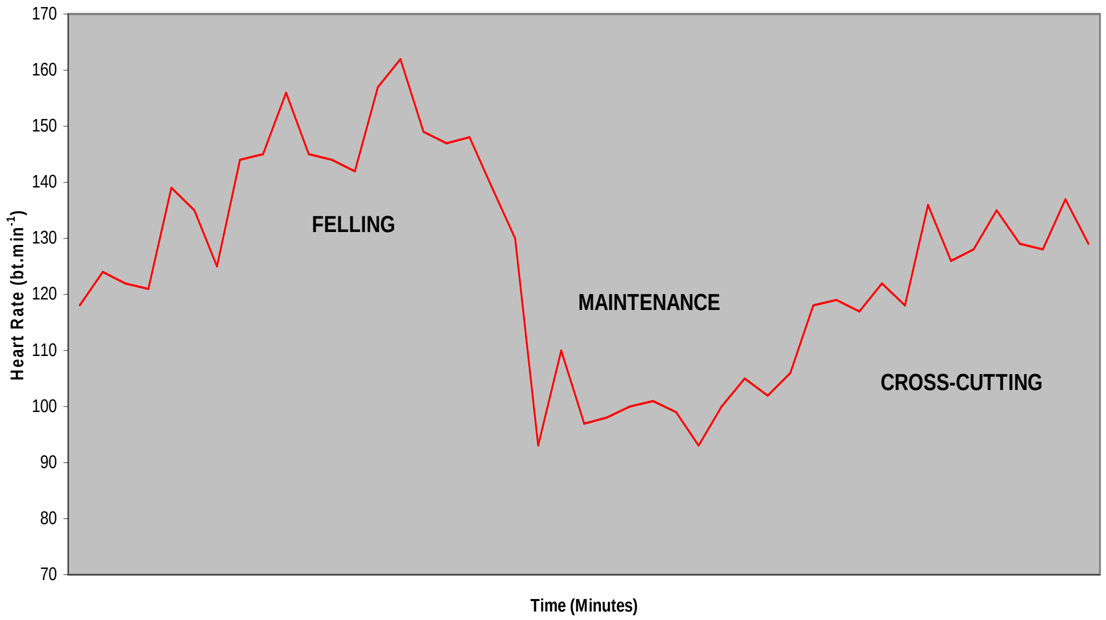
$kcal.min^{-1} \div 0.01433$ = power output (W)

Metabolic Equivalent (MET):

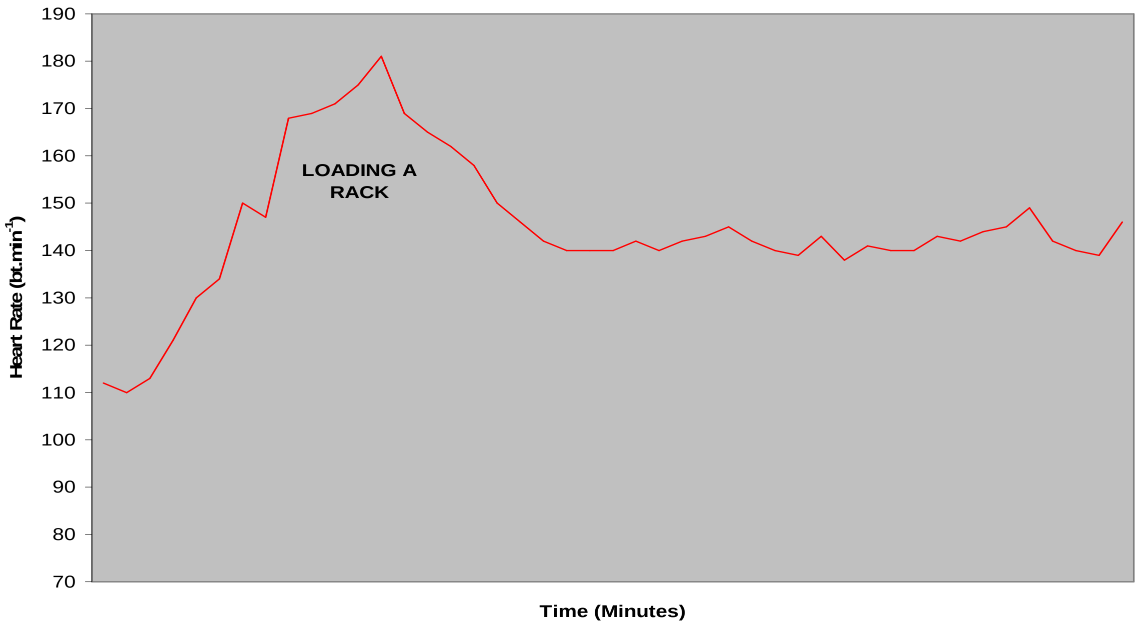
Multiple of resting metabolic rate. 1 MET = 3.5 $ml.kg^{-1}.min^{-1}$.

