ENERGY EXPENDITURE AND WORKING EFFICIENCY OF SOUTH AFRICAN SUGARCANE CUTTERS

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DECLARATION

I, Marié de Lanoy Müller (née Smit), hereby declare that this dissertation is my own work, based on my personal research, and that I have acknowledged all material and sources used in the preparation thereof. I also declare that this dissertation has not been previously submitted, in its entirety or in part, at any university or in fulfillment of the requirements for a degree.

Signature

September 2005
Date

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LIST OF ABBREVIATIONS

The following is a list of abbreviations in the order they appear in this dissertation:

$kcal \cdot L\ O_2^{-1}$	caloric equivalent of oxygen
$kJ \cdot ton^{-1}$ cane	energy required in kilojoules to cut one ton of cane
kg cane $\cdot\ L\ O_2^{-1}$	amount of cane cut per litre of oxygen consumed
EMG	electromyography
kg cane $\cdot\ min^{-1}$	rate of productivity / kilogram cane per minute
RV	recoverable value
ATP	adenosine triphosphate
ADP	adenosine diphosphate
P_i	inorganic phosphate
CP	creatine phosphate
NAD^+	nicotinamide adenine dinucleotide (coenzyme)
NADH	nicotinamide adenine dinucleotide (coenzyme) in reduced form
acetyl CoA	acetyl coenzyme A
GDP	guanosine diphosphate
GTP	guanosine triphosphate
H^+	hydrogen ion
CO_2	carbon dioxide
FAD	flavin adenine dinucleotide (coenzyme)
$FADH_2$	flavin adenine dinucleotide (coenzyme) in reduced form
VO_2	oxygen consumption
RER	respiratory exchange ratio
RQ	respiratory quotient

VCO_2	carbon dioxide output
$L \cdot min^{-1}$	consumption per minute
$kcal \cdot min^{-1}$	kilocalories per minute / energy expenditure
$kcal \cdot min^{-1} \cdot kg^{-1}$	kilocalories per minute per kilogram body mass (relative energy expenditure)
$beats \cdot min^{-1}$	beats per minute (heart rate)
VO_2 max	maximal oxygen consumption
EL	endurance limit
$kJ \cdot min^{-1}$	kilojoules per minute / energy expenditure
VE	minute ventilation
bal N_2	balanced in nitrogen
kg cane $\cdot min^{-1}$	amount of cane harvested per minute / rate of productivity
$kJ \cdot kg^{-1}$ cane	energy required in kilojoules to cut one kilogram of cane
kg cane $\cdot L\ O_2^{-1}$	amount of cane cut per litre of oxygen consumed
ANCOVA	analysis of covariance
$ml \cdot kg^{-1} \cdot min^{-1}$	relative consumption

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ABSTRACT

This study sought to examine the physiological demands as well as selected measures for working efficiency in the manual harvesting of burnt and unburnt sugarcane, along with the effects of using a short handle curved blade knife and a long handle curved blade knife on energy expenditure and working efficiency. The effect of subject observation and unobtrusive observation interaction on the cane cutters' performance was also investigated.

A total of fifteen professional male cane cutters participated with written informed consent. Only cane cutters with five or more years' working experience were randomly selected to participate in this study.

Research in the field of sugarcane cutters in South Africa has been restricted to estimates of energy expenditure only. Evidence shows that heart rate and oxygen uptake during an actual activity differ from measurements in the laboratory at equal workloads. With this in mind, oxygen uptake and energy expenditure were measured directly by means of indirect calorimetry, during the performance of work. The metabolic measures were measured by means of the portable MetaMax I Ergospirometry System. Heart rate was measured telemetrically by means of the Polar Accurex Plus™ wrist receiver and its Polar Pacer transmitter. After data collection, heart rate data were downloaded via a Polar Interface Plus with Training Advisor Software onto a computer, and analysed. For the effects of unobtrusive observation interaction on the cane cutters' performance average heart rate during cane harvesting was related to the oxygen consumption, measured by the MetaMax I, using the corresponding heart rate. From this, the energy expenditure was estimated.

Burnt and unburnt sugarcane

Findings indicated significant differences ($p<0.05$) between harvesting burnt and unburnt sugarcane with regard to the following physiological parameters: absolute oxygen consumption ($p<0.01$) and relative oxygen consumption as well as absolute and relative energy expenditure. The mean and peak heart rates during work were not significant ($p>0.05$), indicative of similar levels of exertion for harvesting burnt and unburnt cane. Ratings of perceived exertion (RPE) did not differ significantly ($p>0.05$), suggesting that the subjective perception of exertion of harvesting burnt and unburnt cane was similar.

The selected measures for working efficiency were as follow: Rate of productivity harvesting burnt cane was significantly higher ($p<0.01$) than that for unburnt cane. Significantly less energy was required to cut one kilogram of burnt cane than that for unburnt cane. The amount of burnt cane cut per litre of oxygen consumed was also significantly higher ($p<0.01$) than in harvesting unburnt cane. The number of cane cutting strokes per minute to cut the stalks of burnt cane was significantly higher ($p<0.05$) than that for unburnt cane while the number of stalks cut per stroke for burnt cane was significantly lower ($p<0.05$) than that for unburnt cane. Despite the last two measures of working efficiency being in favour of unburnt cane, the results in general lend credence to the fact that harvesting burnt cane was more economical with regard to physiological parameters and selected measures of the working efficiency of the cane cutters.

Manual sugarcane harvesting implements

No significant differences ($p>0.05$) were demonstrated for the comparison between the short handle curved blade knife and the long handle curved blade knife in burnt cane in any of the measured variables for the physiological parameters, except for the cane cutters' ratings of perceived exertion (RPE). This suggests that the cane cutters' subjective perception of strain experienced harvesting burnt cane with the short handle curved blade knife was more strenuous than using the long handle curved blade knife.

Though the selected measures for working efficiency for the comparison of the short handle curved blade knife with the long handle curved blade knife did not significantly differ ($p>0.05$), the following measures were all in favour of using the long handle curved blade knife: Rate of productivity, energy required to cut one kilogram of burnt cane, similar amounts of cane were cut per litre of oxygen consumed, number of cane cutting strokes per minute to cut the stalks, and number of stalks cut per stroke.

Subject observation and unobtrusive observation interaction

The effect of observation and unobtrusive observation interaction on the cane cutters' physiological system during cane harvesting revealed significant differences ($p<0.05$) in corrected measures for relative oxygen consumption and relative energy expenditure. Mean heart rate responses were also significantly higher during subject observation interaction. All remaining physiological parameters were statistically insignificant ($p>0.05$).

The rate of productivity of the cane cutters recorded during observation interaction was significantly higher ($p<0.05$). Other selected measures for the working efficiency, though not statistically different ($p>0.05$) were also higher during subject observation compared with the experimental condition of unobtrusive observation interaction. These results show that subject observation interaction leads to increases in the performance of the cane cutter.

CHAPTER ONE

INTRODUCTION

PROLOGUE

In spite of the trend towards mechanisation, manual labour is still common in many industries in various parts of the world. Sugarcane harvesting in South Africa is no exception. Sugarcane is grown in 15 cane-producing areas, extending from Northern Pondoland in the Eastern Cape through the coastal belt and midlands of KwaZulu-Natal to the Mpumalanga Lowveld. Sugarcane in South Africa covers an area of 412 000 hectares, 68% of the cane being grown within 30 km of the coast and 17% in the high rainfall area of the KwaZulu-Natal Midlands. The rest is grown in the northern irrigated areas, which comprise Pongola and Mpumalanga Lowveld. The South African sugar production region benefits from ideal growing conditions, with its hot and humid climate, average temperatures ranging between 18°C and 20°C, and a high rainfall of 1500 mm to 2000 mm per year. Along with efficient milling operations, it is one of the lowest cost producing areas in the world (South African Sugar Association, 2004). Research has been done on occupational health problems found in manual labour tasks as well as in the sugarcane industry (Phoolchund, 1991). Energy expenditure of cane cutters in manual harvesting has extensively been researched (Davies, 1973; Morrison & Blake, 1974; Spurr et al., 1975; Collins et al., 1976; Lambert et al., 1994). However, little is known about the physiological demands and metabolic cost of harvesting cane in burnt and unburnt cane, and secondly, the effects of using different manual cane harvesting implements on the cane cutter's performance. Any progress towards improving the cane cutter's productivity in manual cane harvesting will ultimately depend upon a sound knowledge and understanding of the factors which may contribute to higher work output and increased efficiency of work.

PHYSIOLOGICAL PARAMETERS

Manual sugarcane cutting has been classified as heavy physical labour (Davies, 1973; Morrison and Blake, 1974; Spurr et al., 1975; Lambert et al., 1994), which involves four definite steps: Aiming a slicing stroke at the stalk and cutting the liable stalk just above ground level, topping the cane tops, trashing the leaves, and lastly piling the trashed cane. Different occupations can be classified by rates of energy expenditure. Energy expenditure is therefore defined as a work physiology parameter, which is either estimated by means of an individual's heart rate during work or can be measured by means of oxygen consumption measures using specialised metabolic analysers during work. In most cases, a respiratory quotient of 0.82 can be assumed, and therefore one litre of oxygen has an energy equivalent of approximately 4.825 kilocalories or 20.2 kilojoules, which can be applied in energy transformations (McArdle et al., 1991). Deivanayagam and Ayoub (1979) stated that the amount of oxygen consumed by the worker bears a direct relationship to the level of exertion or the intensity of work stress.

Lambert et al. (1994) measured the energy expenditure of South African sugarcane cutters by extrapolating each worker's heart rate versus oxygen consumption. Baseline oxygen consumption and heart rate were measured prior to the testing procedure. Each subject underwent a graded exercise treadmill test, during which heart rate, oxygen consumption and carbon dioxide production were measured continuously by means of the Oxycon Sigma (Mijnhardt BV, The Netherlands). Calibration curves of the heart rate versus the oxygen consumption were determined for each subject at workloads eliciting heart rates ranging from 60 to 150 beats per minute. During the working day, the total oxygen consumption and energy expenditure were calculated from the heart rate values obtained. Spurr et al. (1975) measured oxygen consumption and ventilation of Colombian sugarcane cutters by means of the Kofranyi-Michaelis respirometer. Data collection was done during cane harvesting for a total of ten minutes in the morning and another ten minutes in the afternoon. Immediately following each measurement, the mixed expired air was analysed. Heart rate was determined with a Parks Telemetry System. Energy expenditure was calculated from the oxygen consumption (5.047 kcal · L O_2^{-1}). Collins et al. (1976) measured the energy cost of Sudanese cane cutters also using the Kofranyi-Michaelis portable respirometer. Immediately after data collection, the oxygen content of expired air samples was obtained by means of a portable Servomex oxygen analyser. A respiratory quotient of 0.85 was assumed, oxygen consumption was converted into energy expenditure using Weir's formula in which carbon dioxide concentration is ignored. Morrison and Blake (1974) measured oxygen consumption of Rhodesian (Zimbabwean) and Australian cane cutters during cane harvesting. Samples of expired air were collected over a 3-5 minute period by means of the Douglas bag method, which were later analysed in Beckman oxygen and carbon dioxide analysers or Haldane gas analysis apparatus.

WORKING EFFICIENCY

Posture and movements are often imposed by the task and in the workplace. The human body is involved in adopting a posture, carrying out a movement and applying a force. Poor posture and movement may result in local mechanical stress of the musculoskeletal system and also affect the energy expenditure of a worker (Dul and Weerdmeester, 1993). Efficiency of human movement is the energy required performing a particular task in relation to the actual work performed. It is not always possible to express the mechanical efficiency of men engaged in their job-related tasks, unless special equipment is used. Sun and Hill (1993) developed a force platform system for measuring external mechanical work performed by human subjects inside a whole-room indirect calorimeter. Energy expenditure associated with their physical activity could simultaneously be measured.

High correlations were obtained between mechanical work performed and energy expenditure. However, for the purposes of measuring the external mechanical work in sugarcane harvesting, the force platform system has little to offer.

The measurement of oxygen uptake concerns the amount of oxygen consumed during aerobic work that is directly responsible for the work performance. Of the energy produced, a large part is lost in the form of heat. Provided that work can be accurately measured, a useful arbitrary but practical index is provided by the quotient, where mechanical efficiency equals amount of work performed during the work period divided by total energy expended during the same period of work, multiplied by 100 percent (Gaesser and Brooks, 1975). The higher the value of this quotient, the higher the individual's mechanical efficiency at the task he is performing. Mechanical efficiency varies from 0% to 50-60% during different activities, but in most daily activities, the mechanical efficiency varies between 0% and 20%. It should also be kept in mind that the more complex and skill-demanding a physical activity is, the more oxygen consumption varies between different performers (Wyndham and Cooke, 1964; Kilbom, 1990). However, this index is not applicable when calculating the mechanical efficiency of sugarcane cutters whilst cutting, since it is impossible to calculate the work done in harvesting sugarcane and therefore, an adaptive method of expressing work, should be used.

A more suitable term to define efficiency would be "working efficiency". The subject's work economy should rather be expressed as a ratio between the energy expended against the workload performed. By incorporating these ratios, alternative ways of harvesting burnt or unburnt sugarcane and performing the same task with different sugarcane cutting implements can be compared, as well as the demands of work placed on the physiological system.

Lambert et al. (1994) estimated working efficiency from:

1. the energy expenditure per ton of cane cut (kJ · ton^{-1} cane);
2. the amount of cane cut per litre of oxygen consumed (kg cane · L O_2^{-1}).

Morrison and Blake (1974) compared the mechanical efficiency of Australian and Rhodesian (Zimbabwean) sugarcane cutters, by recording:

1. the number of stalks cut;
2. the number of strokes made by the sugarcane cutters;
3. oxygen consumption per minute and the work output.

Spurr et al. (1975) expressed efficiency in terms of:

1. kilocalories per one kilogram of sugarcane cut;
2. estimating an eight-hour daily caloric expenditure.

Immink et al. (1987) studied the productivity of Guatemalan cane cutters using:

1. tonnage of sugarcane cut per day;
2. number of days worked per fortnight;
3. gross earnings per fortnight.

HAND TOOLS IN MANUAL LABOUR TASKS

Scientific knowledge has the potential to improve the performance and thus the productivity of cane cutters in harvesting sugarcane. Improved productivity of sugarcane cutters may result in reduced labour costs and increased earnings for individual cutters, thereby improving worker satisfaction and workforce stability.

In recent years, hand tools and their use have been given increasing attention from industry, manufacturers and researchers. There is an increased competition between hand tool manufacturers regarding the quality of their products and their ergonomic design. Ergonomically designed hand tools have become commercially interesting and this can be interpreted as the start of a long development process towards ergonomically improved hand tools. The philosophy of customer satisfaction is likely to play an ever-more important role in improving the ergonomic standard of hand tools (Eklund and Freivalds, 1993).

Kadefors et al. (1993) undertook an analysis of variables to be considered in the ergonomic evaluation of hand tools. The evaluation of hand tools is extremely complex, where functional properties, quality and reliability aspects are relevant as well as the user's subjective expectations and apprehensions. The biomechanical and physiological stresses involved in carrying out typical working tasks with the tool, were taken into account. The following aspects in particular have been given consideration:

1. Characteristics of the tool through inspection of the tool, observation of a sequence of work and measurement of the tool.
2. Mechanical output of the tool, which usually consists of forces and torques in six degrees of freedom: three translations and three rotations. The external forces are often essential in order to characterise the work demands. In practice, it is often sufficient to measure in one or two degrees of freedom out of the six.
3. Tool mass and centre of gravity are essential evaluation measures during tool operation and in handling. The centre of gravity of the tool should be as close to the centre of the hand as possible.
4. Tool dimension where the characteristics of the handle are taken into account with respect to the dimensions corresponding to the type of grip applied.

5. Grip characteristics include whether the tool can be operated by left-handed persons, whether different grips can be applied and, for tools requiring high force levels, whether the tool design allows for operation with both hands.
6. Tool surface characteristics include sharp edges or corners in the handles since such features may contribute to high local pressures. A very high friction between hand surface and tool where there is a demand for changing the grip frequently is not ideal, however, and the tool surface should not be too slippery either.
7. Effects on the operator whereby the design of the tool influences how the operator will apply the tool and which postures will be attained.
8. Wrist flexion/deviation angles where the load on the wrist is examined, particularly during extreme positions and when in combination with exertion of force. A goniometer can be employed which measures the angular movements between hand and forearm, in wrist flexion and extension as well as in deviation.
9. Muscular load and fatigue could be measured from the point of view of the muscular involvement and occurrence of muscular fatigue. Either physiological and/or psychophysiological methods could be employed. These include a physiological assessment of the muscular involvement based on the measurement of myoelectric (EMG) signals from the muscles, which are suspected as being particularly strained in the operation of the tools. Even though this method is highly specific, it focuses only on certain muscles and not necessarily on all muscles of relevance. This method is therefore supplemented by using psychophysical methods, based on a body map principle. Areas of discomfort and pain are identified by the subject immediately after completing the task.
10. Type of grip employed since the properties of different grips vary widely with respect to force and precision.

11. Local pressure in the hand could be due to combinations of high contact force and small contact area in the interface between tool and hand. Assessment takes place by means of a subjective rating method.

Freivalds and Kim (1990) quantified the relationship between shovelling performance in terms of shovel weight and blade size. Five male subjects utilised three different commercial shovels and a specially designed lightweight shovel to move sand. Before the test measurement, a 3-minute warm up was introduced so that the subjects could reach a steady rate. The energy expenditure, heart rate, ratings of perceived exertion and shovelling performance were measured over a 2-minute period. Energy expenditure was calculated by a respiratory gas analysis of the expired air and heart rate was taken as an indicator of workload stress during shovelling by means of a Respironics heart rate meter. The Borg scale was implemented to record the subjective ratings of exertion. Shovelling performance was calculated from the amount of sand placed in a barrel per unit time ($kg \cdot min^{-1}$). Energy expenditure was normalised to body mass and to shovelling performance in order to achieve a normalised energy cost. This way the effects of both body size and individual variation in performance of the task could be minimised. The results of this study were that different types of shovels as defined by the shovel weight and blade size had a significant effect on the energy expenditure, energy cost of shovelling, heart rate and Borg's RPE scale. The lighter shovels indicated the lowest expenditure of energy and were rated the least fatiguing according to the Borg scale. Shovels cannot be classified by the blade size or weight alone, and thus the ratio of the two quantities is more practical. Too large a blade or too heavy a shovel will increase energy expenditure and reduce efficiency, while too small a blade or too light a shovel would lead to a reduction in energy expenditure but also a reduced performance.

Only a few studies on the effects of different cane harvesting implements on the cane cutter's performance are known. The design of a cane knife is one of the factors having an effect on the productivity of cane cutters (Brooks, 1983). Morrison and Blake (1974) and Meemeduma and Dhamrawardene (1994) confirmed the above. Their observation was that a curved blade cuts a larger volume than the straight blade, resulting in improved productivity and a more economical cut. Moore (1977) distinguished between the different uses and advantages of the short handle and long handle cane knives in manual cane harvesting.

STATEMENT OF THE PROBLEM

In the literature, it appears that scant attention has been given to the differences in energy expenditure and working efficiency of sugarcane cutters in harvesting burnt and unburnt sugarcane along with the differences using different cane harvesting implements.

Many investigations as well as research done on South African cane cutters' energy expenditure have provided only estimates of oxygen consumption and therefore energy expenditure, which raises the question about the reliability and validity of these measures. This was the impetus for the present study.

The primary focus of this study is to investigate the differences in the energy expenditure and working efficiency of cane cutters with regard to harvesting burnt and unburnt sugarcane *in situ*. It is anticipated that harvesting of burnt versus unburnt sugarcane will place different demands on the physiological system of the cane cutter.

The secondary study is to determine the effects of using different designs in sugarcane knives on the cane cutter's physiological system and working efficiency. The contention is that the design, whether it is a short or a long handle curved blade knife, results in different demands placed on the physical components of the cane cutter. Additionally the design of the knives could affect the cane cutting technique and therefore the working efficiency.

A further aim would be to ascertain whether selected physiological parameters and/or working efficiency would differ on the days of testing from a normal working day. The contention here is that supervision or observation of labourers engaged in moderately hard physical work, will lead to an increase in performance levels or the so called Hawthorne effect (Wyndham and Cooke, 1964). The collection of data through unobtrusive observation will therefore be considered to demonstrate the presence of the Hawthorne effect or at least to determine the magnitude of such an effect.

The present study will attempt to measure the oxygen consumption directly by means of indirect calorimetry, so that the appropriate energy equivalent can be applied to each litre of oxygen consumed to calculate the energy expenditure. This method gives comparable results to whole-body calorimetry, which is highly accurate, though impractical in the field situation. With this in mind, a portable metabolic analyser, the MetaMax I Ergospirometry System, will be employed for the above-mentioned experimental conditions, putting this study in a class of its own.

RESEARCH HYPOTHESIS

The general hypothesis of this project is that manual cane harvesting in burnt cane will result in different physical demands being placed on the cane cutter compared with manual harvesting in unburnt cane. This is due to the increased exertional demands in harvesting unburnt cane. Consequences arising from harvesting burnt cane include distinct outcomes based on the oxygen consumption, energy expenditure, ratings of perceived exertion measures and working efficiency.

TEST HYPOTHESES

Hypothesis 1

No difference exists between harvesting burnt and unburnt sugarcane with regard to selected physiological parameters. Stated statistically the null-hypothesis is:

H_0: μ b $_{(p)}$ = μ unb $_{(p)}$

Where:
b = burnt sugarcane;
unb = unburnt sugarcane;
(p) = physiological measures including oxygen consumption, energy expenditure and heart rate.

Hypothesis 2

No difference exists between burnt and unburnt sugarcane with regard to selected measures for working efficiency. Stated statistically the null-hypothesis is:

H_0: μ b $_{(we)}$ = μ unb $_{(we)}$

Where:
b = burnt sugarcane;
unb = unburnt sugarcane;
(we) = working efficiency including rate of productivity, energy expenditure per kilogram of cane cut, amount of cane cut per litre of oxygen consumed, number of cane cutting strokes per minute and the number of stalks cut per stroke.

Hypothesis 3

No difference exists between the short handle curved blade cane knife and the long handle curved blade cane knife with regard to selected physiological parameters. Stated statistically the null-hypothesis is:

$H_0: \mu s_{(p)} = \mu l_{(p)}$

Where:
s = short handle curved blade cane knife;
l = long handle curved blade cane knife;
(p) = physiological measures including oxygen consumption, energy expenditure and heart rate.

Hypothesis 4

No difference exists between the short handle curved blade cane knife and the long handle curved blade cane knife with regard to selected measures for working efficiency. Stated statistically the null-hypothesis is:

$H_0: \mu s_{(we)} = \mu l_{(we)}$

Where:
s = short handle curved blade cane knife;
l = long handle curved blade cane knife;
(we) = working efficiency including rate of productivity, energy expenditure per kilogram of sugarcane cut, amount of cane cut per litre of oxygen consumed, number of cane cutting strokes per minute and the number of stalks cut per stroke.

Hypothesis 5

No difference exists between subject observation and unobtrusive observation interaction with regard to selected physiological parameters. Stated statistically the null-hypothesis is:

H_0: μ ob $_{(p)}$ = μ unob $_{(p)}$

Where:
ob = obtrusive observation;
unob = unobtrusive observation;
(p) = physiological measures including estimated oxygen consumption, estimated energy expenditure and heart rate.

Hypothesis 6

No difference exists between subject observation and unobtrusive observation interaction with regard to selected measures for working efficiency. Stated statistically the null-hypothesis is:

H_0: μ ob $_{(we)}$ = μ unob $_{(we)}$

Where:
ob = obtrusive observation;
unob = unobtrusive observation;
(we) = working efficiency including rate of productivity, estimated energy expenditure per kilogram of sugarcane cut, amount of cane cut per estimated litre of oxygen consumed.

DELIMITATIONS

A consideration in this study was the exclusive recruitment of professional Zulu male cane cutters for data collection pertinent to the demands of at least five years' experience in manual cane harvesting in both burnt and unburnt cane. Secondly, all cane cutters wore the same working clothes throughout the different testing procedures to minimise the effect of restrictive clothing and different measures of body mass and to ensure optimal safety while harvesting cane. As far as possible, testing procedures were done on the same variety and condition of cane to reduce external factors having an influence on the performance of the sugarcane cutters. In addition, all testing procedures took place between 05h00 and 09h00 to minimise the disadvantageous effects of the climatic conditions on the cane cutters' performance.

LIMITATIONS

Limitations of this study may be seen as environmental influences having a possible effect on oxygen consumption and therefore energy expenditure as well as productivity because it is impossible to keep conditions constant. A second limitation concerns how accustomed the cane cutter was to a specific cane knife and his preference for a specific cane knife design. Level of motivation of cane cutters may also have an effect on their productivity. Selecting subjects (n=15) limits the generalization of the results to cane cutters as a whole.

CHAPTER TWO

REVIEW OF LITERATURE

The measurements to be reported were obtained from sugarcane cutters in the Zululand region, in Northern KwaZulu-Natal, where sugarcane is harvested during eight months of the year, usually from the end of April to mid-December. During the harvesting season, there are no set work hours. Work commenced at about 05h00 and continued, with very brief rest intervals, until noon. The cane was harvested in rows of 20 metres, piled in windrows and accurately recorded, since the cane cutters in this study were remunerated by the number of rows harvested. In general, cane cutters are paid a bonus for each subsequent metre of cane cut. Wages for unburnt cane are slightly higher than for burnt cane. Historically the measure of quality for cane payment purposes in the South African sugar industry has been the sucrose content of the cane, but as from 1 April 2000, being the start of the new sugar season, payment for cane is now on the basis of its recoverable value (RV) content. The RV is a measure of the value of the sugar and molasses that can be recovered from the cane delivered by the individual grower. The RV basis of cane payment provides the necessary incentives for improving still further the quality of the cane delivered to the mill and this together with local area agreements between growers and millers regarding issues that impact on cane quality lead to improved efficiencies all round. The RV payment system recognises that not all the sucrose delivered to the mill can be recovered as sugar, because the amount of sugar that can be extracted during the milling process depends not only on the amount of sucrose in the cane, but also the amount of non-sucrose and fibre present (South African Sugarcane Research Institute, 2004a). The RV price for the season of 2000/2001 was based on a crop of 23 876 162 tons of cane crushed, which converted to 2 729 219 tons of sugar at a cane-to-sugar ratio of 8.75. The average RV content was 11.81% (Naidu, 2001).

HISTORY OF THE SUGARCANE INDUSTRY

It is thought that cane sugar was first used by mankind in Polynesia from where it spread to India. In 510 BC, the Emperor Darius invaded India where he found "the reed which gives honey without bees". When the Arabians invaded Persia in 642 AD, they found sugarcane being grown and learned the skill for making sugar. The sugar production was expanding in other continents such as North Africa and Spain. The western Europeans discovered sugar only in the 11th century AD as a result of the Crusades. The first sugar was recorded in England in 1099 and the subsequent centuries saw a major expansion of western European trade with the East, including the importation of sugar. In 1319 AD, sugar was very much a luxury. In the 15th century AD, European sugar was refined in Venice and in the same period of time, Columbus sailed to the Americas in 1493 and planted the sugarcane plants in the Caribbean. The industry was quickly established due to the advantageous climate for growing sugarcane. By 1750 there were 120 sugar refineries operating in Britain with an output of 30 000 tons per annum. At this stage, sugar was still a luxury, also known as "white gold", vast profits were made, and sugar was taxed highly. Only in 1874 was the tax abolished and sugar prices brought within the means of the ordinary citizen (Sugar Knowledge International, 1998).

In KwaZulu-Natal, Zulu men grew a wild type of sugarcane, called "imfi". The pioneer in the South African sugarcane industry was Edmund Morewood, who in 1847 imported commercial sugarcane plants from Mauritius and Réunion. The farmers had continuous problems in acquiring a reliable and adequate labour force. The local Zulu men preferred to herd cattle and were not anxious to work on the cane farms. Between 1860 and 1866, a large number of Indian workers were therefore imported and employed on the sugarcane farms. Regulations in Zululand stipulated that only the governor could grant land, as it was contrary to traditional Zulu belief to alienate land. By 1894, apart from the local Zulu inhabitants, there were 994 white people living in Zululand, mainly as woodcutters, traders, missionaries, gold prospectors and government officials, but no farmers on the coastal plains of KwaZulu-Natal. In November 1905, the first allotment of land was assigned to 50 white sugarcane farmers on small coastal farms, each approximately 500 acres in extent. The first pioneer north of the Umhlatuzi river was Mr CB Addison. Initially wagons with cane were drawn by teams of oxen, horses and donkeys to the mills. Later the cane arrived at the mill loaded either on railway trucks or in small sugarcane trucks called "gollovaans". From thereon the sugarcane industry grew rapidly in South Africa (Kennis, 1980; Wêreldspektrum, 1982; The Harrison Collection, 1995).

Today sugar is produced in 121 countries and global production now exceeds 120 million tons per annum. Approximately 76% of sugar is produced from sugarcane, largely grown in tropical regions and the remaining 30% is produced from sugar beet, a root crop resembling a large parsnip grown mostly in temperate zones (Sugar Knowledge International, 1998). Brazil, India and the European Union are the top three producers and together account for 71% of the annual production. South Africa's sugarcane industry is ranked eighth in the world in terms of production (Illovo, 2004).

MANUAL HARVESTING OF SUGARCANE

The main sugarcane regions are KwaZulu-Natal and the North Western Province. In KwaZulu-Natal, most of the sugarcane is harvested manually due to the steep topography. Other constraints on the implementation of mechanised harvesting systems include economics, farm size, field conditions, social and political considerations and environmental issues (De Beer and Purchase, 1997). Almost 20 million tons of cane are harvested in South Africa each year, using mainly traditional labour intensive methods (Brooks, 1983). The average production of sugar in South Africa is about 2.2 million tons per annum, the 2000/2001 cane cutting season having had a record production of in excess of 2.7 million tons of sugar (Wixley, 2001).

The following figures reflect the Zululand region for the 2000/2001 cane harvesting season. The Zululand region had the highest number of growers in KwaZulu-Natal and the fourth-highest percentage of the total population of growers in the region. The analysis of the productivity was based on the different harvesting methods, namely cutter (cut only) category and the cutter/stacker category. For the cutter (cut only) the productivity was 6 tons per day and 1305 tons per season. The productivity of the cutter/stacker category amounted to 6.09 tons per day and 1214 tons per season. The harvesting method in the practice of burning and trashing sugarcane, constituted 79.85% and 20.15%, respectively. These figures were based on a sample only and did not include the total population of cane cutters in Zululand as such (South African Cane Grower's Association, 2002).

The pile of harvested sugarcane is either weighed and accurate records are kept or the productivity is measured as the number of sugarcane rows cut. Respectively, the cutters are remunerated by the metric ton of sugarcane cut or the number of rows of sugarcane cut. Sugarcane is either burnt before being harvested or harvested as it stands, called trashing. In general, manual sugarcane harvesting of burnt sugarcane involves the following three steps: the sugarcane cutter bends his back, grasps a number of stalks in one hand whilst cutting the liable stalks with the other hand, the cut stalks are topped, and thrown onto a pile. With unburnt sugarcane the stalks are trashed, in other words, the stalk is stripped of its leaves, topped and then piled.

Base cutting involves cutting the mature sugarcane cleanly at or just below ground level, so that a portion is left underground, allowing the stump to send up strong vigorous shoots, known as ratooning. The old root system supports the regenerating crop until new roots can take over. High base cutting leads to wasted tonnage left in the field, as the highest sucrose content is in the lower end of the stalk, and secondly, ratoon growth is retarded because the buds develop above ground level and are unable to develop their own system of shoot roots. Effective sprouting of the ratoon is therefore delayed and causes a direct loss in sucrose (South African Sugarcane Research Institute, 2004c). Topping involves cutting the top of the stalk in the air by slicing the top off just below the growing point or between the sixth node, distinctive areas where the leaves are attached, and the meristem, which is the growing point. Sugarcane topped too high will show the internal leaf pattern, which is above the meristem and which contains no sucrose, whilst topping it too low wastes millable cane and recoverable sugar (South African Sugarcane Research Institute, 2004a). Unburnt sugarcane is trashed, whereby 80% of the leaves, or trash as it is called, are removed by running the blade of the knife in an up and down stroke along the shaft of the stalk. This can either be done while the sugarcane is standing or in the air after topping, but never executed as a separate operation. Lastly, the harvested sugarcane is neatly stacked in small bundles to ensure proper loading (Morrison and Blake, 1974; Moore, 1977; Sugarcane Agronomy Research Department, 1992).

Barnes (1964) is of the opinion that a well-managed manual operation will give the best quality and least in-field losses. Manual harvesting could be less easy to control than mechanical harvesting, as the cane cutters develop a rate of cutting suited to their own convenience and the field conditions in which they work. Much also depends on the method of payment, for example when teams of cane cutters work together and share the proceeds the field control is simplified. If cutters are paid individually on a basis of weight of cane cut or rows of cane cut, there is an incentive to cut more cane than necessary.

BURNT AND UNBURNT SUGARCANE

The state of the sugarcane, whether it is burnt or unburnt, has various implications for harvesting and milling operations. In South Africa, most cane is burnt at harvest, but since the introduction of the recoverable value (RV) quality payment formula, more growers have started cutting green or unburnt cane.

In many other cane growing countries, there has been a shift to green cane harvesting (South African Sugarcane Research Institute, 2004b). Burnt sugarcane has the advantage that the leaves have been removed and therefore the cane does not require trashing. Loading and transport are improved, which in turn leads to a higher productivity. Topping is more efficient when the cane is burnt, as the cutter can see the exact level at which the cane has to be topped. Barnes (1964) stated that from the moment the cane is cut, it starts to deteriorate and though the perceptible effect on the milling process and recovery is negligible during the first 48 hours, the cane quality declines rapidly after that, burnt cane being affected to a much greater extent than cane cut unburnt, as burning leads to an increase in microorganisms responsible for the formation of dextran. This could be explained by the fact that burning causes damage to the cane stalk which results in quicker deterioration. The wax coating on the stalk melts away and intense fires can affect the cane tissue by killing localised areas within the stalk. Stalk surface temperatures of 400°C for three seconds and 98°C, one millimetre below the stalk surface can be expected. Splitting of the rind may occur which allows bacteria and microorganisms to invade the stalk, leading to rapid deterioration. An issue of increasing importance is the pollution caused by burning cane and, with the increase in environmental awareness, burning practices in most production areas will eventually have to change (De Beer and Purchase, 1997; Zarpelon, 1997).

The main agronomic advantages of harvesting unburnt cane include the formation of a trash blanket, which ensures preservation of soil moisture and suppresses weed growth and controls pests. The trash blanket also improves the condition and nutrient value of the soil due to the organic matter and, under wet conditions, field damage is reduced. The farmer does not have to pay to burn the sugarcane and the deterioration in unburnt sugarcane is much slower than in burnt sugarcane, which provides an extra income to the farmer as well as the miller where sugarcane systems allow it. Harvesting can proceed earlier because there is no delay for sugarcane to dry before burning and during rainy weather, harvesting unburnt cane may be the only way to deliver cane. Harvesting unburnt cane can protect the environment and the public from the nuisance of smoke pollution. Unburnt sugarcane harvesting also has an effect on the harvesting and factory operation. The advantages include less lodging of the cane, which ensures efficient harvesting, and it may be able to haul out more easily under wet conditions with a trash blanket. Dextran levels of unburnt sugarcane are greatly reduced, with easier processing of older sugarcane, while a higher total sucrose concentration is present. The sucrose concentration is dependent on the cleanliness of the cane, the cut-to-crush delays and factors such as the level of the trash and leaf in cane. Wax from the outside of the stalk is retained and therefore ensures an increase in boiler fuel availability at the mill. The disadvantages of harvesting unburnt sugarcane include increased harvesting costs. Increased time is spent trashing the sugarcane during manual cane harvesting, thus reducing the harvesting productivity due to a slower rate of work involved in trashing, increased maintenance is required of machinery and the transport costs are increased due to increased leaf in unburnt sugarcane. In wet and cooler regions, the trash blanket keeps the ground cool which in extreme cases may even stop the cane from regrowing, prevents water evaporation, or both and can enhance frost damage. The accident risk is also increased for manual sugarcane cutters, as it is more difficult to see. More leaf in the sugarcane implies more molasses and higher sugar content loss, reduced milling capacity, and reduced income because of sugarcane losses. As more wax enters the factory, there is an increase in the handling of sugarcane, an increase of starch, and the green leaf could reduce the ability to burn as fuel in the boilers because of its high moisture levels (De Beer et al., 1994; De Beer and Purchase, 1997; Zarpelon, 1997).

MANUAL SUGARCANE HARVESTING IMPLEMENTS

Brooks (1983) defined the design of a cane knife as one of the factors having an effect on the productivity of cane cutters. Since cutting, topping and trashing are contrasting operations, ideally there should be specialised tools for each operation. The sugarcane cutter is expected to perform all three operations with a single tool, however, and it would be impractical to change tools for each operation, as they are performed in rapid succession. Existing sugarcane knives have been examined and the following criteria identified:

1. the weight of a knife should be concentrated at the lower end, thereby increasing the moment of inertia to cut through the fibrous base of the cane;
2. the mass of a knife should allow cutting, topping and trashing to be done efficiently without causing excessive strain on the cutter;
3. the blade of a knife should be long enough to reduce the strain on the cutter's back, but too long a blade will have a negative effect on topping and trashing;
4. the blade should be made of a hard and durable material;
5. the length of the handle as well as the total length of a cane knife should be suitable for the relevant anatomical structures, in most cases the hand and the stature of the sugarcane cutter.

Barnes (1964) makes the point that all equipment used for harvesting operations should be kept in first-class condition to enable the various stages of the work to be conducted efficiently. An apparently simple matter, often overlooked, is the sharpness of cane knives used for manual cutting. He ascribed the low daily cutting rates of the West Indian cane cutters, to the use of blunt cane knives and emphasised the importance of the sharpness of the cane knives to reduce the energy expenditure required for harvesting cane. According to Morrison and Blake (1974) and Meemeduma and Dhamrawardene (1994) the curved blade cuts a larger volume than the straight blade as the aforementioned has a larger cutting edge. In addition to the improved productivity using the curved blade, the sugarcane is cut more economically, i.e., the stalk is cut almost horizontally, thus leading to the elimination of the operation for stubble shaving and enabling even germination, compared to the short handle straight blade knife where the sugarcane is cut at an angle, thereby leaving the stalks behind which contain the highest concentration of sucrose. Voss (2000) reasons that the harvested sugarcane can easily be picked up using the curvature of the blade, thereby minimizing forward flexion of the trunk of the sugarcane cutter and reducing strain being placed on the musculoskeletal system.

Moore (1977) recommended a short handle, straight blade cane knife in harvesting unburnt sugarcane whereas burnt cane could be harvested either with a short or with a long handle but curved blade knife. Straight cane is ideally cut with a long handle curved blade knife and badly lodged cane or cane growing on steep slopes is either cut with a long or short handle curved blade knife. Lodged cane results in slower harvesting rates and higher extraneous matter compared to straight cane. The lighter weight of the short handle knife makes it a popular choice amongst cane cutters. On the other hand, the relatively shorter length produces a shorter lever arm, which results in a greater input from the cane cutter. The number of strokes will therefore increase to meet the same standard of production compared with the long handle knife. In addition, it is necessary for the sugarcane cutter to bend further to make a cut, clear the base and pick up the stalks, which depletes the cane cutter's energy level sooner than would be the case were the cutter using a long handle knife.

The long handle curved blade knife cuts almost similarly to the short handle curved blade knife. There is however an increase in the length of the stalk from the lowest part of the stalk which contains the highest concentration of sucrose, thereby increasing the weight, sugar content and the quality of the stalk. The length of the handle adds to the lever arm length, producing an increased momentum and force, whilst reducing the number of strokes at the same time. Furthermore, it does not require bending forward to such an extent as with the short handle knife in cutting, clearing the base and picking up the felled stalks. This reduction in forward bending leads to less fatigue and an increase in the productivity. Voss (1999) comments that it has taken a long time to convince cane cutters of the advantages of using the long or medium handle knife, as they were accustomed to the short handled straight blade cane knives. This contention appears to be supported by the findings of De Beer et al. (1994) who reported that the long handle cane knife has overcome the disadvantageous features of the short handle knife, which provides considerable benefits to the cutter, the farmer and the miller.

Extensive work on the examination of different cane harvesting knives has been done by the researchers Morrison and Blake (1974). They described the use of different cane harvesting knives by Rhodesian (Zimbabwean) cane cutters and compared the physical working capacity and performance with Australian cane cutters. The Rhodesian cane cutters used a relatively short, straight blade cane knife for the purposes of harvesting, trashing and topping unburnt cane. In the case of burnt cane, where the leaves have been removed and therefore did not require trashing, a longer knife, supplied with a wooden handle and a steel blade bent at an angle of approximately 120° to the shaft, allowing a cutting edge of 10 to 18 cm, was used. The superior performance of the Australian cane cutters was due to their technique as well as the better design in knife. The knife had its centre of gravity close to the blade because of a relatively short shaft that was not more than 38 cm long. The wooden handle was short and strong and a small weight was attached to the back of the blade, which acted as a counterbalance. The cutting edge was also sharpened frequently. In the same study it was noted that the less efficient individuals worked with their bodies bent forward at an acute angle, which necessitated greater elbow action and limited the participation of the shoulder, trunk and leg muscles in the cane cutting action. Less force and speed of movement were achieved by the smaller muscle mass used and the advantage of a long lever was lost by grasping the knife halfway down the shaft. A more upright stance allowed the shoulders, trunk and legs to contribute effectively to the action and limited the elbow movement, because the arm is held almost straight during the swing, ensuring sufficient length of the arm-knife lever. This contributed to a greater speed at the distal end of the knife. The Australian cane cutters showed a pronounced backswing of the knife, which increased the length of the arc through which the knife travelled and allowed more time to build up momentum. According to the South African Sugarcane Research Institute's (2004b) senior certificate course in sugarcane agriculture, a cane cutter with a traditional or normal short handle straight blade cane knife, has to get his wrist within 10 to 20 cm of the ground in order to get a clean, level base-cut. However, in burnt, erect cane, using the long handle curved blade Australian knife, the cane cutter hardly has to bend. Provided there is adequate coaching and training, it is conservatively estimated that a cane cutter's daily output is increased 10% to 15% through the introduction of the Australian long handle curved blade knife. De Beer et al. (1994) elaborate upon the implementation of this knife in Mauritius, for example, which has resulted in an increase of 3 tons per cane cutter per day. In Mpumalanga, Swaziland and the Natal midlands, the Australian knife is the standard knife, yet it is still under-used in the traditional sugar growing areas. Using the Australian knife, after base cutting, the untopped cane can be placed in such a way that topping is done on the ground, either with the same knife, or a straight blade knife. In unburnt cane, the Australian knife cannot be used, as it is too heavy and too long to trash the cane effectively. A short handle curved blade knife was developed locally and field tests showed that harvesting with this knife leads to an increase in productivity of more than 7%, compared with the traditional short handle straight blade knife. It is used to base-cut sugarcane cleanly at ground level, without the cutter having to bend much. Trashing unburnt cane is as easy as it is with the short handle straight blade knife. Topping is done with a different part of the blade so the knives wear very well. It has been observed that the implementation of the short handle knife in burnt cane, leads to an average task of 8 tons per day harvested, topped and windrowed. The correct use of the long handle Australian knife should increase the productivity to 9 or 10 tons and, with further training, there are many cane cutters who can achieve 15 tons per day. Topping cane in the air is slower than topping it in a windrow, but it is more accurate.