HEART RATE RESPONSES PRINTOUTS

Chainsaw Operator:



Stacker:



K4b^2 PRINTOUT

t	Rf	VT	VE	VO2/Kg	R	HR
hh:mm:ss	b/min	l	l/min	ml/min/Kg	---	bpm
00:00:01	15.54404	0.568238	8.832709	3.624375	0.853399	77
00:00:04	16.52893	0.761051	12.57935	6.516631	0.82376	80
00:00:08	16.34877	0.685558	11.20803	5.390747	0.839008	79
00:00:11	15.74803	0.744728	11.728	5.884812	0.823259	79
00:00:15	17.96407	0.725345	13.03014	6.208952	0.880727	77
00:00:18	17.3913	0.75697	13.1647	6.319463	0.876693	78
00:00:21	18.98734	0.892653	16.94911	8.45711	0.908928	80
00:00:24	19.35484	0.842665	16.30964	7.290376	0.924662	79
00:00:27	20.06689	0.922238	18.50646	8.719018	0.903292	81
00:00:30	19.67213	0.924279	18.18253	8.082799	0.951653	85
00:00:33	20.68966	0.821241	16.9912	7.416486	0.976771	90
00:00:36	23.90438	0.905916	21.65535	9.761395	1.01449	96
00:00:38	28.16901	0.776353	21.86911	10.14698	0.990524	100
00:00:40	26.31579	0.81614	21.47737	11.16303	0.922786	104
00:00:42	27.77778	0.839604	23.32234	12.22782	0.912073	107
00:00:44	29.70297	0.767172	22.78728	11.84679	0.878075	111
00:00:47	28.30189	0.786555	22.26099	11.14493	0.934271	112
00:00:49	27.27273	0.879391	23.98339	12.77743	0.892151	114
00:00:51	28.16901	0.949783	26.75446	14.96549	0.878972	116
00:00:53	27.77778	0.857967	23.83243	12.90012	0.863247	118
00:00:55	26.78571	1.022216	27.38078	14.43495	0.911737	120
00:00:58	25	1.040579	26.01447	14.94411	0.88828	121
00:01:00	25.1046	1.10587	27.76243	15.5751	0.909311	121
00:01:02	25	1.026296	25.65741	14.09229	0.923478	121
00:01:05	23.71542	1.031397	24.46001	13.32543	0.905435	120
00:01:07	24.79339	1.135455	28.15178	16.36503	0.884806	120
00:01:10	27.77778	1.239513	34.43092	20.53016	0.873004	119
00:01:12	29.26829	1.128314	33.02382	19.94808	0.836024	119
00:01:14	23.71542	1.246654	29.56492	18.01568	0.838857	118
00:01:16	26.08696	1.306845	34.0916	21.65598	0.814108	117
00:01:19	27.14932	1.083426	29.41428	17.61263	0.818168	116
00:01:21	26.78571	1.150758	30.82387	19.42001	0.823518	115
00:01:23	27.14932	1.010994	27.44779	17.29563	0.8016	115
00:01:25	25.53191	1.126274	28.75592	18.39376	0.78963	115
00:01:28	20	1.149738	22.99475	15.08322	0.795395	115
00:01:31	22.72727	1.236452	28.10119	19.53932	0.783639	114
00:01:33	27.14932	1.138516	30.90993	21.93028	0.752537	114
00:01:36	27.39726	1.121173	30.71706	20.18478	0.78989	113
00:01:38	25	1.177282	29.43206	19.25305	0.798423	114
00:01:40	26.66667	1.382338	36.86233	24.97594	0.791021	114
00:01:42	28.57143	1.152798	32.93709	21.49096	0.792661	115
00:01:44	29.12621	1.111991	32.38809	19.86191	0.8063	115
00:01:47	25.86207	1.174222	30.3678	20.2914	0.791098	116
00:01:49	28.70813	1.291542	37.07776	24.28131	0.808351	117
00:01:51	28.43602	1.306845	37.16146	25.29147	0.788258	118
00:01:53	27.52294	1.172181	32.26187	22.15649	0.777064	119
00:01:56	23.80952	1.201766	28.61349	19.70957	0.792587	119
00:01:58	25.1046	1.027317	25.79037	17.04392	0.765446	118
00:02:00	28.16901	1.04466	29.42703	20.11422	0.755184	118
00:02:02	26.90583	1.177282	31.67576	22.4293	0.762553	117
00:02:04	27.52294	1.111991	30.60526	20.03665	0.790934	117
00:02:07	26.90583	1.319087	35.49112	24.54237	0.807491	116
00:02:09	27.02703	1.10485	29.86081	19.40031	0.789496	115