METABOLISM AND WORK

In Chapter Two when dealing with occupational work, the term "work", referring to job or manual labour has deliberately been used instead of the term "exercise". Vander et al. (1994) defined metabolism as a highly integrated process. It is the sum of all chemical reactions in the body. Metabolism includes the synthesis of specific molecules required for cell structure and function, called anabolism, and the breakdown of molecules and the provision of energy for cellular function, throughout the body, known as catabolism. The functioning of a cell depends on its ability to extract and use the chemical energy in organic molecules such as carbohydrates, fats, and proteins. Energy is derived from the hydrolysis of adenosine triphosphate (ATP), which is a major molecule that transfers energy from metabolism to cell functions during its breakdown to adenosine diphosphate (ADP) and inorganic phosphate (P_i). The energy derived from the hydrolysis of ATP amounts to 7.3 kcal $\cdot$ mol^{-1}, and is used for all energy-requiring processes in cells for the production of force and movement as in muscle contraction, active transport across membranes and molecular synthesis. All the body's fuels are processed into ATP to sustain metabolism.

In a cell, energy is continuously cycled through ATP molecules. A typical ATP molecule may exist for only a few seconds before it is broken down to ADP and P_i, with the released energy used to perform a cell function. The products of ATP hydrolysis, ADP and P_i, are equally rapidly converted back into ATP through the coupling to reactions that release energy during the catabolism of carbohydrates, fats and proteins. The total quantity of ATP in the body is sufficient to maintain the resting functions of the tissues for only about 90 seconds. Thus, ATP must be recycled continuously within each cell. About 40% of the energy released by the catabolism of fuel molecules is transferred to ATP, the remaining 60% appearing as heat.

The three distinct but integrated metabolic pathways, as outlined by Vander et al. (1994), are glycolysis, the Krebs cycle and oxidative phosphorylation. The cells transfer energy, released from the breakdown of fuel molecules to ATP. The energy released in glycolysis is rapid and does not require oxygen, and it can occur in either the presence or absence of oxygen, but relatively little ATP is resynthesized in this manner. Consequently, aerobic reactions, such as the Krebs cycle and oxidative phosphorylation, provide the important final stages for energy transfer, especially if vigorous work proceeds beyond several minutes.

It has been suggested previously by McArdle et al. (1991) that the proportion of energy production in exercising skeletal muscle depends largely on the mode (continuous or intermittent), intensity (light or heavy in relation to the maximal aerobic power of the engaged muscle groups), and duration (brief or prolonged) of the work being performed, along with intra-individual differences (state of physical training, skill, motivation, etc.). The energy for all-out work for up to two minutes' duration, comes mainly from the immediate and short-term energy systems. Both systems operate anaerobically because their transfer of chemical energy does not require molecular oxygen. At the initiation of movement, the stored phosphates ATP and creatine phosphate (CP) provide immediate and nonaerobic energy for muscle contraction. After the first few seconds of movement, an increasingly greater proportion of energy is generated by the glycolytic energy system. For work to continue, a greater demand is then placed on the aerobic metabolic pathways for purposes of ATP resynthesis. During work of increasing intensities, substrate utilization shifts from a greater reliance on fats during low intensity work to a preferential use of carbohydrates during high intensity work (Thompson et al., 1998). Therefore, all activities can be classified on an anaerobic-aerobic continuum. Some activities require the capacity of more than one energy system, whereas others rely predominantly on a single system of energy transfer. Brooks and Mercier's (1994) findings concur with the findings of the above authors, who found a "crossover" concept which represents a theoretical means of understanding the effects of exercise intensity and endurance training or skill on the balance of carbohydrate and lipid metabolism during sustained exercise. Endurance training results in biochemical adaptations within the muscular system, which in turn enhance lipid oxidation during mild to moderate intensity exercise along with decreases in the sympathetic nervous system responses to given submaximal exercise. Increases in exercise intensity, increase contraction-induced muscle glycogenolysis, the pattern of muscle fibre type recruitment is altered, and the sympathetic nervous system's activity is also increased. The pattern of substrate utilisation therefore depends on the interaction between exercise intensity-induced responses and endurance training-induced responses.

ENERGY METABOLISM DURING STEADY RATE WORK

In their writing on substrate energy metabolism, Vander et al. (1994) described the three metabolic pathways, namely glycolysis, the Krebs cycle and oxidative phosphorylation.

Glycolysis

Within skeletal muscle, glycolysis begins with either glycogenolysis, the breakdown of glycogen to glucose-1-phosphate, or the entry of glucose into the skeletal muscle fibre, where glucose is broken down to either pyruvate or lactate. The breakdown of glycogen in the skeletal muscle is regulated and limited by the enzyme phosphorylase, which in turn is greatly influenced by the hormone, epinephrine. Glycolysis consists of 10 enzymatic reactions that convert a six-carbon molecule of glucose into two three-carbon molecules of pyruvate and in the process produce a net gain of two molecules of ATP. These reactions, none of which utilizes oxygen, take place in the cytosol, in contrast to the mitochondrial location of the enzymes for the Krebs cycle and oxidative phosphorylation.

In the early steps of glycolysis, ATP molecules are used to form phosphorylated intermediates. A six-carbon intermediate is split into two three-carbon molecules, dehydroxyacetone phosphate and 3-phosphoglyceraldehyde. Thereafter, the dihydroxyacetone phosphate is converted into another molecule of 3-phosphoglyceraldehyde. Thus, at that point in the pathway, there are two molecules of 3-phosphoglyceraldehyde derived from one molecule of glucose. From this point on, two molecules of each intermediate are involved. The first formation of ATP in glycolysis occurs when a phosphate group is transferred from 1,3-diphosphoglycerate to ADP to form ATP. This mechanism of forming ATP is known as substrate level phosphorylation since the phosphate group is transferred from a substrate molecule to ADP. Since two intermediates exist, two molecules of ATP, one from each of them, are produced. This mechanism is quite different from that used during oxidative phosphorylation in which free inorganic phosphate is coupled to ADP to form ATP. A similar substrate level phosphorylation of ADP occurs, where again two molecules of ATP are formed. Thus, a total of four molecules of ATP for every molecule of glucose, entering the pathway, are produced. There is a net gain, however, of only two molecules of ATP during glycolysis because of the two molecules of ATP used in the earlier reactions. The end product of glycolysis, pyruvate, can proceed in one of two directions, depending on the availability of molecular oxygen, which is not utilized in any of the glycolytic reactions themselves. If oxygen is present, that is, if aerobic conditions exist, pyruvate enters the Krebs cycle and is broken down into carbon dioxide. In contrast, in the absence of oxygen (anaerobic conditions), pyruvate is converted to lactate by a single enzyme-mediated reaction. In this reaction, two hydrogen atoms are transferred to pyruvate to form lactate. These hydrogens were originally added to NAD^+ during glycolysis and so the coenzyme NAD^+ shuttles hydrogen between the two reactions during anaerobic glycolysis.

Under aerobic conditions, pyruvate is not converted to lactate but rather enters the Krebs cycle. The mechanism for regenerating NAD^+ from NADH + H^+ by forming lactate therefore no longer occurs. Instead, the NADH and H^+ are reconverted to NAD^+ by the transfer of its hydrogens to oxygen during oxidative phosphorylation. In most cells, the amount of ATP produced by glycolysis is much smaller than the amount formed by the other two ATP-generating pathways, the Krebs cycle and oxidative phosphorylation. Certain types of skeletal muscles contain considerable amounts of glycolytic enzymes but have a few mitochondria. During intense muscle activity, glycolysis provides most of the ATP in these cells and is associated with the production of large amounts of lactate. Most cells do not have sufficient concentrations of glycolytic enzymes or enough glucose to provide, by glycolysis alone, the high rates of ATP production necessary to meet their energy requirements and thus are unable to function under anaerobic conditions.

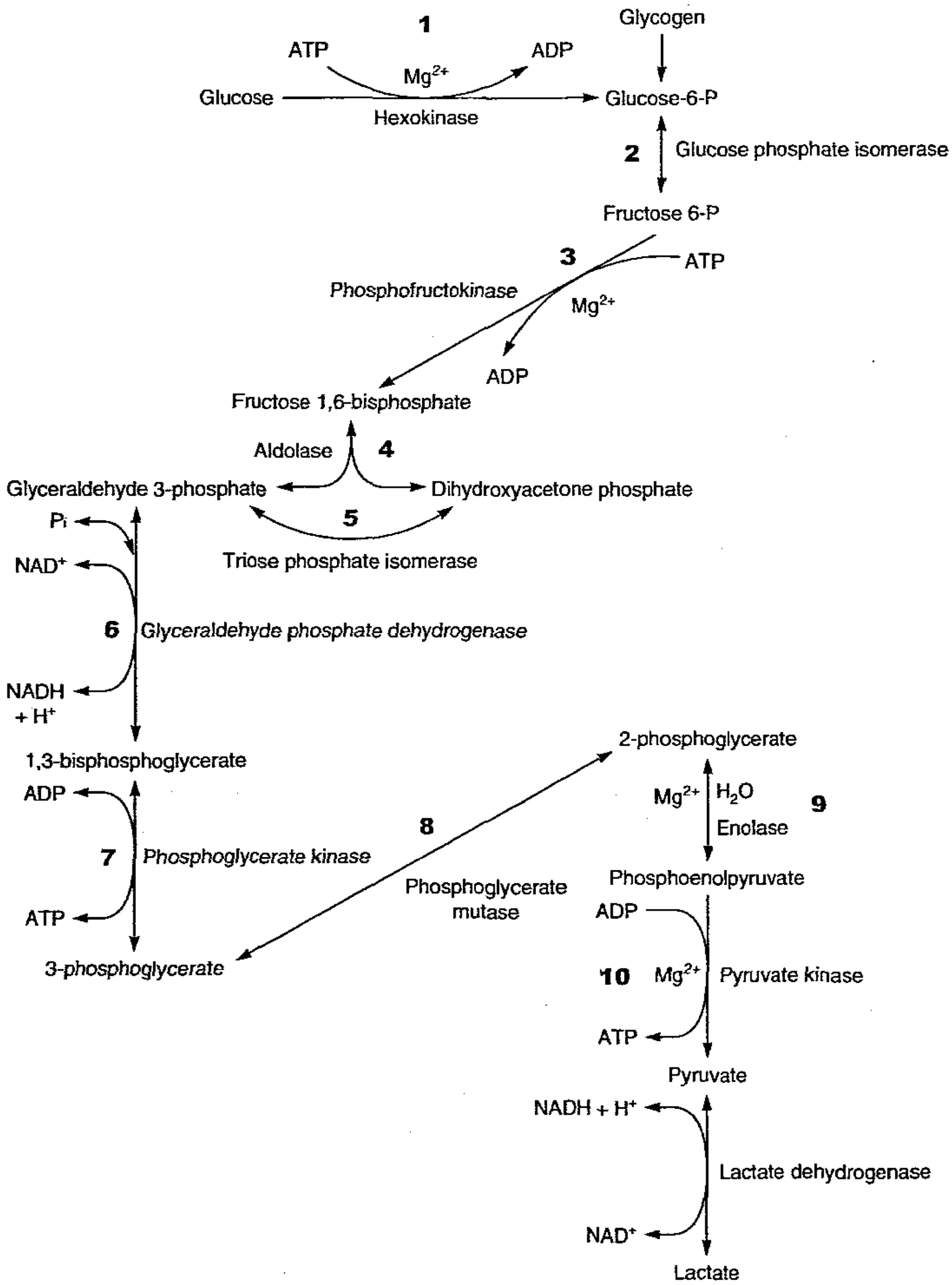

FIGURE 1. The reactions of glycolysis (Adapted from Houston, 1995)

Krebs cycle

The Krebs cycle is the second of the three pathways involved in fuel catabolism and ATP production. It utilizes molecular fragments formed during carbohydrate, protein, and fat breakdown, and it produces carbon dioxide, hydrogen atoms bound to coenzymes, and small amounts of ATP. The enzymes for this pathway are located in the mitochondria. The primary molecule entering at the beginning of the Krebs cycle is acetyl coenzyme A (acetyl CoA). Coenzyme A, a precursor of acetyl CoA, is derived from the B vitamin pantothenic acid, and its primary function is to transfer the two-carbon acetyl group from one molecule to another. These acetyl groups come either from pyruvate, which is the end product of glycolysis, or from the breakdown of fatty acids and some amino acids.

This reaction produces the first molecule of CO_2 in the pathways of fuel catabolism, and hydrogen atoms have been transferred to NAD^+. The Krebs cycle begins with the transfer of the acetyl group of acetyl CoA to the four-carbon molecule, oxaloacetate, to form the six-carbon molecule, citrate. At the third step in the cycle one molecule of CO_2 is produced, and again at the fourth step. Thus, two carbon atoms entered the cycle in the form of the acetyl group attached to CoA and now two carbons have left in the form of CO_2. The oxygen that appears in the CO_2 is not derived from molecular oxygen but from the carboxyl groups of Krebs-cycle intermediates.

In the remainder of the cycle, the four-carbon molecule formed in reaction 4 is modified through a series of reactions to produce the four-carbon molecule oxaloacetate, which becomes available to accept another acetyl group and repeat the cycle. In addition to producing carbon dioxide, intermediates in the Krebs cycle donate hydrogen atoms to the coenzymes NAD^+ and FAD. Two hydrogen atoms are transferred to NAD^+ in each of steps 3, 4, and 8, and to FAD in reaction 6. These hydrogens will be transferred from the coenzymes to oxygen in the next stage of fuel metabolism, oxidative phosphorylation. Since oxidative phosphorylation is necessary for regeneration of the hydrogen-free form of these coenzymes, the Krebs cycle can operate only under aerobic conditions. There is no pathway in the mitochondria that can remove the hydrogen from these coenzymes under anaerobic conditions. The Krebs cycle directly produces only one high-energy adenosine triphosphate. This occurs during reaction 5 in which inorganic phosphate is transferred to guanosine diphosphate (GDP) to form guanosine triphosphate (GTP). The hydrolysis of GTP can provide energy for some energy-requiring reactions. In addition, the energy in GTP can be transferred to ATP.

This reaction is reversible, and the energy in ATP can be used to form GTP from GDP when additional GTP is required for this molecule's roles in protein synthesis and signal transduction. The formation of GTP is the only mechanism by which ATP is directly formed in the Krebs cycle. The importance of the Krebs cycle lies in its ability to transfer the hydrogen atoms in the cycle to the coenzymes, which are used in the oxidative phosphorylation, to form large amounts of ATP.

Although the major function of the Krebs cycle is the provision of hydrogen atoms to the oxidative phosphorylation pathway, some of the intermediates in the cycle can be used to synthesize organic molecules, especially several types of amino acids, required by cells.

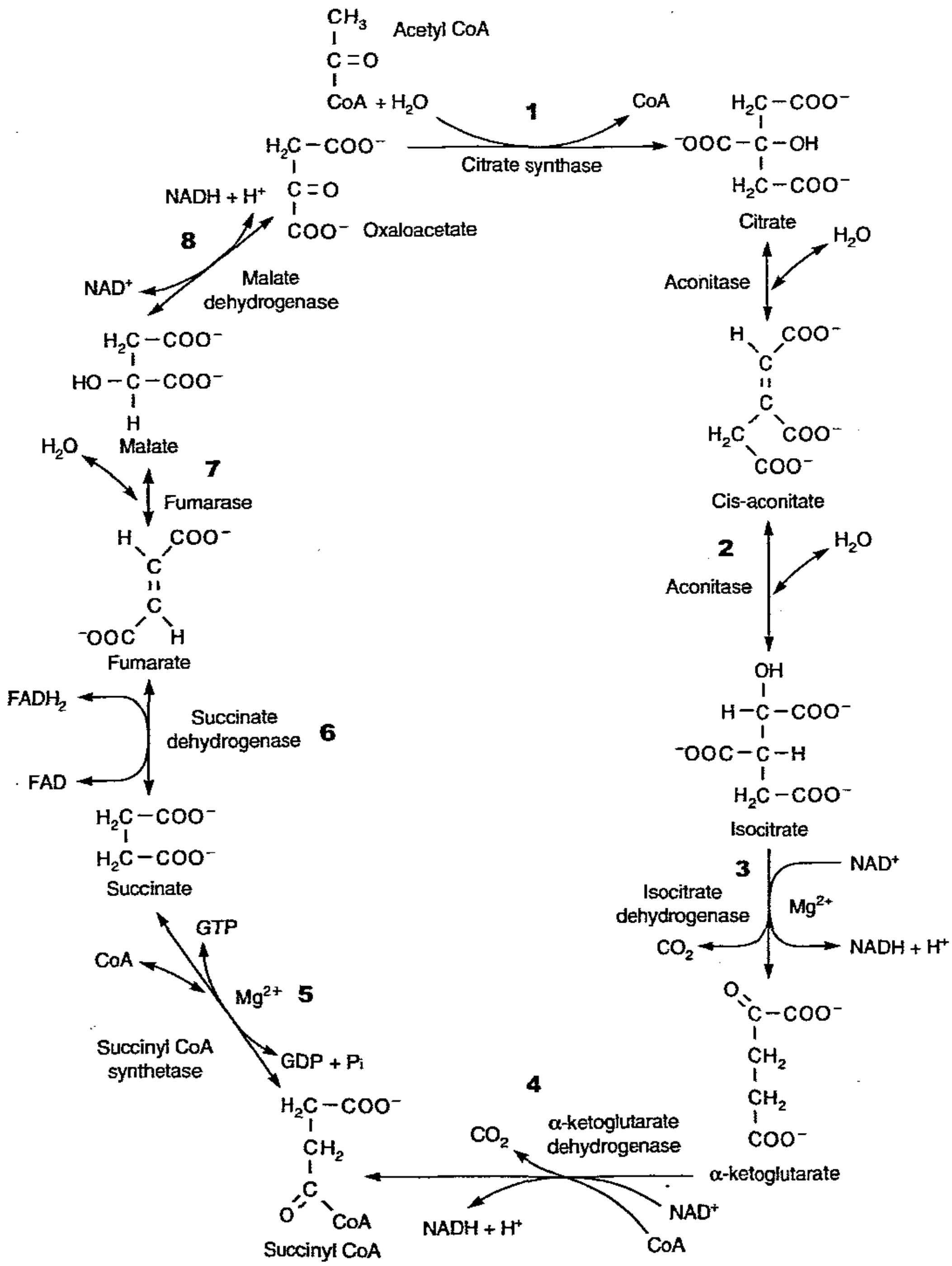

FIGURE 2. The Krebs cycle (Adapted from Houston, 1995)

Oxidative phosphorylation

Oxidative phosphorylation provides the third, and quantitatively most important, mechanism by which energy derived from fuel molecules can be transferred to ATP. The energy transferred to ATP is derived from the energy released when hydrogen combines with molecular oxygen to form water. The source of the hydrogen is the NADH + H^+ and $FADH_2$ coenzyme molecules.

Since only 7 kcal · mol^{-1} of energy is required to synthesize 1 mol of ATP from ADP and P_i, there is enough energy released in the above reaction to form more than one molecule of ATP. The proteins that mediate oxidative phosphorylation are located in the mitochondria, but unlike the enzymes of the Krebs cycle, which are soluble enzymes in the matrix compartments, the proteins that mediate oxidative phosphorylation are embedded in the inner mitochondrial membrane. These proteins can be divided into two groups: those that mediate the series of reactions by which hydrogen is transferred to molecular oxygen, and those that couple the energy released by these reactions to the synthesis of ATP. Most of the first group of proteins contain iron and copper cofactors, forming proteins known as cytochromes. The cytochromes form the components of the electron-transport chain, in which two electrons from the hydrogen atoms are initially transferred either from NADH + H^+ or $FADH_2$ to one of the elements in the electron-transport chain. These electrons are then successively transferred to other elements in the chain, often to or from an iron or copper ion, until the electrons are finally transferred to molecular oxygen, which then combines with the hydrogen ions (protons) to form water. These hydrogen ions, like the electrons, come from the hydrogen-bearing coenzymes, having been released from them early in the transport chain when the electrons from the hydrogen atoms were transferred to the cytochromes. In addition to transferring the coenzyme-hydrogens to water, this process regenerates the hydrogen-free form of the coenzymes, which then become available to accept two more hydrogens from intermediary reactions. Thus, the electron-transport chain provides the aerobic mechanism for regenerating the hydrogen-free form of the coenzymes, whereas the anaerobic mechanism is coupled to the formation of lactate. At each step along the electron-transport chain, small amounts of energy are released, which in total amount to the full 53 kcal · mol^{-1} released from a direct reaction between hydrogen and oxygen. Because this energy is released in small steps, it can be linked to the synthesis of several molecules of ATP, each of which requires only 7 kcal · mol^{-1}. Overall, 40% of the energy released from this chain of reactions is transferred to ATP, the remaining 60% appearing as heat.

At three points along the electron-transport chain ATP is formed. The mechanism by which this occurs is known as the chemiosmotic hypothesis. As electrons are transferred along the cytochrome chain, the energy released is used to move hydrogen ions (protons) from the matrix to the cytosolic side of the inner mitochondrial membrane, thus producing a source of potential energy in the form of a hydrogen-ion gradient across the membrane. At three points along the chain a complex of proteins forms a channel through which the highly concentrated hydrogen ions on the cytoplasmic side of the membrane can flow back to the matrix side and in the process transfer their potential energy to the formation of ATP from ADP and P_i. $FADH_2$, which is formed during one of the steps in the Krebs cycle, has a slightly lower chemical energy content than does NADH + H^+ and enters the electron-transport chain at a point beyond the first site of ATP generation. Thus, the transfer of its electrons to oxygen produces only two ATP rather than the three formed from NADH + H^+.

Finally, the majority of the ATP formed in the body is produced during oxidative phosphorylation as a result of the processing of hydrogen atoms provided, largely via the Krebs cycle, during the breakdown of carbohydrates, fats, and proteins. The mitochondria, where oxidative phosphorylation occurs, are thus considered the powerhouses of the cell.

VENTILATORY AND PULMONARY RESPONSES TO STEADY RATE WORK

OXYGEN CONSUMPTION DURING WORK

It is well documented (Sietsema et al., 1989; Xu and Rhodes, 1999; and McArdle et al., 1991) that the oxygen uptake response to work is a function of work intensity, which can be divided into three domains, namely moderate, heavy and severe work.

In the moderate work domain, three phases of the work oxygen uptake are identified. The first phase represents a rapid rise in oxygen uptake, which is usually completed in 15 to 25 seconds of work. This increase in oxygen uptake is due to the increase in cardiac output and thus pulmonary blood flow. The second phase reflects the influence of muscle metabolic change on oxygen uptake, which increases exponentially toward a steady rate level. The third phase, a plateau, is reached between the third and the fourth minute, and the oxygen consumption remains relatively stable for the rest of the work period. The plateau of the oxygen consumption curve is generally considered the steady rate, when all the ATP demand from muscle contraction is met by oxidative phosphorylation. The duration to the attained steady rate varies depending on the magnitude of the increment and the fitness of the individual. For low to moderate intensities, small increases in intensity result in an exponential increase in oxygen consumption until steady rate is reached.

Oxygen uptake kinetics becomes more complicated when the work intensity is above an individual's lactate threshold. As the oxygen uptake during the second phase still increases exponentially, an additional slow component is developed after a few minutes of work. This slow component causes the oxygen uptake to increase progressively and delays the attainment of the steady rate level. It is closely related to the onset of lactate accumulation.

In heavy work, the oxygen uptake cannot stabilise, and continues to increase until the point of fatigue. The slow component during severe work is even greater than in heavy work and depends on the duration of the work.

The larger the increment, the longer the time to steady rate, although individuals with a high cardiorespiratory endurance have a shorter time to steady rate. Therefore, oxygen-consuming reactions supply the energy for work, and any lactic acid produced is either oxidized or reconverted to glucose, presumably in the liver and possibly kidneys. Under steady rate metabolic conditions, lactic acid accumulation is minimal and metabolic acidosis does not develop.

Robergs and Roberts (1997) draw attention to the fact that the increase in ventilation during the transition to an increased steady rate work intensity is abrupt, exponential, and proportional to the change in intensity. Steady rate ventilation is attained earlier than steady rate VO_2 for a given bout of work, which is understandable given the effectiveness of both the neural and humoral controls of ventilation. The increase in ventilation is due to increases in tidal volume and the breathing frequency.

RESPIRATORY QUOTIENT AND RESPIRATORY EXCHANGE RATIO

Robergs and Roberts (1997) pointed out that for many metabolic and work conditions the respiratory exchange ratio (RER) is often assumed to be equal to the respiratory quotient (RQ) if a steady state is maintained. The ratio between carbon dioxide production and oxygen consumption is traditionally called the respiratory quotient (RQ). This measure is calculated the same way as the respiratory exchange ratio (RER), but the conditions of production of carbon dioxide differ. The RQ is used to indicate cellular respiration and therefore the volume of oxygen consumed (VO_2) and the volume of carbon dioxide produced (VCO_2) resulting from the catabolism of carbohydrates, fats, and protein.

The RER is used when VO_2 and VCO_2 are measured from ventilated air resulting from external respiration at the lung. When sampling air from the lung, the ratio of VCO_2/VO_2 can be modified by increased exhalation of CO_2 that is unrelated to the cellular production of CO_2 from the catabolic pathways of carbohydrate, fat, or protein. When the RER is assumed equal to the RQ for metabolic and work conditions, the RER is used to calculate contributions of either fat or carbohydrate to catabolism and to calculate caloric expenditure. However, the assumption of equality between RQ and RER cannot be made under certain conditions. Robergs and Roberts (1997) have listed these conditions as follows:

1. Metabolic acidosis: Within the cell the production of carbon dioxide cannot exceed the consumption of oxygen, and the maximal value of 1.0 for VCO_2/VO_2 occurs from the metabolism of pure carbohydrate. During metabolic conditions that increase acid production (intense work, ketosis, etc.), the added carbon dioxide produced from the buffering of acid in the body increases VCO_2 independent of oxygen consumption (VO_2), and therefore RER values can exceed 1.0. Consequently, during work the RER value can also be used as an indirect measure of work intensity. During work, if the RER increases to above 1.0, it can be concluded that acid production (presumably lactate) is increasing. If the RER continues to increase above 1.0 during work, fatigue is imminent unless the work intensity is decreased.

2. Non-steady state conditions: When a person has increased his or her work intensity, it takes time for the VO_2 to increase to a level that accounts for the ATP produced during metabolism. During these times, the ATP is produced from alternative sources, namely creatine phosphate hydrolysis and glycolysis. Calculating VO_2 during non-steady state conditions would give a lower metabolic intensity than if the person was at steady state. In addition, a higher RER may be calculated, and together these values would yield incorrect calculations of energy

expenditure and the contribution of fat and carbohydrate to steady state catabolism. If the work intensity is not too high, approximately three minutes are required for the attainment of steady state.

3. Hyperventilation: Excessive exhalation increases the volume of carbon dioxide exhaled from the lung. If this phenomenon occurs without similar increases in VO_2, a higher VCO_2 results from indirect gas analysis calorimetry, yielding an inflated RER value.

The energy released from catabolism for every litre of oxygen consumed at different non-protein RQ values is as follow: The RQ values theoretically reflect carbohydrate and lipid catabolism, with an RQ value of 1.00 reflecting pure carbohydrate catabolism and an RQ value of 0.707 reflecting pure lipid catabolism. The RQ is important because when carbon dioxide production is occurring only from cellular metabolism, and assuming that no change in protein (amino acid) catabolism occurs during work, the RQ value can be used to accurately reflect the proportion of fat and carbohydrate catabolized for energy during work, which allows calculations of energy expenditure during work.

The metabolic computation for indirect calorimetry in open-circuit spirometry uses the following method for the calculation of energy expenditure. The nonprotein data are used whereby the oxygen consumption during work is transposed to the energy expended in kilocalories per minute. It involves the multiplication of the oxygen consumption ($L \cdot min^{-1}$) and the caloric equivalent for the respective nonprotein RER ($kcal \cdot L\ O_2^{-1}$). Assume that a cane cutter had an average RER of 0.97 during work and he consumed an average of 2.206 $L \cdot min^{-1}$ of oxygen. Then, the caloric equivalent for an RER of 0.97 is 5.010 $kcal \cdot L\ O_2^{-1}$, and the caloric expenditure of the work can be calculated as follows:

$$\text{Energy expenditure } (kcal \cdot min^{-1}) = 2.206\ L \cdot min^{-1} \times 5.010\ kcal \cdot L\ O_2^{-1}$$
$$= 11.05\ kcal \cdot min^{-1}$$

Assuming the RER value reflects the nonprotein RER, a reasonable estimate of both the percentage and quantity of carbohydrate and fat metabolised during each minute can be obtained (Appendix D). The percentage of kilocalories derived from carbohydrate for the above-mentioned example is 90.4% and that from fat 9.58%. The grams of carbohydrate utilised are 1.097 per litre of oxygen or 2.42 g per minute. The grams of fat utilised are 0.054 per litre of oxygen or approximately 0.12 g per minute.

ASSESSMENT OF WORK LOAD DURING STEADY RATE WORK

Physical workload can be assessed either through calorimetry, whereby the oxygen uptake is measured during the actual work operation, or by estimation of the oxygen uptake on the basis of the heart rate recorded during the performance of the work (Åstrand and Rodahl, 1986).

CALORIMETRY

The body's basic needs for function and survival are supported by the occurrence of many chemical reactions. The sum of all these reactions is referred to as metabolism. The science that quantifies the heat release from metabolism is termed calorimetry. Calorimetric methods that directly measure heat dissipation from the body are termed direct calorimetry. When heat dissipation is calculated from other measurements, these methods are termed indirect calorimetry. Indirect calorimetry can be subdivided into open-circuit and closed-circuit systems. Open-circuit indirect calorimetry can involve the inhalation of atmospheric air and the sampling and measurement of exhaled air for respiratory gas analysis. Closed-circuit indirect calorimetry involves the recirculation of inhaled and exhaled air, thus necessitating the removal of carbon dioxide and the replenishment of oxygen (Robergs and Roberts, 1997).

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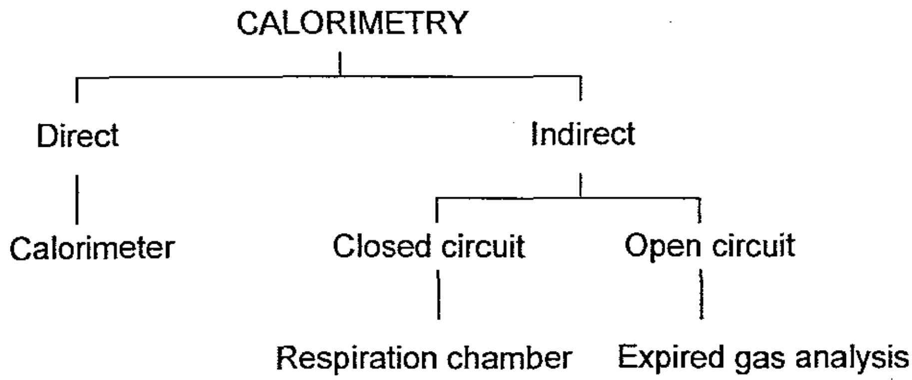

FIGURE 3. The divisions of calorimetry (Adapted from Robergs and Roberts, 1997)

Direct calorimetry

Direct calorimetry was the first tool used to measure caloric expenditure in animals and humans. It measures energy expenditure as the rate at which heat is lost from the body to the environment (Murgatroyd et al., 1993). All of the processes that occur within the body result ultimately in the production of heat. Heat production and metabolism can be viewed consequently in a similar context. Human heat production can be measured directly in a calorimeter to determine the energy content of food and is not influenced by the metabolic processes producing the heat. It is therefore potentially the most accurate measure of energy expenditure. The calorimeter consists of an airtight, thermally insulated living chamber. The heat produced and radiated by the person is removed by a stream of cold water that flows at a constant rate through tubes coiled near the ceiling of the chamber. The difference in the temperature of the water entering and leaving the chamber reflects the person's heat production. Humidified air is continually supplied and circulated while the expired carbon dioxide is removed by chemical absorbents. Oxygen is added to the air before it re-enters the calorimeter to maintain a normal oxygen supply (McArdle et al., 1991; Plowman and Smith, 1997).

The techniques of direct calorimetry, although highly accurate due to the direct measurement of energy expenditure and a good environment for strictly controlled studies and of great theoretical importance, are impractical for studies of human energy expenditure during various occupational activities. In these situations, indirect methods are usually used (McArdle et al., 1991). Direct calorimeters are expensive pieces of equipment and are more suited to measuring basal metabolic demands than those of exercise or work for several reasons listed by the authors Brooks et al. (1996), Plowman and Smith (1997), Robergs and Roberts (1997):

1. Exercise or work performed in a direct calorimeter causes added heat production from friction developed by an ergometer and the subject.
2. During exercise or work the body stores heat, as evidenced by the rise in core temperature.
3. The method is not suited to providing data in small time intervals, which is necessary to measure the rapidity of the changes in metabolic rate during changes in exercise or work intensity and therefore provides no information about the relative contributions of different substrates to expenditure of energy.

Indirect calorimetry

The researchers McArdle et al. (1991) and Murgatroyd et al. (1993) make mention of the fact that energy consumption is calculated from the rate of respiratory gas exchange (oxygen consumption and carbon dioxide production) associated with the oxidation of the energy-yielding substrates: carbohydrate, fat, and protein. All energy metabolism in the body ultimately depends on the utilization of oxygen. Thus, by measuring a person's oxygen consumption at rest and under steady rate conditions, it is possible to obtain an indirect estimate of energy metabolism because the anaerobic energy yield is very small under such conditions. The fact that a known amount of oxygen is required to oxidize gram equivalents of carbohydrate, fat, and protein is therefore extremely important. Studies with the bomb calorimeter have shown that approximately 4.825 kcal of heat are liberated when a blend of carbohydrate, fat, and protein is burned in one litre of oxygen. Indirect calorimetry through oxygen consumption measurement is the means by which the caloric stress of most activities has been evaluated. Indirect calorimetry has a major advantage over direct calorimetry by providing a measure of in vivo fat and carbohydrate oxidation rates. The ratio of carbon dioxide production to oxygen consumption differs for each substrate (Murgatroyd et al., 1993). Although the techniques for indirect calorimetry are relatively simple and inexpensive compared with direct measurement in the human calorimeter, both measures give comparable results. Closed-circuit and open-circuit spirometry represent the two applications of indirect calorimetry.

Closed-circuit spirometry

The method of closed-circuit spirometry is routinely used in hospitals and other laboratory settings where resting estimates are made of energy expenditure. The subject breathes and rebreathes from a sealed container or spirometer filled with a gas of designated composition. This method is considered a "closed system" because the person rebreathes only the gas in the spirometer. Carbon dioxide in the expired air is absorbed by soda lime (potassium hydroxide), placed in the breathing circuit. A drum revolving at a known speed is attached to the spirometer to record changes in the volume of the system as oxygen is consumed. During work, it is exceedingly difficult to measure oxygen consumption with closed-circuit spirometry. The spirometer is bulky, the subject must remain close to the equipment, resistance offered by the circuit to the large breathing volumes required by exercise or work is considerable, and the rate of carbon dioxide removal may be inadequate during moderate and heavy work. For these reasons, the method of open-circuit spirometry is the most widely used to measure work oxygen consumption (McArdle et al., 1991).

Open-circuit spirometry

With this method, the subject does not rebreathe from a container of oxygen as in the closed-circuit method but instead, inhales ambient air that has a constant composition of 20.93% oxygen, 0.03% carbon dioxide, and 79.04% nitrogen. The nitrogen fraction also includes the small quantity of inert gases. Oxygen consumption (VO_2) is the amount of oxygen taken up, transported, and utilised during energy-yielding reactions at cellular level. It equals the amount of oxygen inspired minus the amount of oxygen expired. Carbon dioxide (CO_2) produced is the amount of carbon dioxide generated during metabolism, primarily from aerobic cellular respiration. It equals the amount of carbon dioxide expired minus the carbon dioxide inspired. The amount of gas equals the volume of air, either inspired or expired times the percentage of the gas. To determine these amounts, the volume of expired air is measured from the volume of inspired air and the percentages of oxygen and carbon dioxide. The volume of inspired and expired air is not the same, as the volume of expired air is slightly expanded through heating and the addition of carbon dioxide and humidity. Therefore, the inspired CO_2 must be corrected for differences in temperature, humidity and carbon dioxide content. A complete calculation of the oxygen uptake includes the analysis of the volume, carbon dioxide and oxygen concentrations of expired air, and the temperature of the ambient air (Kilbom, 1990). The open-circuit method provides a relatively simple means to measure oxygen consumption and indirectly determine energy metabolism. An analysis of the difference in composition between the expired air and the ambient air brought into the lungs reflects the body's constant release of energy and the ratio between carbon dioxide production and oxygen consumption is used to indicate the contribution of carbohydrate and fat substrates to energy production. Two common techniques for open-circuit spirometry in exercise or work make use of either the Douglas bag or a lightweight, portable spirometer that is actually worn during an activity.

The Douglas bag method

The Douglas bag is the classical method for the collection of expired air to measure the energy expenditure in the field both at rest and during physical activity. This is a gas-impermeable bag, typically of 100-litre volume, in which the subject's expired air is collected over short periods (Murgatroyd et al., 1993). With this method a special form of headgear is worn to which a two-way, high velocity, low-resistance breathing valve is attached. Ambient air is breathed through one side of the valve while expired air moves out of the other side and passes into either a large canvas or plastic Douglas bag, or directly through a gas meter, that measures the volume of expired air. A small sample of expired air is collected and analysed for its oxygen and carbon dioxide composition. As with all indirect calorimetric techniques, energy expenditure is computed from the oxygen consumption using the appropriate calorific transformation (McArdle et al., 1991). This method can be cumbersome and inconvenient for the subject and therefore tends to interfere with the normal activities of the subject (Murgatroyd et al., 1993).

Portable Spirometer

The boxed-shape portable spirometer was originally used to estimate the energy requirements of people working in different industrial jobs. The unit is lightweight and is usually worn on the back. By means of a two-way breathing valve, ambient air is inspired while the expired air passes through the gas meter that measures the volume and collects a small gas sample. This sample is later analysed for oxygen and carbon dioxide content, and oxygen consumption and energy expenditure are computed for the measurement period. The attractive aspect of the portable spirometer is that the subject has considerable freedom of movement in a variety of diverse activities as it is light and small and it yields reliable results. The equipment does become cumbersome during vigorous activity, and there is some question as to the accuracy of the measurement of airflow through the meter during rapid breathing rates in heavy work (McArdle et al., 1991). Coetsee (1998/99), Murgatroyd et al. (1993), and Devienne (2003) commented that the energy expenditure measured by the portable spirometer is precise and valid during steady rate conditions only.

The sophistication of the equipment used in indirect calorimetry has increased remarkably in the past 20 years. Today, data are obtained, processed, and calculated within seconds, enabling the monitoring of changes during very small time intervals. Ventilation measurement is now performed by advanced electronics less than one tenth the size of the original volume meters, and the response times of the electronic analysers for oxygen and carbon dioxide are now as short as 100 ms. The computerised sophistication regarding indirect calorimetry has enabled the production of several different systems, e.g. the time-averages system and breath-by-breath systems. For the time-average system, the subject breathes ambient air through a volume measuring device and expired air is directed to flow into a mixing chamber. Air from the mixing chamber is continuously pumped through separate oxygen and carbon dioxide analysers. The time-average systems are able to calculate indirect calorimetry values such as VO_2, VCO_2, RER, caloric expenditure, and other respiratory parameters at intervals of 15 or 30 seconds. The breath-by-breath systems have rapidly responding analysers and advanced computerization that enable the calculation of parameters with every breath. Expired air is sampled close to the mouth, avoiding the need for a mixing chamber and ventilation. The breath-by-breath system has the ability to detect the rapidity of change in VO_2. When these improvements are combined with computer software and hardware advances that enable the handling of information at high speed, the automation of indirect calorimetry data collection is now a common feature of many advanced research and clinical exercise testing laboratories (Robergs and Roberts, 1997).

The newest approach to indirect calorimetry makes use of computer technology and microelectronic instrumentation for the collection, measurement, and computation of respiratory and metabolic data. Usually a computer is interfaced with four measuring devices: an automated system that continuously samples expired air, a flow meter for measuring the volume of expired air and rapid electronic oxygen and carbon dioxide gas analysers for measuring the fractional concentration of gases in the expired air sample. The output data from the measuring devices either are fed directly into the computer or can be punched in by the technician. The computer is pre-programmed to perform all of the necessary computations for oxygen consumption, carbon dioxide production, and caloric expenditure. A printed output of the subject's data can occur simultaneously during work to provide a record of all necessary computations by the time the data collection is completed (McArdle et al., 1991). McArdle et al. (1991) stated that regardless of the sophistication of a particular "automated" system, the output data are only as good as the accuracy of the measuring devices, which depends on careful and frequent calibration of the electronic equipment using previously established standards. The distinct disadvantages include the high cost of equipment and possible delays due to system breakdowns.