ACCELEROMETER PRINTOUT

Device Infc RT3
ATR Serial EE000473
ATR Hardv 0.1
ATR Firmw 255.4
ATR CoBrε 0
User Info:
User ID Cele
User Heigh 160 cm
User Weig 66.3 Kg
User Age 24
User Gend 0 Male
User AMR 1.2261 Calories per Minute
Test Info:
Notes
Activity Data:
Download ' 12/03/2003 00:37:07
Start Time 12/02/2003 16:59:00
Format 3 XYZ 1 Minute
Number Re 458

Entry	Date	Time	Total Calor	VM	ActCntsX	ActCntsY	ActCntsZ
1	12/02/2003	16:59:00	3.14	773.46	484.00	388.00	462.00
3	12/02/2003	17:01:00	3.24	814.48	551.00	482.00	357.00
4	12/02/2003	17:02:00	6.96	2321.98	1671.00	1345.00	889.00
5	12/02/2003	17:03:00	6.59	2170.65	1690.00	1152.00	727.00
6	12/02/2003	17:04:00	6.61	2177.62	1466.00	1295.00	957.00
7	12/02/2003	17:05:00	6.63	2188.81	1476.00	1379.00	843.00
8	12/02/2003	17:06:00	5.65	1791.77	1153.00	1143.00	758.00
9	12/02/2003	17:07:00	6.33	2064.95	1502.00	1127.00	859.00
10	12/02/2003	17:08:00	6.20	2012.56	1580.00	998.00	747.00
11	12/02/2003	17:09:00	5.52	1739.15	1233.00	1028.00	669.00
12	12/02/2003	17:10:00	6.18	2006.23	1261.00	1227.00	964.00
13	12/02/2003	17:11:00	6.83	2270.38	1585.00	1438.00	758.00
14	12/02/2003	17:12:00	3.93	1093.11	552.00	763.00	555.00
15	12/02/2003	17:13:00	6.10	1973.03	1375.00	1011.00	990.00
16	12/02/2003	17:14:00	4.31	1247.07	574.00	909.00	632.00
17	12/02/2003	17:15:00	4.47	1315.15	884.00	863.00	451.00
18	12/02/2003	17:16:00	2.55	536.43	203.00	449.00	212.00
19	12/02/2003	17:17:00	3.49	917.30	500.00	655.00	403.00
20	12/02/2003	17:18:00	3.26	823.09	407.00	630.00	339.00
21	12/02/2003	17:19:00	2.89	673.99	324.00	471.00	357.00
27	12/02/2003	17:25:00	3.09	754.51	375.00	516.00	403.00
28	12/02/2003	17:26:00	2.57	542.77	408.00	304.00	189.00
29	12/02/2003	17:27:00	2.48	507.87	233.00	406.00	197.00
30	12/02/2003	17:28:00	2.58	547.12	313.00	303.00	331.00
31	12/02/2003	17:29:00	5.03	1540.92	773.00	1067.00	799.00
32	12/02/2003	17:30:00	5.40	1688.15	954.00	1194.00	717.00
33	12/02/2003	17:31:00	4.57	1352.50	860.00	857.00	596.00
34	12/02/2003	17:32:00	2.02	322.41	163.00	249.00	124.00
39	12/02/2003	17:37:00	2.12	363.35	187.00	300.00	84.00
40	12/02/2003	17:38:00	2.97	706.85	441.00	508.00	217.00
41	12/02/2003	17:39:00	2.99	714.16	399.00	563.00	184.00
42	12/02/2003	17:40:00	3.78	1034.60	640.00	742.00	332.00
43	12/02/2003	17:41:00	3.54	935.75	521.00	692.00	354.00
44	12/02/2003	17:42:00	2.71	600.03	326.00	424.00	272.00
45	12/02/2003	17:43:00	3.22	808.92	431.00	632.00	263.00
46	12/02/2003	17:44:00	3.13	771.17	590.00	450.00	210.00