THE USE OF HEART RATE TO ESTIMATE THE OXYGEN CONSUMPTION

Heart rate is recognised as a good indicator of bodily effort or stress involved in the performance of physical work. Throughout a wide range of aerobic activities, heart rate and oxygen uptake tend to be linearly related for each individual. An increase in heart rate is the main cardiovascular response to demands for the increased oxygen necessary for the performance of physical work (Green et al., 1986; Bridger, 1995). If this heart rate-oxygen uptake relationship is known, the work heart rate can be used to estimate oxygen uptake and then to compute energy expenditure during similar forms of physical activity (Åstrand and Rodahl, 1986; McArdle et al., 1991). The continuous measurement of the heart rate during work is a common method to evaluate cardiovascular strain (Kilbom, 1990). It gives a general picture of the activity level during the entire working day and it is possible to relate the individual worker's reaction to different work operations as observed by the heart rate response, by keeping detailed time-activity records for each subject (Rohdahl, 1989). Most work operations involve a dynamic type of work, where each period of work is brief. The use of the recorded heart rate as a basis for the estimation of workload may be acceptable even in many work situations involving arm work or the use of small muscle groups (Åstrand and Rodahl, 1986). Although the heart rate is practical, it may be of limited use for research purposes because its reliability has yet to be adequately established. Determining the degree of similarity between the laboratory test used to establish the heart rate-oxygen consumption relationship and the specific activity to which it is applied, often poses a problem. The heart rate response to work could easily be influenced by the following factors: environmental temperature, psychological stress, previous food intake, body position, muscle groups exercised, continuity of the work, or static and dynamic work. The estimation of oxygen uptake from the recorded heart rate may therefore be subject to considerable inaccuracy. During arm work or when muscles are acting statically in a straining-type work, heart rates are consistently higher compared with dynamic leg work at any particular submaximal oxygen uptake. Consequently, when heart rate during upper body or static work is applied to a heart rate-oxygen uptake relationship developed during running or cycling, the result is an overprediction of the actual oxygen uptake (Jørgensen, 1985; Åstrand and Rodahl, 1986; Ballor et al., 1989; Meijer et al., 1989; Rohdahl, 1989; Kilbom, 1990; McArdle et al., 1991).

During moderate dynamic work at a constant workload heart rate increases during the first one to three minutes and then reaches a steady state. Steady-state heart rates are linearly related to workload or oxygen uptake. During static work steady-state levels are usually not reached (Kilbom, 1990). Because heart rate is an unspecific measure of cardiovascular strain, the value of heart rate as a measure of energy expenditure is limited and it should be used with a certain degree of caution (Jørgensen, 1985). Measurements should be supplemented with activity recordings, i.e. the type of physical activity, psychologically stressful situations, subjective ratings, measurements of oxygen uptake, and environmental measurements (Kilbom, 1990).

RATINGS OF PERCEIVED EXERTION

A well-known, curvilinear relationship exists between the intensity of a range of physical stimuli and a worker's perception of their intensity. A positive relationship has been found between the physical workload and perceived exertion. The ratings of perceived exertion (RPE) can be defined as one's subjective rating of the intensity of the work being performed and as a psychological evaluation of the physical demands made on the body where physical effort is required (Olivier and Scott, 1993). The Borg scale for ratings of perceived exertion consist of scale steps that have been adjusted so that the ratings, from 6 to 20, are linearly related to the heart rate multiplied by ten. The scale is presented to the subject before the start of work and the "endpoints", 6 and 20, are thoroughly defined. The scale is then shown to the subject during work and the subject is asked for a rating. This scale can be used to supplement physiological measurements during testing and offers valuable additional information about subjective responses, especially where the heart rate response could be unreliable, although high positive correlations between heart rate and RPE are usually found. Findings in the industry and in industrial tasks suggest that ratings are influenced not only by the overall perception of exertion, but also by previous experience and motivation of the subjects. Thus, highly motivated subjects tend to underestimate their exertion (Kilbom, 1990). Capodaglio (2002) mentioned that the use of psychological methods for subjectively evaluating work tasks and for determining acceptable workloads is common practice in ergonomics. Daily activities at the work site are studied with physiological methods, perceptual estimation, and production methods.

The perceived exertion, difficulty and fatigue that a subject experiences in a specific work situation are important signs of real or objective loads. Olivier and Scott (1993) stated that very little appeared to have been done to examine subjective self-reported effort in normal field conditions as most studies have been confined to the laboratory. Extrapolation of the RPE responses from the laboratory to the normal working environment should therefore be approached with caution. Scott (1985) proposed a perceived exertions scale that could be used universally, regardless of spoken language or state of literacy. This was achieved using diagrammatic presentations of the behavioural tasks, which is an adaptation to the use of the RPE scale. Scott (1990) was of the opinion that a combination of a diagrammatic and numerical scale would lead to the best subjective ratings of physical effort and the Universal RPE scale was suggested (Appendix C). In assessing the reliability of the Universal RPE scale, two scales were drawn up, the first depicting different behavioural tasks of increasing metabolic cost. The second scale used the same tasks but diagrammatically displayed progressively increasing intensity of effort in different stages. These scales were shown to 40 black and white university students, both male and female. No physiological differences were found between the verbal or diagrammatic scales. A t-test for means of independent samples showed no significant difference in the mean values of either the verbal or the diagrammatic scale, indicating that both scales could be used as reliable indicators of perceived exertion.

ENERGY EXPENDITURE OF WORK

CLASSIFICATION OF WORK AND PERMISSIBLE WORKLOADS

Åstrand and Rodahl (1986) are of the opinion that in most instances, at least in the Western world with its advanced technology, excessively heavy work can easily be eliminated with technical aids; it is merely a matter of cost and priority. Establishing limits for permissible physical workloads is therefore of limited practical value. Occupations falling within the category of sedentary or light may show appreciable differences in the energy expended by groups of people within the same general category (Durnin, 1991). Of far greater importance to the worker today, is the manner in which the work is being performed, the opportunity to influence the work situation and to govern one's own work rate, the safety and the general atmosphere of the working environment. In most situations in modern industry, the worker is able to adjust the rate of work according to his or her personal capacity. However, there are some exceptions, as when work is performed by a team. The weak have to keep up with the strong. In teamwork, older workers, who are generally slower and who have a reduced physical working capacity, may be hard-pressed to keep pace with the younger members.

Åstrand and Rodahl (1986) and Rohmert (1987) emphasised the importance of the physiological and psychological effects of a given energy output that are determined by the individual's maximal aerobic power, size of the engaged muscle mass, working position, the type of work (intermittent or continuous, static or dynamic), the speed of the movement and environmental conditions. A person's subjective experience of a particular workload or rate of work is more closely related to heart rate than to oxygen uptake during the performance of the work, since the work pulse, in addition to the actual workload, also reflects emotional factors, heat, and the size of the muscles groups engaged.

For continuous work over an eight-hour shift, the energy expenditure should not exceed a value of 33% of an individual's maximum capacity, i.e. 5 kcal $\cdot$ min^{-1} for men and 3.5 kcal $\cdot$ min^{-1} for women. These recommendations, quoted by Bridger (1995) were based on data provided by the National Institute for Occupational Safety and Health. Different classification systems exist for rating the strenuousness of physical work. Work could be classified in terms of oxygen uptake, heart rate, and energy expenditure.

The figures in Table 1 refer to average individuals 20 to 30 years of age. The relative energy expenditure (kcal · min^{-1} · kg^{-1}) is based on a 65-kg man. Classification systems of physical work can be used only as general guidelines in view of the vast individual variations in the ability to perform physical work (Bridger, 1995):

TABLE 1. Severity of work in terms of VO_2, heart rate, absolute and relative energy expenditure (Adapted from Bridger, 1995)

Work severity	**VO_2** (L · min^{-1})	**Heart rate** (beats · min^{-1})	**Absolute energy expenditure** (kcal · min^{-1})	**Relative energy expenditure** (kcal · min^{-1} · kg^{-1})
Light	<0.5	<90	<2.5	<0.04
Moderate	0.5-1.0	90-110	2.5-5.0	0.04-0.08
Heavy	1.0-1.5	110-130	5.0-7.5	0.08-0.12
Very heavy	1.5-2.0	130-150	7.5-10.0	0.12-0.15
Extremely heavy	>2.0	150-170	>10.0	>0.15

Kilbom (1990) classified tasks demanding an oxygen uptake of more than 1.75 L · min^{-1} as very heavy, those demanding 1.5 to 1.75 L · min^{-1} as heavy, those demanding 1.0 to 1.5 L · min^{-1} are considered moderately heavy and those demanding less than 1.0 L · min^{-1} are classified as light.

Jørgensen, (1985) referred to the energy expenditure as a classical work physiology parameter, which can be measured indirectly by oxygen uptake, since one litre of oxygen has an energy equivalent of approximately 5 kcal or 20 kJ. Oxygen uptake can be measured accurately and with a high degree of reproducibility, making this method invaluable for both laboratory and field conditions. Heart rate is another indirect measure of human energy expenditure, because of the relationship between heart rate and oxygen consumption. This relation is, however, influenced by a number of factors, e.g.

size of the muscle mass involved, type of contraction (dynamic versus static), heat, psychological factors and the training condition of the individual. Because of this, the value of heart rate as a measure of energy expenditure is limited and it must be used with a certain degree of caution. Several attempts have been made to establish maximum acceptable or permissible loads, not only for physical work in general but also for manual handling tasks, based on metabolic criteria. Metabolic criteria are usually based on or related to the maximal aerobic capacity (VO_2 max). Most of the VO_2 max values in the literature were obtained during pure dynamic leg work performed on either a treadmill or cycle ergometer. If these values are used as the basis for metabolic criteria for practical physical work, one has to be careful in the interpretation of these criteria. Many manual handling operations, such as harvesting sugarcane consist of arm and upper body work and not pure dynamic leg work. "Acceptable" limits for physical work of eight hours' duration based on VO_2 criteria indicate that work can be continued at a constant work pace throughout the day, without any changes in homeostasis, e.g. no increase in arterial lactate concentration and heart rate. Based on these homeostatic criteria the upper tolerance limit for dynamic work over an eight-hour working day is suggested to be 50% of the VO_2 max in trained individuals. If repetitive lifting or other types of manual handling operations are essential components of the task, the upper tolerance limits will probably be lower because of the static components involved from the back, the shoulders and the arms. Therefore, it is likely that the upper limit of tolerance over an eight-hour workday, consisting of mixed physical work including manual handling operations, is approximately 30-35% VO_2 max. Several possibilities are available for establishing permissible loads for different kinds of manual handling operations:

1. The VO_2 max level of the tasks can be determined so that the 35% of the VO_2 max level of the majority of the labour force is not exceeded. The consequence of this will be that all jobs with oxygen demands exceeding the above-mentioned value will be banned and this may therefore have serious implications for the industry.

2. The VO_2 level of the tasks can be set to ensure that the 35% VO_2 max level of specific groups within the labour force (young/old, male/female) is not exceeded.

3. The VO_2 max of the individual worker can be tested in pre-employment investigations. From that value and knowledge about the energy demands of the tasks in the industry, it can be secured that the load on the individual worker does not exceed the appropriate value. Such a procedure requires the necessary facilities and knowledge, and the selection and recruitment of a labour force in such a manner could be viewed as unethical and impolitical.

Even if the general metabolic rate is below accepted rates for long-term work, overstrain and/or fatigue in the back muscles during manual handling operations of long duration can occur. Local fatigue of the muscles in the back can lead to bad coordination and to awkward working movements and postures in handling operations.

Rohmert (1987) mentioned that, with regard to suitable work intensity, the endurance limit (EL) was evolved. EL is a physiological limit that characterizes the ability of the human body during muscular work to bring various inner balances into the highest possible "steady state" of muscular work. The EL can be expressed in terms of endurance time, energy expenditure, heart rate, or other physiological terms. The behaviour of the heart rate in the course of the working and resting periods of the day has proved to be the safest measure for fulfilling the requirement of EL. However, fatigue and suitable work intensity, as seen from an individual's heart rate, are not linked unconditionally to the limit of energy expenditure of 2000 kcal per day as keeping to this limit does not ensure that prolonged work is free from fatigue. Banister and Brown (1968) also considered 2000 kcal for a full working day to be a more suitable load for heavy workers, giving an average rate of energy expenditure of 4.2 kcal $\cdot$ min^{-1} (17.6 kJ $\cdot$ min^{-1}).

Great individual differences exist in an individual's physical working capacity. Workloads taxing 30 to 40 percent of the individual's maximal oxygen uptake is a reasonable average upper limit for physical work performed over an eight-hour working day (Åstrand and Rodahl, 1986).

According to McArdle et al. (1991), intensity and duration are two important factors in rating the difficulty or strenuousness of a particular task. The intensity of the work is the factor distinguishing the manner in which a specific work task is completed. Several classification systems have been proposed for rating the difficulty of sustained physical activity in terms of its strenuousness. One recommendation is that work tasks be rated by the ratio of energy required for work to the resting or basal energy requirement. With this system, light work for men is defined as that eliciting an oxygen consumption or energy expenditure up to three times the resting requirement. Heavy work is categorised as that requiring six to eight times the resting metabolism, whereas maximal work is considered as any task requiring an increase in metabolism nine times or more above the resting level. As a frame of reference, most industrial jobs and household tasks require less than three times the energy expenditure at rest.

ENERGY EXPENDITURE IN VARIOUS MANUAL LABOUR TASKS

Åstrand and Rodahl (1986) postulate that in the majority of professional activities and light industry, the energy output is less than 5 kcal $\cdot$ min^{-1} (less than 20.9 kJ $\cdot$ min^{-1}, or less than1 L $\cdot$ min^{-1}). Many jobs in the building industry, agriculture, and the iron and steel industries, occasionally demand a caloric expenditure of up to 7.5 kcal $\cdot$ min^{-1} (or 31.4 kJ $\cdot$ min^{-1}) or even higher, particularly if mechanical aids are limited and/or utilised to only a small extent. Higher demands of energy are found in the fishing, forestry, and mining industries, where figures up to or exceeding 10 kcal $\cdot$ min^{-1} (41.9 kJ $\cdot$ min^{-1}) have been reported.

According to Kilbom (1990) the oxygen uptake during manual work in forestry and mining is between 2.0 and 3.0 L · min^{-1}. In many industrial tasks, the level of activity is self-regulatory in that the rate of work and the spacing of rest pauses are set by the individual's level of physical fitness.

Rodahl et al. (1974) studied the average energy expenditure of Norwegian commercial fishermen. During a whole day on the sea, the energy expenditure amounted to 34%-39% of the fisherman's maximal aerobic power, with occasional peaks of up to 80%. In general, it appeared that the energy expenditure of commercial fishermen during the active fishing season may have reached levels as high as 5000 kcal per day. It is, however, suitable for a person to endure workloads close to the permissible physiological limits, through working intermittently, with periods of high work intensity interspersed with frequent, brief rest periods.

Forestry work involves heavy expenditure of energy. Lumbering is probably the hardest form of physical work, requiring as much as 6000 kcal per day (Åstrand and Rodahl, 1986). Hagen et al. (1993) studied the physical workload, perceived exertion and output of cut wood in motor-manual cutting using a chainsaw, among 15 young lumberjacks with a mean age of 29 years. The oxygen consumption was measured with a portable spirometer and the heart rate was measured telemetrically during different phases of work. The oxygen consumption for all working phases was 1.8±0.2 L · min^{-1}, which corresponded to 49% of their maximal oxygen consumption. The mean heart rate was 138±10 beats · min^{-1}. Ratings of perceived exertion (RPE) and simultaneous heart rate recordings in the field showed a slight correlation (r=0.38). Kurumatani et al. (1992) studied the aerobic capacity and the physical demands of the occupation of forestry workers. Heart rates were continuously recorded during a normal working day. The metabolic rates of various forestry activities were estimated from the average heart rate during the specific activity and the predicted maximal oxygen consumption of the subject, during a submaximal cycle ergometer test. The mean energy expenditure was 4.5 METs with a range of 3.3 to 6.3 METs for an average of 509 minutes at a worksite. The results indicated that the forestry workers had a high aerobic capacity and that this was ascribed to the high physical demands of their occupation. Kukkonen-Harjula and Rauramaa (1984) measured the oxygen consumption of lumberjacks during a variety of tasks and it was found to be between 1.9 and 2.2 $L \cdot min^{-1}$.

In the mining industry, prior to the introduction of mechanisation, mining was backbreaking work as they spend up to three to six hours underground, often working in restricted workspaces and under the most demanding environmental conditions. Mining in India is still relatively unmechanised, and in the hot, humid, and noisy environment with uncomfortable postures, many work operations impose a considerable physiological strain. Pal and Sinha (1994) studied the physical characteristics of 54 workers in an Indian metalliferous mine as well as the energy expenditure of different tasks of work. The average energy expenditures for different tasks ranged between 9.4 and 22.8 $kJ \cdot min^{-1}$, which were usually more than 33% of the worker's maximal work capacity. The principal tools of a miner are the shovel and pick and it appears that the energy expenditure of shovelling ranges from 6 to 7 $kcal \cdot min^{-1}$ (25.1 to 29.3 $kJ \cdot min^{-1}$). Lehmann et al. (1950) studied the mean gross energy expenditure during actual coal mining and found it to be 5 $kcal \cdot min^{-1}$ (20.9 $kJ \cdot min^{-1}$), whereas the mean energy expenditure for the total time spent underground was 3.5 $kcal \cdot min^{-1}$ (14.7 $kJ \cdot min^{-1}$). Gallagher (1999) stated that modern mining is characterised by short bursts of high energy expenditure tasks, interspersed with periods of rest or lower energy tasks. Many mining tasks can be classified as heavy work ranging from 5.0 to 7.5 $kcal \cdot min^{-1}$, or very heavy work, ranging from 7.5 to 10.0 $kcal \cdot min^{-1}$. In spite of the increased mechanisation, mining is still considered as hard physical work (Åstrand and Rodahl, 1986).

Salokhe and Mamansari (1995) investigated the physical workload of agricultural workers during selected farm operations in paddy fields in Thailand. Four common farm operations, i.e. ploughing, planting, weeding and harvesting, were selected. During the four different field operations, heart rate, oxygen consumption and pulmonary ventilation were recorded and the energy expenditure was estimated. The average heart rate during work ranged between 81 and 146 beats $\cdot$ min^{-1} for different agricultural activities. The ploughing operation elicited a heart rate of 117 beats $\cdot$ min^{-1}. The oxygen consumption varied from 0.65 to 0.97 L $\cdot$ min^{-1}. Ploughing demanded a higher oxygen consumption compared with the other operations, where the oxygen consumption was almost the same. The pulmonary ventilation varied from 21.3 to 29.8 L $\cdot$ min^{-1}, with ploughing demanding a higher pulmonary ventilation than the other operations. The estimated energy expenditure for the ploughing operation was 19.5 kJ $\cdot$ min^{-1}, which is considered to be heavy work. The estimated energy expenditure figures for weeding, harvesting and planting were 14.1 kJ $\cdot$ min^{-1}, 13.0 kJ $\cdot$ min^{-1} and 12.4 kJ $\cdot$ min^{-1}, respectively, which are classified as moderate work. The physical workload for these operations, expressed as a percentage of the physical work capacity, was 44, 33, 44, and 41%, respectively. In general, ploughing was found to be the heaviest work, and the other operations were moderate.

Morrison and Blake (1974) measured the oxygen consumption and productivity to determine the mechanical efficiency of Australian and Rhodesian cane cutters. In burnt cane, the Australian cutters had an average oxygen intake of 1.69±0.34 L $\cdot$ min^{-1}, which constitutes 50% of their VO_2 max and the Rhodesian cane cutters 1.90±0.44 L $\cdot$ min^{-1}. In unburnt cane, the average oxygen intake for the Rhodesian cutters was 1.42±0.15 L $\cdot$ min^{-1}, which amounted to approximately 7.2 kcal $\cdot$ min^{-1}. Spurr et al. (1975) measured the energy expenditure of 61 Colombian cane cutters while harvesting unburnt cane. The energy expenditure ranged from 4.5 to 12.4 kcal $\cdot$ min^{-1}, with a mean energy expenditure of 7.4±1.5 kcal $\cdot$ min^{-1}. The cane cutters sustained approximately 35% of their VO_2 max during an eight-hour workday.

Lambert et al. (1994) reported an energy expenditure for South African cane cutters during a full working day to be that of 11 695±1288 kJ. Mean oxygen consumption of Sudanese cane cutters and found it to be 1.62±0.32 $L \cdot min^{-1}$ Collins et al. (1976).

EFFICIENCY AND ECONOMY OF WORK

Efficiency and economy are often used synonymously, when describing work conditions. In fact, these terms pertain to very different conditions of the body. Efficiency of movement refers to the mechanical energy produced during the movement relative to the metabolic energy used to cause the movement. To compute the efficiency of movement for an individual, the change in the energy output during ergometry is expressed relative to the change in the chemical energy used during the movement. When applied to work it is the ratio, expressed as a percentage, between the mechanical energy produced during the work and the energy cost of the work. Under favourable circumstances the muscular performance can achieve a mechanical efficiency of between 20% and 25%, whilst the other energy appears as heat, is dissipated and tends to raise the body temperature (deVries and Housh, 1994).

Economy of movement refers to the energy cost of the movement and may be described as the submaximal oxygen consumption required to perform a given task, which is practically useful for the evaluation of the performance of endurance activities.

State of training can influence the efficiency of locomotion. Well-trained subjects with a high aerobic capacity are somewhat more efficient than those with a lower aerobic capacity. Well-conditioned individuals are more economical than poorly conditioned individuals, meaning that the conditioned individual will respond with a lower submaximal oxygen consumption for any given workload (Robergs and Roberts, 1997).

Factors influencing the economy of movement are classified according to intrinsic and extrinsic factors. Intrinsic factors influencing economy of movement are: body mass, where larger individuals are more economical per unit of body mass than smaller individuals, psychological state, although not conclusive, but if there is an effect, it appears that reduced tension is associated with improved working economy, body centre of mass excursion, and energy transfer between segments. Extrinsic factors include ambient temperature, where moderate work performed at an ambient temperature of 38°C requires an average of 13.3% higher metabolic rate than work being performed at 29°C. With heavy work, the increase is 11,7% (deVries and Housh, 1994). This decreased economy is the result of the increased workload on the circulatory system for meeting the demand for increased peripheral circulation to transport heat from the core to the skin.

In this study, the term work efficiency was used whereby the subject's working efficiency was expressed as a ratio between the energy expended against the workload performed. According to the South African Sugarcane Research Institute (2004b) the production figures measured in tons per day, of a fair task for a young male cane cutter in straight burnt cane, on a level to moderately steep topography, using a short handle knife, were found to be 4.5 to 5 tons cane cut, topped and stacked in six to eight hours' time. Cutting and topping take up two-thirds of the time. An average task is about 8 tons cut, topped and windrowed. In unburnt cane in similar conditions, a good task is about 3 to 3.5 tons cut, topped, trashed and stacked. Here cutting, trashing and topping take up three-quarters of the total time. On a steep topography, these tasks will often be reduced by 30 to 40%. An average task with the long handle Australian knife increases the productivity by up to 9 or 10 tons, and with further training and coaching, many cane cutters can achieve 15 tons per day.

Measuring the energy cost based on oxygen uptake or heart rate, or by recording output at a constant oxygen uptake or heart rate, a rough estimate of the efficiency of a particular work operation may be achieved. Hansson (1968) studied the influence of the choice of tools on the rate of work and work effort in a group of men engaged in the nailing of impregnated paper under standardised conditions. When using a stapler the work rate that was attained was three to four times higher than when using an ordinary hammer. There were no significant differences in oxygen uptake per minute, quality of work, or estimated degree of fatigue when different tools were used. Åstrand et al. (1968) studied the energy cost of hammer nailing at three different heights: at bench level, into a wall at head level, and into a ceiling above the head. The number of strokes did not differ significantly in the three situations, but the number of nails driven per minute was lower when nailing into the wall than when nailing into the bench, and even lower for nailing into the ceiling. The oxygen uptake for the three different positions for nailing was approximately 1.0 $L \cdot min^{-1}$. This indicated that the strokes became less powerful or were less well aimed when nailing into the wall and ceiling than into the bench. These examples illustrate that the work output may vary with tools used and with the working positions, even though the energy expenditure was the same; and the physiological effects of a given energy demand may vary considerably depending on tools and techniques.

SUBJECT OBSERVATION AND UNOBTRUSIVE OBSERVATION

Wyndham and Cooke (1964) studied the influence of the quality of supervision on the production of men engaged on moderately hard physical work. For the purpose of this study, 28 South African miners were divided into two gangs, each interchanging at weekly intervals between different supervisors. The result was that quality supervision led to an increase in performance levels of the gang as a whole and caused individual performances within the gang to cluster more closely around their maximum performance level. Poor quality supervision resulted in performances around a lower mean level. In the work of Cicciarella (1997) the researcher must take the Hawthorne effect into consideration, as the subjects selected to participate in any research project usually show an increase in their performance. Åstrand and Rodahl (1986) also mentioned that it is evident that the measured oxygen consumption during the work performance represents the energy expenditure only at the time when the expired air sample is collected, and may not be representative of the work performed otherwise. The Hawthorne effect and therefore the validity of selected measurements were determined through either obtrusively observing the cane cutters or not doing so.

CHAPTER THREE

METHODS AND PROCEDURES

AIMS AND DESIGN

The main purpose of this study was to investigate the differences in the energy expenditure and working efficiency of sugarcane cutters with regard to harvesting burnt and unburnt sugarcane *in situ*. The secondary study was to examine the effects of the short handle curved blade knife and the long handle curved blade knife on the cane cutter's work performance. A further aim was to ascertain whether selected physiological parameters and selected measures for working efficiency would differ when the cane cutters were observed or not observed.

Until now, research in the field of sugarcane cutters in South Africa has been restricted to estimates of energy expenditure only. Evidence shows that heart rate and oxygen uptake during an actual activity differ from measurements in the laboratory at equal workloads. With this in mind, oxygen uptake and energy expenditure were measured directly, during the performance of work.

The design of this study took cognisance of the fact that there are a number of factors that may affect demands placed on the cane cutter's physiological system and his working efficiency. Three studies were set in motion to investigate the following:

1. Differences between harvesting burnt and unburnt cane with regard to selected physiological parameters and selected measures for working efficiency of cane cutters *in situ*;
2. differences between the short handle curved blade knife and long handle curved blade knife with regard to selected physiological parameters and selected measures for working efficiency of cane cutters *in situ*;
3. differences between subject observation and unobtrusive observation interaction with regard to selected physiological parameters and working efficiency of cane cutters *in situ*.

SUBJECTS

The present study was carried out on the Dover-Logoza Estate of the Umhlatuzi Valley Sugar Company in Zululand. Out of 45 cane cutters employed on the estate, fifteen professional male cane cutters, all right handed, were randomly selected. Subjects were questioned on their general health and or any past and present orthopaedic injuries. No history of known illnesses and/or any cardiovascular diseases at the time of conducting the study, nor orthopaedic injuries, which could have limited their working capacity, were reported.

INFORMED CONSENT

The topic of research was proposed to and approved by the Research and Ethics Committee, University of Zululand, as well as the employer, the "Induna" and the cane cutters. A timetable was set, coordinating the dates of data collection with the harvesting plan of the sugarcane estate.

Seven contact sessions were held, prior to participation, to explain all testing procedures under the different experimental conditions. With the assistance of an interpreter, the procedures were explained verbally, as some of the cane cutters were illiterate, and in writing (Appendix A). All were given the opportunity to ask questions and subjects could withdraw from the research, if they so wished. Participants were required to either sign or thumbprint the written informed consent form (Appendix B).

CANE CUTTING IMPLEMENTS

Two different types of Okapi cane knives were used and compared with each other, namely the short handle curved blade knife (Reference number 1010C) and the long handle curved blade (Reference number 1020C). Both the short and the long handle cane knives' blades are made from carbon steel material, and the blades are attached to a wooden handle. The specifications of the two cane knives are summarised in Table 2. Figures 4 and 5 depict the above-mentioned cane harvesting knives.

TABLE 2. Specifications of the short handle curved blade knife and the long handle curved blade knife (From: Okapi, n.d.)

Specifications	Short handle curved blade	Long handle curved blade
Length of blade (mm)	360	288
Length of handle (mm)	200	530
Total length (mm)	560	818
Weight (kg)	0.605	0.825

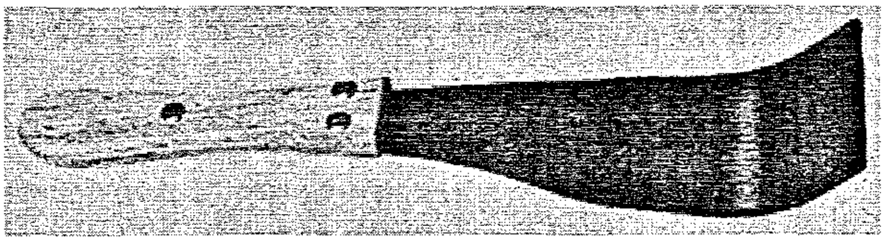

FIGURE 4. The short handle curved blade cane knife (From: Okapi, n.d.)

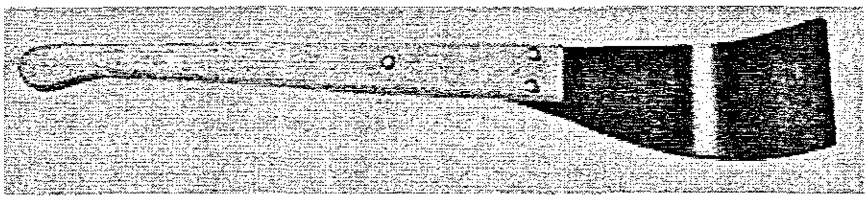

FIGURE 5. The long handle curved blade cane knife (From: Okapi, n.d.)

HABITUATION AND IMPLEMENT FAMILIARISATION

Special attention was given to adequate habituation before the collection of data. Each subject was exposed to wearing the MetaMax I Ergospirometry System and the Polar Accurex Plus™ wrist receiver during cane harvesting. The Universal RPE Scale (Appendix C) and its use were verbally explained in both Zulu and English according to standard instructions as described in the work of Scott (1990). Questions were also asked regarding the cane cutters' preference for either the short handle or long handle cane knife, straight or curved blade, harvesting burnt or unburnt and the number of years work experience. To ensure that all subjects were familiar with both the short and long handle curved blade cane knives, they were questioned concerning the use thereof and their preference for the different cane knives. Mchunu (1999), Training Officer in the Training Department at the South African Sugarcane Research Institute, recommended additional training sessions for at least one week (40 hours) until improved skill was demonstrated with a specific cane knife. In the present study all of the cane cutters needed additional training sessions, as they were accustomed to the long handle curved blade knife. The farmer and the "Induna" ensured the correct implementation of the different cane knives for the recommended period of familiarisation.

MEASURED VARIABLES

ANTHROPOMETRIC MEASURES

The anthropometric measurements included stature, body mass and percentage body fat which was calculated from skinfold measures of four sites, namely triceps, subscapular, biceps and suprailiac according to Durnin and Womersley (1974). These above-mentioned measures were taken on the sugarcane estate, approximately a week before the actual physiological measurements and the measurement of working efficiency.

Stature

Stature was recorded in centimetres to the nearest millimetre with a required accuracy of <2 mm, using a Holtain stadiometer. The subject stood erect and barefoot, with the weight evenly distributed on both feet, and the head in the Frankfurt Horizontal plane. The arms hung freely at the sides of the trunk with the palms facing the thighs. The heels were placed together, with the heels, gluteus, scapulae and posterior aspect of the cranium in contact with the stadiometer. Before taking the measurement, the subject was instructed to inhale deeply and stretch upward to the fullest extent. The vertical distance was measured from the vertex in the mid-sagittal plane to the floor.

Body mass

Subjects were weighed in their working clothes on a calibrated Soehnle scale. Body mass was measured in kilograms and recorded to the nearest 100 grams, with a required accuracy of <0.5 kg.

Skinfold measurements

Measuring the skinfold thickness at various sites assesses body composition. The following measurement technique was applied for all sites using a Lange spring-loaded skinfold calliper (Cambridge Scientific Instruments, Inc.), taking all measurements on the right hand side of the subject. All measurements were recorded in millimetres, with a required accuracy of <1.5 mm.

The thumb and index finger of the left hand were used to elevate the double fold of the skin and subcutaneous adipose tissue one centimetre proximal to the site at which the skinfold was measured. The jaws of the calliper were applied at right angles to the site, and the spring-loaded handles were fully released. Once full pressure was applied and a maximum period of three seconds had passed, the measurement was taken. Two measures were taken and recorded to the nearest 0.5 mm. If the difference was greater than 1 mm, a third measurement was taken and the mean of the closest two was recorded.

Triceps skinfold

This is a vertical fold, measured on the posterior surface of the unclothed pendant arm at a level midway between the acromion and the olecranon processes with the arm held freely to the side of the body.

Subscapular skinfold

The skinfold was measured in an oblique plane ascending medially at an angle of approximately 45 degrees to the horizontal. This was measured 1 to 2 cm below the inferior angle of the scapula, with the subject standing erect and the upper limbs pendant.

Biceps skinfold

This is a vertical fold on the anterior aspect of the pendant upper arm, midway between the acromion and the olecranon process of the elbow joint. It was measured 1 cm above the level used to mark the triceps site.

Suprailiac skinfold

This is a diagonal fold in line with the natural angle of the iliac crest, taken in the anterior axillary line, 3 cm superior to the iliac crest.

Percentage body fat

In order to assess percentage of body fat for individuals, the body density had to be calculated first. This was done by adding the four skinfolds: triceps, subscapular, biceps and suprailiac. Using the equations derived from Durnin and Womersley (1974) the density was calculated from a linear regression, which estimates density from the logarithm of skinfold thickness:

Density = c - m x log skinfold

Where:
"c" and "m" vary in regression equations depending on age and gender. The formula for estimating percentage of body fat is calculated from the density using Siri's equation (as cited by Durnin and Womersley, 1974):

Percentage of body fat = (4.95/body density) - 4.50 x 100

The implementation of this equation is applicable to cane cutters, as it accounts for the effect of age on body fat distribution, as well as the curvilinear relationship between skinfold and percent fat.

PHYSIOLOGICAL PARAMETERS

The physiological parameters involved the recording of the metabolic measures, namely oxygen consumption and energy expenditure. Heart rate recordings were measured telemetrically by means of a Polar Accurex Plus™ wrist receiver.

Metabolic measurements

Sugarcane cutting involves repetitive movements for prolonged periods of time. On this basis it may be termed as a continuous loading activity, whereby the workload is matched by the metabolic cost. The predominant energy-releasing reactions in the body ultimately depend on the utilisation of oxygen. Energy expenditure is a work physiology parameter, which can be measured indirectly by oxygen uptake, since one litre of oxygen has an energy equivalent of approximately 4.825 kcal or 20.2 kJ (McArdle et al., 1991). Oxygen intake can be measured precisely and with a high degree of reproducibility even in field conditions (Jørgensen, 1985; McArdle et al., 1991; Murgatroyd et al., 1993). To help reduce intra-subject variability, subjects were given clear specifications regarding meals ingested and activity prior to testing, including:

1. no cigarette smoking 3 hours prior to the test;
2. no caffeine 3 hours prior to the test;
3. no drugs affecting the nervous system;
4. all tests were performed between 05h00 and 09h00;
5. subjects were requested not to alter sleeping or eating patterns;
6. subjects were requested to refrain from undertaking any other form of exhaustive activities other than harvesting cane within the period 24 hours prior to testing.

The metabolic measurements were obtained by means of the portable MetaMax I Ergospirometry System (CORTEX Biophysik GmbH, Leipzig, Germany). The MetaMax I measures oxygen and carbon dioxide concentrations of expired air, frequency of breathing, tidal volume, cardiac frequency, air temperature, ambient temperature and ambient pressure (Appendix E). The online systems are programmed to take a sample from air at specific intervals and to synchronise this with the ventilation volume to produce the calculated values. The following were calculated: oxygen uptake (VO_2), carbon dioxide production (VCO_2), minute ventilation (VE), respiratory exchange ratio (R), measured gas concentrations for oxygen and measured gas concentrations for carbon dioxide. If the body mass of the individual is known, the following relative values can be calculated: relative ventilation, relative oxygen intake and relative carbon dioxide output.

The MetaMax I base unit contains a complete electronic system for measuring and processing. The main parts of the processing unit consist of several microprocessors. In addition, several sensors and mechanical components are controlled by these microprocessors. Several sensorial parts of the system need a specific working temperature, so that it is important to wait at least 30 minutes after switching on the device before a real measurement can start. Accurate calibration of the unit ensures quality results and includes the calibration of volume and the concentration of ambient and machine oxygen and carbon dioxide values.

To start the volume calibration, it was required to pump six times using a 3-litre Hans-Rudolph syringe. While the pumping was done, five volume measurements were performed. From the average value of the volumes, the factor of calibration was calculated, as any difference in the flow rate between calibration and measurement will mediate substantial errors in the concentration estimates. The flow rate is calculated from the speed of a turbine to compensate for both low and high flow rates. The value was sent to and stored in the permanent memory of the MetaMax I.

The gas calibration for the oxygen and carbon dioxide gas sensors was done with two different test gases, namely ambient air: 20.93% O_2 and 0.03% CO_2; and a technical test gas mixture of 16.3% O_2 and 4.2% CO_2, (bal N_2). Starting from the nominal and the measured values a linear equation will result in a calibration factor and an offset, as the physical state of the ambient air should be identical to the technical gas mixture. The correction values were stored in the permanent memory of the MetaMax I. The calibration gas (technical gas) outlet was connected to the gas inlet of the MetaMax I. Any gas pressure should be avoided, as the MetaMax I must only suck off the gas, otherwise it will generate unpredictable results. When both present values have been determined, the calibration factor and shift were calculated automatically.

The face mask with the head cap assembly was used together with the Triple-V volume transducer for measurement of ventilation volumes. Three mask sizes are available to accommodate diverse face sizes. The head cap assembly guarantees an optimal fitting of the mask to the subject's head. A Nafion drying tube was used to guarantee a constant humidity during the measurement. The MetaMax I system is powered either from mains or from a lead acid cell battery with a 1.5 hour working time. The telemetry system downloads data to a computer every 10 seconds up to a distance of 2000 metres. The validity of the MetaMax I has been evaluated by comparisons to Douglas bag measurements and by comparisons to other validated stationary devices by Schulz et al. (1997), Coetsee (1998/99), Meyer et al. (2001), and Medbo et al. (2002).

In the study of Schulz et al. (1997) the comparison between the MetaMax I and the Oxycon Gamma measurements revealed no significant differences in oxygen uptake (F = 0.97) and carbon dioxide production (F = 0.90). Measurements were done on fifteen subjects during an incremental cycle ergometry test. Coetsee (1998/99) validated the MetaMax I by comparing it with the Oxycon Sigma. Fifteen male subjects performed a graded exercise test on the treadmill. The measurements of the MetaMax I may differ from the Oxycon Sigma measurements as the ratio limits of agreement were - 11% to + 10% for the oxygen uptake, - 11% to + 6% for the carbon dioxide production, and - 0% to + 22% for the minute ventilation. The breathing frequency as well as the tidal volume followed the same pattern as the ventilation volume. The respiratory exchange ratio measurements indicated limits of agreement of - 9% to + 4%, for measured gas concentrations for oxygen - 0% to + 6%, measured gas concentrations for carbon dioxide - 4% to + 19%. The findings of Coetsee (1998/99) were that the MetaMax I gave comparable data and can be regarded as valid, provided that subjects are working at a steady rate. Reliability testing in sports medicine depends on testing for systematic differences, reporting the degree of linear relationship as well as giving an impression of the absolute error size between two consecutive determinations. Meyer et al. (2001) investigated the reliability of the MetaMax I in 19 subjects. After a habitual trial, all subjects performed two identical ramp protocols on a cycle ergometer. No systematic differences between the two measurements of oxygen uptake and minute ventilation were found. Intra-class coefficients of correlation were 0.984 and 0.973, respectively. A mean bias ±95% limits of agreement of 0.05±0.25 $L \cdot min^{-1}$ for the oxygen uptake and 1.0±8.0 $L \cdot min^{-1}$ for the minute ventilation was revealed. This indicated that the MetaMax I for the measurement of gas exchange parameters produce reproducible results. Medbo et al. (2002) examined the MetaMax I in subjects either on the treadmill or on a cycle ergometer and comparing it with the Douglas bag. The error of regression for the oxygen uptake was 2% to 3% in comparison to the measurements of oxygen uptake of the Douglas bag. Minute ventilation measured by the MetaMax I was slightly lower, the fractional extraction of oxygen uptake slightly higher compared to the Douglas bag. The respiratory exchange ratio reported by the MetaMax I, was in good agreement with the Douglas bag. This study suggested that the oxygen uptake recorded by the MetaMax I was precisely measured within the subjects, although some systematic errors occurred between the subjects. In the scientific literature of Meyer et al. (2005) on portable devices used for the measurements of gas exchange during exercise, the MetaMax I could be regarded as valid and reliable and the results from the portable device did not differ appreciably from other stationary metabolic carts.

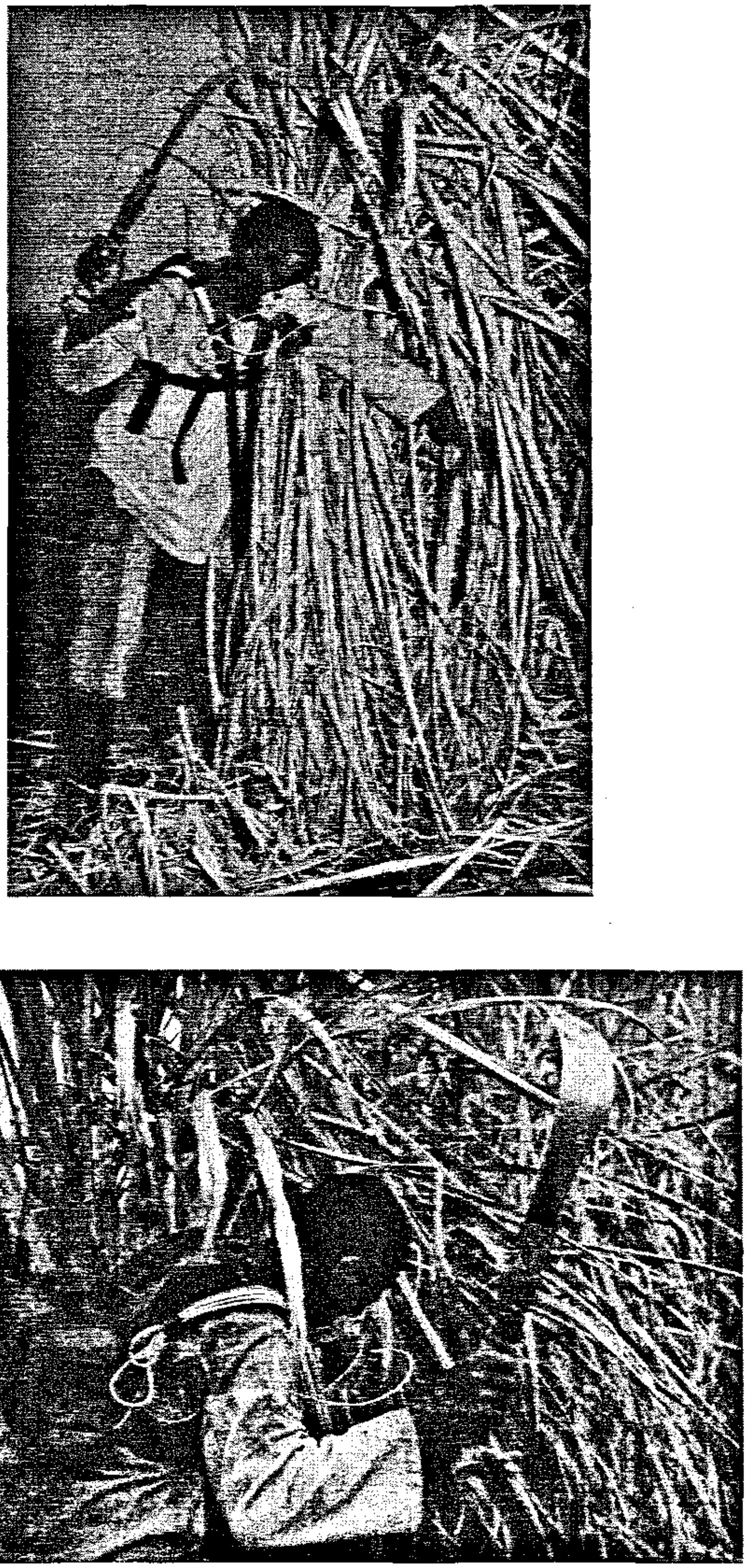

FIGURE 6. Cane cutter with the MetaMax I Ergospirometry System harvesting unburnt sugarcane

Heart rate

Heart rate (HR) or cardiac frequency is recognised as an indicator of bodily effort or stress involved in the performance of physical work. This is an indirect measure of human energy expenditure, given the relatively linear relationship between heart rate and the volume of oxygen consumed per minute.