***FOODFINDER 3* PRINTOUT**

```
Foodfinder 3 - Export Analysis


Individual Code   Individual  Meal Date   Meal Time Code    Meal Time
      Food Group Code   Food Group  Meal Item Code    Meal Item   Tot.
Grams Energy (kJ) Total protein (g) Total fat (g)     "Carbohydrate, avail.
(g)"

M1    Anton Mahaye      04/05/20    4     In-between  1     Cereal and
cereal products   3401  "Maize Meal, Cooked Crumbly Porridge"     75g   519
      2.7   0.8   25.1
M1    Anton Mahaye      04/05/20    4     In-between  4     Legumes and
legume products   3185  "Beans, Haricot, Dried, Boiled"     50g   308   4.4
      0.3   10
M1    Anton Mahaye      04/05/20    5     Lunch 1     Cereal and cereal
products    267802      Mahewu      1000g 1590  8     3     78
M1    Anton Mahaye      04/05/20    7     Supper      1     Cereal and
cereal products   3247  "Rice, White, Cooked"   30g   159   0.8   0.1   8.2
M1    Anton Mahaye      04/05/20    7     Supper      9     Fish and
seafood     3092  "Fish, Low Fat, Baked With Butter"  120g  839   25.1
      11.2  0
M1    Anton Mahaye      04/05/20    7     Supper      16    Miscellaneous
      4038  "Tea, Brewed  "   250g  12    0     0     0.8
M1    Anton Mahaye      04/05/20    7     Supper      11    "Sugar, syrups
and sweets" 3989  "Sugar, White, Granulated"    10g   170   0     0     10
```

STATISTICA PRINTOUT

Variable	T-tests; Grouping: CODE (Basic Subject information (Final)) Group 1: CO Group 2: STACKERS Mean CO	Mean STACKERS	t-value	df	p
AGE	35.800	36.094	-0.14522	60	0.885027
EXP	98.931	35.069	3.07216	56	0.003278
HR	81.700	68.312	4.37247	60	0.000050
SBP	135.667	141.312	-1.37966	60	0.172811
DBP	87.233	86.500	0.23694	60	0.813511
STATURE	1714.200	1715.000	-0.04724	60	0.962475
MASS	65.613	65.266	0.19305	60	0.847569
WAIST	786.860	787.119	-0.02220	60	0.982361
HIP	922.240	913.450	0.91318	60	0.364801
TRICEPS	6.060	6.322	-0.52622	60	0.600678
BICEPS	3.423	3.594	-0.91350	60	0.364636
SUBSCAP	8.397	7.956	0.65469	60	0.515172
SUPRA	5.720	5.397	0.59985	60	0.550864
ABD	9.007	8.891	0.12144	60	0.903750
THIGH	7.459	8.228	-0.95387	59	0.344041
CALF	4.990	5.694	-1.41549	59	0.162183
SUM	44.640	46.081	-0.39841	60	0.691743

PAPERS PUBLISHED BY AUTHOR

(Directly and indirectly related to the this research)

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

Christie CJ and Scott PA (2005). Physiological and perceptual responses of female debarkers during forestry work. **Fourth International Cyberspace Conference on Ergonomics,** 1 September-1October.

Christie CJ, Forbes MJ and Wolfe A (2005). Possible use of heart rate to predict oxygen consumption during moderate intensity lifting. **Fourth International Cyberspace Conference on Ergonomics,** 1 September-1October.

Scott PA and Christie CJ (2004). An indirect assessment of energy expenditure of manual labourers *in situ*. **South African Journal of Science,** 100 (11/12): 694-698.

Scott PA, Christie CJ and Renz, MC (2004). Two 'Micro' IDC Field Investigations requiring 'Macro" interventions. **Proceedings: Human Factors and Ergonomics Society 48th Annual Meeting**, 20 – 24 September, New Orleans, USA.

Scott PA and Christie CJ (2004). A Preliminary field assessment of the energy expenditure of forestry workers in South Africa. **Proceedings: Human Factors and Ergonomics Society 48th Annual Meeting**, 20 – 24 September, New Orleans, USA.

Christie CJ (2002). Relationship between energy intake and energy expenditure during manual work in South Africa. **Third International Cyberspace Conference on Ergonomics,** 15 September – 15 October.

Christie CJ (2001). Consideration of the effect of nutritional status and disease patterns on the work output amongst Black South African workers involved in manual materials handling (MMH) tasks. **Ergonomics SA,** 13 (1): 23.32.