The heart rate was measured telemetrically by means of a Polar Accurex Plus™ wrist receiver (FIN-90440, KEMPELE, Finland). The Polar Pacer transmitter with grooved electrode areas was attached to the elastic strap. The strap was adjusted to fit snugly and comfortably around the subject's chest, at the level of the inferior border of the pectoralis major muscle. This device transmits impulses, parallel to the cardiac frequency, to the receiver of the MetaMax I base unit. The best position for the heart rate receiver is near the transmitter, as placement of the receiver near the MetaMax I may cause interference.

In addition to the heart rate recording by the MetaMax I, the telemetric Polar Accurex Plus™ wrist receiver was also used. The watch was coded to avoid interference caused by other users of heart rate monitors. The watch consisted of a portable heart rate monitor and recorder, which was set at a 60-second interval. After data collection, the heart rate data were downloaded via a Polar Interface Plus with Training Advisor Software onto a computer, and analysed (Appendix F).

RATINGS OF PERCEIVED EXERTION

Ratings of perceived exertion (RPE) have been found a valuable and reliable indicator when monitoring an individual's exercise tolerance (Borg, 1982). They provide a perceptual and cognitive complement to physiological responses to exercise.

Subjects were shown the Universal RPE Scale (Scott, 1990), which is a revised and simplified scale, based on the principles of the Borg scale, using diagrams, which are better understood by the subject, thereby providing the tester with more valid information. This scale was applied to evaluate the cane cutters' perceptions of effort, during harvesting burnt and unburnt cane as well as the implementation of different cane knives. The subjects were familiarised with the principle that the numbers from 6 to 20 are descriptive terms, which represent their perception of effort or work intensity. Thus, "6" equals very, very light and "20" equals very, very hard. Subjects were verbally informed on how to respond to the "6" to "20" point scale.

Ratings of perceived exertion were recorded every 10 minutes, presenting a clearly readable and visible Universal RPE Scale. The subject was instructed by the researcher to point out the appropriate diagram on the scale that most accurately reflected his perception of strain at that point in time. The procedure was repeated three times until the end of the 30-minute test period.

MEASUREMENT OF WORKING EFFICIENCY

The subject's working efficiency was expressed as a ratio between the energy expended against the workload performed. Work output was measured by means of accurately collecting and weighing the amount of cane cut during the different experimental conditions. Through incorporating this ratio, alternative ways of performing the same task were compared with each other, namely, the demands of the work placed on the physiological system of the cane cutter harvesting burnt or unburnt cane and the use of different cane harvesting implements. Working efficiency was expressed as:

1. Amount of cane harvested per minute or rate of productivity, expressed as kg cane · min^{-1};
2. energy required in kilojoules to cut one kilogram of cane, expressed as kJ · kg^{-1} cane;
3. amount of cane cut per litre of oxygen consumed, expressed as kg cane · L O_2^{-1};
4. number of cutting strokes;
5. number of stalks cut per stroke.

The recording of the number of cutting strokes per minute, related to the strokes needed to cut the stalk of the cane only, and not the strokes required for the purposes of trashing.

CLIMATIC PARAMETERS

To assess environmental conditions during the study the ambient air temperatures were measured by means of a Barigo Chip 907 Electronic Hygrometer displaying the relative humidity and dry bulb readings during each test period. Recording of all experimental conditions took place between 05h00 and 09h00.

THE EXPERIMENTAL PROTOCOL

ANTHROPOMETRIC MEASURES

Anthropometric measures included stature, body mass and percentage of body fat. Percentage body fat was calculated from skinfold measures of four sites: triceps, subscapular, biceps and suprailiac as described by Durnin and Womersley (1974). Anthropometric measures were taken on a separate occasion. A comprehensive description of the anthropometric measures and procedures is presented on pages 68 to 71.

PHYSIOLOGICAL PARAMETERS AND SELECTED MEASURES FOR WORKING EFFICIENCY HARVESTING BURNT AND UNBURNT CANE

The recordings were conducted on two consecutive occasions, separated by at least 3 to 6 days, harvesting burnt and unburnt cane. The short handle curved blade knife was implemented for both burnt and unburnt cane. A test period of 30 minutes was allocated to each of the subjects. An additional five minutes were used as a warm up to reach steady rate. Only the data from the 5^{th} until the 34^{th} minute were taken into consideration for the measurement of oxygen consumption and corresponding energy expenditure.

Subjects were divided into groups of four and were chosen at random, and not selected on the basis of productivity. Thus, four subjects were measured each day in the cane field from 05h00 to 09h00. Consequently, the first subject did not work prior to the test, whereas the second subject had been working for approximately one hour, the third subject two hours and the fourth subject, three hours before undergoing the testing procedure. This order was changed with every experimental condition. For the experimental condition in burnt cane, the cane field was burnt on the same morning.

PHYSIOLOGICAL PARAMETERS AND SELECTED MEASURES FOR WORKING EFFICIENCY USING THE SHORT HANDLE CURVED BLADE KNIFE AND THE LONG HANDLE CURVED BLADE KNIFE IN BURNT CANE

The recordings were conducted on two consecutive occasions, to guard against the characteristics of one knife confounding those of the other. Recordings for the different knives took place over a period of between 1 to 10 days. A test period of 30 minutes was allocated to each of the subjects, of which the first five minutes were used as a warm up to reach steady rate.

Therefore, the data from the 5th until the 34th minute were taken into consideration for the measurement and analysis of the physiological parameters, using a short handle curved blade and a long handle curved blade cane knife in burnt cane.

Each day, four subjects were measured in the cane field from 05h00 to 09h00. Consequently, the first subject did not work prior to the test, whereas the second subject had been working for approximately one hour, the third subject two hours and the fourth subject, three hours before undergoing the testing procedure. This order was changed with every experimental condition. For the experimental condition in burnt cane, the cane field was burnt on the same morning. The different measurements were randomly allocated and coordinated with the harvesting plan of the estate and with respect to the climatic conditions. Therefore, each cane cutter harvested cane under six different experimental conditions. It took approximately six to ten days per subject to complete the different experimental conditions.

Metabolic measurement protocol

The following procedures were adopted before, during and after the 30-minute recording time for the different experimental conditions for harvesting burnt and unburnt cane as well as the different experimental conditions for the short handle curved blade knife and the long handle curved blade knife in burnt cane:

1. The MetaMax I was switched on and warmed up for at least 30 minutes before calibration.
2. The MetaMax I was calibrated in the cane field using known calibration gases. Not more than 10 minutes have passed between calibration and the actual measurements.
3. The ambient air temperature and relative humidity were recorded.

4. The Polar Pacer Transmitter was attached to the elastic strap. The strap was adjusted to fit snugly and comfortably around the subject's chest, at the level of the inferior border of the pectoralis major muscle. The telemetric Polar Accurex Plus™ wrist receiver was placed on the subject's wrist of the right hand.
5. The MetaMax I was placed into a backpack and mounted firmly onto the subject's back.
6. The face mask with the head cap assembly, together with the Triple-V volume transducer was fitted onto the subject's face. All cables were adjusted to ensure free movement of the subject's shoulders, arms and upper body.
7. The subject commenced harvesting the cane for a continuous period of 35 minutes of which five minutes were allocated as a warm up to ensure that the cane cutter had reached a steady rate. Therefore, only data from the 5^{th} until the 34^{th} minute were taken into consideration for the calculation and analysis of the oxygen uptake and corresponding energy expenditure measurements.
8. The MetaMax I continuously sampled the metabolic measures at 10-second intervals.
9. Heart rate was measured every 60 seconds.
10. The number of cane cutting strokes per minute was recorded twice for a period of two minutes each. These recordings were made from minute 5 to 7 and again from minute 11 to 13.
11. The number of stalks cut per stroke was recorded twice for a period of 1 minute, from minute 8 to 9 and again from minute 15 to 16.
12. Ratings of perceived exertion (RPE) were recorded every 10 minutes, presenting a clearly readable and visible Universal RPE Scale at minutes 9, 19 and 29. The subject had to point out and verbalise the appropriate diagram on the Universal RPE Scale that most accurately reflected his perception of strain at that point in time. Thus, a total of three RPE recordings per experimental condition were conducted.

13. After the completion of the test, the face mask, MetaMax I and heart rate monitor were removed from the subject and the subject returned to his work.
14. The harvested cane was carefully sampled and weighed by means of a Salter Brecknell mechanical hanging scale. The harvested cane was measured in kilograms and recorded to the nearest 100 grams, with a required accuracy of <0.2 kg.

SUBJECT OBSERVATION AND UNOBTRUSIVE OBSERVATION

Subjects selected to participate in research, usually show an increase in their productivity. The validity of selected measurements could be questioned if subject observation interaction poses a problem. Therefore, the collection of data through unobtrusive observation should be considered to demonstrate the presence of a Hawthorne effect or at least to determine the magnitude of such an effect. The effect of obtrusive observation interaction on the subjects' performance was determined during the collection of data by means of the MetaMax I, as the researcher and the research assistant continuously observed the cane cutters during the experimental condition. For the unobtrusive observation interaction, only heart rate measures were taken over an 1-hour period by means of the Polar Accurex Plus™ wrist receiver. The Polar Pacer Transmitter transmitted impulses parallel to the cardiac frequency to the Polar Accurex Plus™ wrist receiver on the cane cutter's wrist. The cane cutters were instructed to work *ad libitum*. This investigation was done to determine the cane cutters' habitual activity and they were examined during all experimental conditions: harvesting burnt and unburnt cane with the short handle curved blade knife, and using the short handle curved blade knife and the long handle curved blade knife in burnt cane. Recordings for subject observation and nonobtrusive observation varied over a period of between 1 to 18 days.

After the data collection, the average heart rate during cane harvesting was related to the oxygen consumption, measured by the MetaMax I, using the corresponding heart rate. From this, the energy expenditure could be estimated. The following procedure was adopted before, during and after the measurements:

1. The coded Polar Pacer transmitter was attached to the elastic strap and secured around the chest.
2. The Polar Accurex Plus™ wrist receiver was placed on the arm of the subject.
3. The ambient air temperature and relative humidity were recorded.
4. Subjects were instructed to work *ad libitum* for 1 hour.
5. The Polar Accurex Plus™ wrist receiver was activated at the start of work and the heart rate recording was stopped after one hour. The Polar Accurex Plus™ wrist receiver and Polar Pacer transmitter were removed and the recorded data downloaded onto the computer for analysis.
6. The harvested cane was carefully sampled and weighed by means of a Salter Brecknell mechanical hanging scale. The harvested cane was measured in kilograms and recorded to the nearest 100 grams, with a required accuracy of <0.2 kg.

STATISTICAL ANALYSIS

In addition to the descriptive statistics, the principal statistical treatment of the results was the analysis of covariance (ANCOVA) in order to compare variables. ANCOVA is a combination of simple linear regression analysis with a one-way analysis of variance. Both a quantitative variable (x) and an ANOVA grouping variable are used to describe the measurement (y) variable. Covariance is used when the response variable (y), in addition to being affected by the treatments, is also linearly related to another variable (x). It is useful as it increases precision in an experiment, controls for an extraneous variable and compares regressions among several groups. The significance level for all experimental conditions was established at $p<0.05$, unless otherwise indicated. All statistics were done by an independent statistician using the BMDP Statistical Software Package (1993), Version 7.0.

CHAPTER FOUR

RESULTS AND DISCUSSION

INTRODUCTION

The focus of this study was to investigate the effects in harvesting burnt and unburnt cane on the physiological system of the cane cutter *in situ*. This section critically examines the physiological parameters and work efficiency of the cane cutter, comparing these parameters with previous studies in sugarcane harvesting and discussing the apparent similarities and differences between harvesting burnt and unburnt cane.

The second area of analysis was to investigate the effects of implementing different designs in cane knives on the cane cutter's physiological system and work efficiency. It has been argued that the use of the long handle cane knife has several advantages compared with the short handle knife.

Finally, the effects of obtrusive observation interaction on the cane cutter's performance will be discussed. This is important, as it is known that workers show an increase in their work output when observed, so that the validity of selected measurements could be questioned if subject observation interaction poses a problem.

The results and discussion are arranged under the following main headings to facilitate clarity of thought and ease of data presentation: general, burnt and unburnt sugarcane, manual sugarcane harvesting implements and subject observation and unobtrusive observation interaction.

GENERAL

CLIMATIC CONDITIONS

Climatic conditions were ascertained by the measurement of dry bulb temperatures and relative humidity for each experimental condition (Table 3). Work performed in hot or humid environments could have a significant effect on the cardiovascular system, central nervous system and motor function (McArdle et al., 1991; American College of Sports Medicine, 1995; Robergs and Roberts, 1997; Brukner and Khan, 2001). There is no well-accepted standard for determining safe upper temperature and humidity limits for testing purposes, though guidelines exist for proposed heat stress (American College of Sports Medicine, 1995).

One can conclude that the cane cutters in the present study are acclimatized to the environmental conditions of KwaZulu-Natal, as they are professional cane cutters with an average working experience of more than 12 years. Repeated exposure to hot and humid environmental conditions in combination with hard physical work, naturally results in an improved capacity for work and less discomfort upon heat exposure. Robergs and Roberts (1997) stated that chronic adaptations associated with heat acclimation consist of an increased plasma volume, an earlier onset of sweating, a decrease in the osmolality of sweat and decreased muscle glycogen degradation. This had earlier been demonstrated by Davies et al. (1976) and Collins et al. (1976) where it seemed that despite the environmental heat load, Sudanese cane cutters performing a self-paced task demanding heavy physical work, were able to sustain work levels in excess of those recommended for most European factory workers. Differences in average ambient temperature and relative humidity between the different experimental conditions in the present study were statistically insignificant, therefore insignificant in terms of affecting a difference in response.

TABLE 3. Means and standard deviations for dry bulb temperature and relative humidity measured in the cane field for the different experimental conditions

Experimental condition	Dry bulb temperature (°C)	Relative humidity (%)
Burnt cane	22.27±4.42	74.73±14.45
Unburnt cane	18.57±3.14	80.70±13.91
Short handle curved blade knife	22.27±4.42	74.73±14.45
Long handle curved blade knife	20.87±4.36	82.97±12.58
Obtrusive observation of cane cutters	21.44±3.67	79.29±12.32
Unobtrusive observation of cane cutters	19.69±4.65	79.64±15.57
All conditions combined	20.57±4.26	79.47±13.96

ANTHROPOMETRIC RESULTS

The physical characteristics of the subjects in the present investigation were taken on a separate occasion to the experimental conditions. Measurements of age, stature, body mass, percentage body fat and the sum of four skinfolds (Σ sf), namely triceps, subscapular, biceps and suprailiac, were made on the 15 professional male cane cutters (Table 4).

TABLE 4. Means and standard deviations for the physical characteristics of cane cutters in the present study

Age (years)	Stature (cm)	Body mass (kg)	Body fat (%)	Σ sf (mm)
34.13±7.50	171.85±7.54	66.27±7.42	13.45±4.84	26.77±10.18

According to the South African Sugarcane Research Institute (2004b), the average age of cane cutters is increasing. Young men are less inclined to become cane cutters than before and as a group, they are also more vulnerable to AIDS, and their death rate is much higher than it used to be. In the present study the ages ranged from 23 to 45 years. In previous studies of cane cutters the following mean ages in years were reported: 26.8±4.7 (Davies, 1973), 29.8±6.7 ranging from 18 to 56 years (Spurr et al., 1975), 20.6±1.7 for the younger group of cane cutters ranging from 16 and 24 years and 31.9±7.9 for the older age group ranging from 25 to 45 years (Collins et al., 1976), 42.70±8.8 ranging from 27 to 63 years (Immink et al., 1987) and 32.80±2.1 (Lambert et al., 1994). The physical characteristics of cane cutters in terms of the stature and body mass in the present study, compare well to the findings of Lambert et al. (1994) on South African cane cutters. In the present study, cane cutters' stature and body mass were slightly greater.

Immink et al. (1987) found the body composition of a group of Guatemalan cane cutters unrelated to levels of productivity. At the start of the cane cutting season, when the demand for labour was low, the trend in productivity during the cutting season was equal among workers with different body composition, thus body composition was not a limiting factor in productivity. The fat reserves of workers with a relatively high initial mean skinfold value decreased during the season, the pattern of change in their productivity was not different from workers with initially low mean skinfold values. He further made the suggestion that workers with a history of employment in physically demanding occupations, respond positively as long as energy availability places no restriction on energy to be expended to maintain a specific level of productivity. Furthermore, the optimal body composition for cane cutting may be muscular and lean. In addition, Davies (1973) found no association between the various indices of body composition and the total productivity for the season. However for daily productivity, significant relationships were shown in the younger cane cutters (18 to 35 years), but in older cane cutters (over 35 years), these relationships disappeared. It could therefore be concluded that factors, other than body composition, influence the productivity. These include the cane cutter's skill, method of harvesting, physical condition and motivation, the quality and state of the cane, whether it is straight or lodged, the terrain (flat or steep topography) and environmental conditions (Lambert et al., 1994). Spurr et al. (1977) measured the VO_2 max and daily productivity in 46 cane cutters. A multiple regression analysis demonstrated that productivity was affected by VO_2 max. Anthropometrical results from similar studies on cane cutters, along with the results of the present study, are presented in Table 5.

TABLE 5. Means and standard deviations for stature, body mass and sum of four skinfolds (Σ sf) of cane cutters in general

Country	Stature (cm)	Body mass (kg)	Σ sf (mm)	AUTHOR(S)
Tanzania	165.9±5.2	62.2±5.3	23.2±4.0	Davies (1973)
Rhodesia Australia	- -	61.0±8.5 75.0±5.2	- -	Morrison & Blake (1974)
Colombia	163.3±6.7	58.6±6.5	-	Spurr et al. (1975)
Egypt	173.8±6.1* 172.8±7.5#	59.2±6.7* 58.0±7.1#	22.7±4.8* 21.1±4.3#	Collins et al. (1976)
Guatemala	158.4±5.6	54.6±6.8	-	Immink et al. (1987)
South Africa	169.2±1.9	64.2±2.4	-	Lambert et al. (1994)
South Africa	171.85±7.54	66.27±7.42	26.77±10.18	Present study

* Representative of age group 16 to 24 years

\# Representative of age group 25 to 45 years

The work experience of the cane cutters in the present study in harvesting cane ranged from 5 to 26 years with a mean value of 12.18±7.32 years. Cane cutters with more than 10 years' experience had a 17.44% higher rate of productivity compared to cane cutters with between five to 10 years' working experience. In the study of Collins et al. (1976) on Sudanese cane cutters the number of seasons' experience in cutting ranged from one to five or more seasons, with an average number of seasons' experience of 1.4±1.46. The number of seasons' experience was regarded as one of the factors which positively related to age and mean production. Spurr et al. (1975) reported the work experience of Colombian cane cutters to vary between 9 months and 17 years with the majority reporting 2 to 6 years of experience.

BURNT AND UNBURNT SUGARCANE

Data demonstrated a marked difference of response between harvesting burnt and unburnt cane with regard to the physiological parameters and the selected measures for working efficiency. With the exception of heart rate and ratings of perceived exertion (RPE), all other measured values were statistically different ($p<0.05$).

PHYSIOLOGICAL PARAMETERS

The physiological parameters of cane cutters in harvesting burnt and unburnt cane are summarised in Table 6.

TABLE 6. Means and standard deviations for absolute (Abs VO_2) and relative oxygen consumption (Rel VO_2), absolute (Abs EE) and relative energy expenditure (Rel EE), mean and peak heart rate (HR), along with the level of significance in burnt and unburnt cane

Physiological parameters	Burnt	Unburnt	Significance
Abs VO_2 ($L \cdot min^{-1}$)	1.95±0.45	2.19±0.35	p<0.01
Rel VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	29.85±7.88	33.42±5.74	p<0.05
Abs EE ($kJ \cdot min^{-1}$)	40.76±9.49	45.93±7.45	p<0.05
Rel EE ($kJ \cdot min^{-1} \cdot kg^{-1}$)	0.63±0.17	0.70±0.12	p<0.05
Mean HR ($beats \cdot min^{-1}$)	119.80±18.61	123.67±13.23	p>0.05
Peak HR ($beats \cdot min^{-1}$)	131.13±19.16	135.93±14.32	p>0.05

After an initial 5 minutes to reach the steady rate level of work, the measurements commenced. Absolute average oxygen consumption was highly significant ($p<0.01$) and the calculated average absolute energy expenditure significantly different ($p<0.05$) for cane cutters in burnt and unburnt cane. Average relative oxygen consumption and calculated average relative energy expenditure of cane cutters in harvesting burnt cane were both significantly lower ($p<0.05$) than for unburnt cane. The following percentage differences are reported in favour of harvesting burnt cane: absolute oxygen consumption of 10.96%, absolute energy expenditure of 11.26%, relative oxygen consumption of 10.68%, and relative energy expenditure of 10%. A previous study done on South African cane cutters (Lambert et al., 1994) has shown an absolute energy expenditure of 1577 ± 130 kJ $\cdot$ h^{-1} during a full working day. It is unclear whether harvesting took place in burnt or unburnt cane, which makes comparison difficult. When one converts the above-mentioned absolute energy expenditure to kilojoules per minute, it equals 26.28 ± 2.17 kJ $\cdot$ min^{-1}. The present study yielded a much higher energy cost, i.e. 40.76 ± 9.49 kJ $\cdot$ min^{-1} in burnt cane and 45.93 ± 7.45 kJ $\cdot$ min^{-1} in unburnt cane, 35.53% and 42.78% respectively. This was linked unquestionably to the higher rate of productivity in burnt and unburnt cane in the present study compared to the lower values of productivity of cane cutters in the study of Lambert et al. (1994).

Mean and peak heart rates during work showed no significant differences between burnt or unburnt cane. The percentage differences were 3.13% and 3.53% for mean and peak heart rate, respectively, between burnt and unburnt cane, with the latter being higher in unburnt cane. This implies that cutting burnt and unburnt cane produces similar peak and mean levels of exertion, as indicated by the heart rate response. Though statistically insignificant, cane cutters do indeed respond with a marginally higher mean and peak heart rate in harvesting unburnt cane. The most common method for calculating maximal heart rate is 220 minus age (American College of Sports Medicine, 1995), from which it can be deduced that the cane cutters in the present study whose average age was 34.13 years, had a maximal heart rate of 185.87 beats $\cdot$ min^{-1}.

The average predicted work intensity, calculated as the mean heart rate expressed as a percentage of the predicted maximal heart rate in harvesting burnt cane, was less (64.45% of predicted maximal heart rate) than that in unburnt cane (66.54% of predicted maximal heart rate). Harvesting unburnt cane produced a higher peak heart rate (73.13% of predicted maximal heart rate) compared with burnt cane (70.55% of predicted maximal heart rate). The figures for absolute oxygen consumption ($L \cdot min^{-1}$) were highly comparable with those of other researchers: 1.69±0.34 and 1.90±0.44 (Morrison and Blake, 1974), 1.62±0.32 (Collins et al., 1976) in burnt cane, and 1.42±0.15 (Morrison and Blake, 1974) and 1.46±0.34 (Spurr et al., 1975) in unburnt cane. It has been previously reported by Spurr et al. (1975) that the relative oxygen consumption in unburnt cane was 25.2±5.6 $ml \cdot kg^{-1} \cdot min^{-1}$, which agrees with the findings in the present study. Severity of work, i.e. harvesting burnt or unburnt cane, could be classified in terms of absolute oxygen consumption, absolute energy expenditure and relative energy expenditure (Åstrand and Rodahl, 1986; Bridger, 1995). This would tend to indicate that harvesting burnt cane is classified as heavy to very heavy work, whilst harvesting unburnt cane is considered to be heavy to extremely heavy work. Both the oxygen consumption and the energy expenditure data are in the upper level of the range found in manual labour. An eight-hour daily caloric expenditure may be estimated, which approximates to 19 565±4555 $kJ \cdot day^{-1}$ for harvesting burnt cane and 22 046±3576 $kJ \cdot day^{-1}$ for unburnt cane. In general, work of this intensity, cannot be sustained continuously over an eight-hour day, and should rather be carried out sporadically, interspersed with frequent rest periods. Data from previous analysis of daily energy expenditure by Lambert et al. (1994) on South African cane cutters, showed the figure to be 11 695±1288 kJ for a working day, where the voluntary working time for cane cutters was 7 hours and 19 minutes. This figure when converted, points to an energy expenditure during an eight-hour day of approximately 12 787±1408 $kJ \cdot day^{-1}$. It is however not clear whether these figures were obtained during harvesting of burnt or unburnt cane.

Mean heart rate measures (Burnt = 119.80±18.61 beats · min^{-1} and Unburnt = 123.67±13.23 beats · min^{-1}) during cane harvesting in the present study agree with the findings of Collins et al. (1976) with 132±16 beats · min^{-1} and Lambert et al. (1994) with 103±3 beats · min^{-1}. Lambert et al. (1994) reported an average predicted work intensity of 54±1% for South African cane cutters. Conversely, there was no relationship between total average heart rate and productivity. Davies (1973) measured the heart by palpation during the first 10 seconds of recovery. High producers in cutting had a heart rate of 118 beats · min^{-1}, medium producers 123 beats · min^{-1} and the low producers 124 beats · min^{-1} at a fixed oxygen consumption of 1.5 L · min^{-1}. In the same study, average maximal heart rates during cutting burnt cane and unburnt cane, were 131.13 and 135.87 beats · min^{-1}, respectively. Bearing this in mind, these heart rate measures can be classified as heavy work (Åstrand and Rodahl, 1986; Bridger, 1995).

Spurr et al. (1975) found the average heart rates for the top, medium and low cane cutters to be 123±9, 133±7, and 141±20 beats · min^{-1}, respectively. The lower heart rate of the top producers at a given workload indicated that they were in a better physical condition than the poorer producers were. The trends illustrating the differences in the oxygen consumption, energy expenditure and heart rate between the two conditions (burnt and unburnt cane) were in line with expectations of this study.

It was previously stated by Jørgensen (1985) that one should exercise some caution estimating the oxygen consumption and energy expenditure from recorded heart rate data, as seen in previous studies on cane cutters, as they are subject to considerable inaccuracy. This raises the question about classification systems for physical workload, based on either relatively short measurements and/or measurements in which subjects were influenced by external factors.

RATINGS OF PERCEIVED EXERTION

Ratings of perceived exertion (RPE) were recorded every 10 minutes, thus a total of three RPE recordings were done to evaluate the degree of general fatigue experienced by the cane cutters during work. According to Borg (1982) the RPE scale is a valuable and reliable indicator when monitoring an individual's work tolerance. It provides a perceptual and cognitive complement to physiological responses to work such as heart rate and respiratory changes. Scott (1990) considers the Universal RPE Scale an acceptable method to evaluate subjective assessment of work intensity. The Universal RPE Scale is a revised and simplified scale using diagrams.

Measures for RPE showed no significant differences between harvesting burnt and unburnt cane ($p>0.05$). The mean RPE values for burnt and unburnt cane were 11.71±1.88 and 11.13±2.27, respectively, reflecting only a 4.95% difference. These measures are representative of fairly light work according to the Borg scale (Borg, 1982) and the Universal RPE scale (Scott, 1990). Interestingly, harvesting unburnt cane is expected to give rise to higher RPE values given the fact that it is physically more demanding compared with harvesting burnt cane as unburnt cane has to be trashed. The majority of cane cutters in the present study indicated, by means of a questionnaire, their preference for harvesting unburnt cane. One might postulate, as the wage for unburnt cane is higher, cane cutters preferred harvesting unburnt cane even though trashing is a less efficient method of harvesting cane because of the work involved in stripping the leaves from the stalks. The contention that harvesting unburnt cane is rated as less strenuous by the cane cutters is congruent with the observations made by Morrison and Blake (1974), who stated that the energy expenditure in harvesting unburnt cane was 25% lower, and the productivity during trashing, considerably lower than when harvesting burnt cane. It may well be that trashing is experienced as less strenuous and serves as a period of recuperation. A further explanation for the lower energy expenditure in unburnt cane is probably that cane cutters pace themselves, therefore exerting themselves equally in harvesting burnt and unburnt cane. The outcome would be a lower rate of productivity in unburnt cane. Kilbom (1990) points out that the level of activity is self-regulatory whereby the rate of work and the spacing of rest pauses are set by the individual's level of physical fitness. Åstrand (1967) proceeds from the assumption that workers involved in manual labour, who are free to set their own pace, normally accept working with an energy expenditure which is less than 40% of their individual maximal oxygen consumption.

However, as the RPE responses were statistically the same, and the cane cutters worked at a higher percentage of their oxygen consumption in harvesting unburnt cane, this raises the possible question of whether RPE is an accurate method to assess one's tolerance for work. Further, the relatively low rating of 11 is in contradiction with other physiological responses such as oxygen consumption, energy expenditure and heart rate, which are classified as heavy to extremely heavy work. As cane cutters are used to this high intensity of work, experienced cane cutters exhibiting highly skilled methods, actually "underestimate" their exertion. Ladoucier and Carrier (1983) stated that when individuals experience the stress of physical work, cognitive coping strategies are undoubtedly applied, irrespective of intensity. Bridger (1995) investigated the workload and fatigue in highly trained subjects. A discrepancy was found between ratings of perceived exertion and objective physiological measures, with the subjects underestimating the actual workload. Though the RPE measures were statistically insignificant, harvesting unburnt cane does indeed respond with a marginally higher RPE.

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WORKING EFFICIENCY

The following parameters were ascertained with regard to selected measures for working efficiency: rate of productivity (kg cane · min^{-1}), energy required in kilojoules to harvest one kilogram of cane (kJ · kg^{-1} cane), amount of cane harvested per litre of oxygen consumed (kg cane · L O_2^{-1}), number of cutting strokes per minute and number of stalks cut per stroke. The means and standard deviations of these parameters of working efficiency are displayed in Table 7.

TABLE 7. Means and standard deviations for working efficiency, expressed as rate of productivity, energy required in kilojoules to harvest one kilogram of cane (Efficiency kJ), amount of cane harvested per litre of oxygen consumed (Efficiency kg), number of cutting strokes per minute and number of stalks cut per stroke, along with the level of significance in burnt and unburnt cane

Parameters	Burnt	Unburnt	Significance
Rate of productivity (kg cane · min^{-1})	30.30±11.52	22.98±5.86	$p<0.01$
Efficiency kJ (kJ · kg^{-1} cane)	1.51±0.58	2.13±0.61	$p<0.01$
Efficiency kg (kg cane · L O_2^{-1})	16.43±8.61	10.62±2.79	$p<0.01$
Number of strokes per minute	34.42±6.87	25.45±3.30	$p<0.05$
Number of stalks per stroke	2.45±0.37	2.55±0.49	$p<0.05$

The rate of productivity for burnt cane was significantly higher (24.16%) than that for unburnt cane. Lambert et al. (1994) observed a mean productivity of 9.0±0.7 tons per day or 1227±78 kg per hour, which approximates to 20.45±1.3 kg cane · min^{-1}. However, it is not clear whether burnt or unburnt cane was harvested. The investigation of Morrison and Blake (1974) indicated an average output of 60.0±17 kg · min^{-1} in burnt cane and 9.0±1.6 kg · min^{-1} in unburnt cane for Rhodesian cane cutters. It was mentioned that normally the rate of productivity in burnt cane for Rhodesian cane cutters was 40 kg · min^{-1} and the increased value of 60 kg · min^{-1} was related to a higher than normal rate due to the presence of observers. The reason given by Morrison and Blake (1974), for the low rate of productivity in unburnt cane was the fact that trashing is a slower and less efficient method of harvesting cane. The cutting rate was also low because stripping of the leaves is best done when 1-2 stalks are cut at a time. In the same study, Australian cane cutters had an average output of 85.0±13 kg · min^{-1} in burnt cane. Compared with Rhodesian cane cutters harvesting unburnt cane, the cane cutters in the present study exhibited a higher rate of productivity that approximated to two and a half times more. Davies (1973) divided East African sugarcane cutters into three groups according to their relative output in kilotons per day for unburnt cane. The high producers had a mean output of 3.51, medium producers 3.04 and low producers 2.60 kilotons per day, which approximate to 7.31, 6.33 and 5.42 kg · min^{-1} for the three groups, respectively. Spurr et al. (1975) have indicated a daily productivity varying from 2.12 to 5.22 tons per day and a mean *productivity of 3.52±0.72 tons per day or 7.33±1.5 kg · min^{-1} in unburnt cane.* Spurr et al. (1975) also divided the cane cutters into three groups according to their productivity. The top producers had a mean output of in excess of 4.48±0.37 (9.33±0.77 kg · min^{-1}), the medium producers 3.62±0.24 (7.54±0.5 kg · min^{-1}) and the low producers 2.63±0.29 (5.47±0.6 kg · min^{-1}) tons per day, respectively. The mean daily weight of cane cut for the Sudanese cane cutters was 14.08±3.03 kg · min^{-1} (Collins et al., 1976), which was lower compared with the cane cutters in the present study. Immink et al. (1987) reported the productivity of Guatemalan cane cutters in burnt cane to be 3.65±0.88 tons per day, which approximates to 7.6±1.8 kg · min^{-1}. If one takes cognisance of previous studies, which examined the average work output, one can observe that the rate of productivity of cane cutters in the present study in burnt cane was relatively high, with the exception of the Rhodesian and Australian cane cutters whose productivity was extremely high.

As for unburnt cane, the rate of productivity was considerably higher than previously reported values. Differences in productivity between cane cutters in the present study and those in other studies may in part be explained by the fact that they had more work experience and that harvesting was performed under relatively mild climatic conditions. Different times during the harvesting season, technique and skill involved, level of motivation and the condition of the cane all may have had a positive influence on their productivity. In addition, data recorded were applicable to the harvesting operation only, therefore, excluding other operations such as stacking.

Energy required to cut one kilogram of burnt cane was significantly lower than that for unburnt cane, with a difference of 29.11% in favour of burnt cane. The amount of cane cut per litre of oxygen consumed in burnt cane was significantly greater (35.36%) than that for unburnt cane. One might draw a tentative conclusion from the above that harvesting burnt cane is more efficient and economical compared with unburnt cane. Spurr et al. (1975) also calculated the energy expenditure (kcal) per kilogram of sugarcane cut from the cane cutters' oxygen consumption and the weight of the cut cane, to express the working efficiency. These values were compared in the morning and afternoon, with afternoon values being less. They reported a decrease in the energy expenditure per kilogram of cut cane from 0.676±0.159 kcal $\cdot$ kg^{-1} cane (2.83±0.67 kJ $\cdot$ kg^{-1} cane) in the morning to 0.616±0.147 kcal $\cdot$ kg^{-1} cane (2.58±0.62 kJ $\cdot$ kg^{-1} cane) in the afternoon. This would tend to suggest that an increase in efficiency of approximately 9% took place. Cane cutters in the present study were more efficient, compared with the Colombian cane cutters in the study of Spurr et al. (1975).

Interestingly enough, the number of cane cutting strokes per minute for unburnt cane was significantly lower (26.06%), than that for burnt cane. The number of stalks cut per stroke for unburnt cane was significantly higher, with 3.92%, than that for burnt cane. An explanation could be the fact that the stalks of the unburnt cane were in general, straight compared with field measurements conducted in burnt cane, where some of the stalks were lodged. Clearly, this would lead to an increase in the number of cane cutting strokes needed to harvest burnt cane, while secondly, the number of stalks cut per stroke was thereby reduced. Another factor concerns the calculation of the number of cane cutting strokes per minute: only the strokes required to cut the stalks were taken into account, and not the strokes needed for the purposes of trashing. Despite these values in unburnt cane, the total highest productivity rate, less energy required to harvest one kilogram of cane, and the greatest amount of cane harvested consuming a litre of oxygen, remained with burnt cane. Lambert et al. (1994) reported 35 strokes per minute to cut the cane. Morrison and Blake (1974) observed that the Rhodesians cut one to two stalks per stroke, whilst the Australian cane cutters grasp an average of seven stalks and cut them in two or three strokes. Analysis of the data on the selected measures for working efficiency, suggest that the cane cutters in the present study have a high degree of parity compared with previous studies in manual cane harvesting.

MANUAL SUGARCANE HARVESTING IMPLEMENTS

Data collected indicated no significant differences in any of the measured variables for the comparison of the short handle curved blade knife with the long handle curved blade cane knife in burnt cane. The only major divergence was the cane cutters' ratings of perceived exertion (RPE), which was in favour of the long handle curved blade cane knife ($p<0.05$).

PHYSIOLOGICAL PARAMETERS

The physiological parameters of cane cutters in burnt cane for the short handle curved blade and long handle curved blade knives can be observed in Table 8. After an initial 5 minutes to reach the steady rate level of work, the measurements started. No significant differences ($p>0.05$) were observed in absolute and relative oxygen consumption, absolute and relative energy expenditure, and mean and peak heart rates. A counter to the above observations occurs however, if one examines the responses carefully. Though statistically insignificant ($p>0.05$), cane cutters using the long handle curved blade knife indeed showed a trend in the direction of higher absolute and relative oxygen consumption values as well as higher values for absolute and relative energy expenditure. The tentative assumption for the above was that the long handle curved blade knife had an increased mass (0.855 kg) compared with the short handle curved blade knife (0.605 kg), and secondly, more cane was cut with the long handle curved blade knife, which explains the higher physiological cost. Conversely, the mean and peak heart rates of the cane cutters during work was lower for the use of the long handle curved blade knife, which is contradictory to the oxygen consumed and energy expended by the cane cutters for this particular cane knife. Although posture and lumbar motion were not measured, it was clear that the cane cutters bent less when they used the long handle curved blade knife. The literature indicates that not all exercise elicits the same cardiac response. Dynamic exercise induces increases in heart rate, stroke volume, cardiac output and blood pressure that differ from isometric exercise. Similarly, dynamic upper body exercise, which involves a smaller muscle mass than the dynamic exercise of the larger muscles of the legs, also elicits a slightly different cardiac response. Arm or upper body work for a given submaximal steady rate, invokes a higher heart rate, blood pressure and ventilation response compared with lower body dynamic work. Cardiac output is similar and understandably, stroke volume is lower (Robergs and Roberts, 1997). Bridger et al. (1997) compared the energy expenditure required using a two-handled (levered) shovel with a conventional shovel. No statistical differences in energy expenditure were found, although heart rate was slightly higher using the levered tool. Oxygen consumption of coal miners was increased when working in a stooped position, while the heart rate was not significantly affected by this working position (Gallagher, 1991). Of the many plausible factors influencing the heart rate response, differences in physiological measures are probably explained by a combination of factors such as body position, orthostatic pressure, cardiac output, neural and humoral factors influencing ventilation, and venous return. Many of these were beyond the scope of this study. One might hypothesise that a greater number of subjects would have increased the significance of the results in terms of the physiological parameters.

TABLE 8. Means and standard deviations for absolute (Abs VO_2) and relative oxygen consumption (Rel VO_2), absolute (Abs EE) and relative energy expenditure (Rel EE), mean and peak heart rate (HR), along with the level of significance in burnt cane for the short handle and long handle curved blade knives

Physiological parameters	Short handle curved blade	Long handle curved blade	Significance
Abs VO_2 ($L \cdot min^{-1}$)	1.95±0.45	2.02±0.39	p>0.05
Rel VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	29.85±7.88	30.95±7.24	p>0.05
Abs EE ($kJ \cdot min^{-1}$)	40.76±9.49	42.40±8.18	p>0.05
Rel EE ($kJ \cdot min^{-1} \cdot kg^{-1}$)	0.63±0.17	0.65±0.15	p>0.05
Mean HR ($beats \cdot min^{-1}$)	119.80±18.61	115.80±14.16	p>0.05
Peak HR ($beats \cdot min^{-1}$)	131.13±19.16	127.57±15.34	p>0.05

RATINGS OF PERCEIVED EXERTION

The difference in RPE between the different harvesting knives was 11.71 for the short handle curved blade knife and 10.58 for the long handle curved blade knife, both knives representing "fairly light" work. For the use of the short handle curved blade knife, there was a trend towards "somewhat hard". Thus, a difference of 9.65% in favour of the long handle curved blade knife existed. All cane cutters indicated their preference for using the long handle curved blade knife.

It can therefore be concluded that neither the use of the long nor the short knife had any effect on overall energy expenditure or working efficiency and it appears to depend largely on the preference of the cane cutter for a certain knife.

WORKING EFFICIENCY

The working efficiency was ascertained with regard to the following selected measures: rate of productivity (kg cane · min^{-1}), energy required in kilojoules to harvest one kilogram of cane (kJ · kg^{-1} cane), amount of cane harvested per litre of oxygen consumed (kg cane · L O_2^{-1}), number of cutting strokes per minute and number of stalks cut per stroke. Table 9 provides means and standard deviations of the aforementioned parameters of working efficiency in burnt cane for the short handle and long handle curved blade cane knives.

TABLE 9. Means and standard deviations for working efficiency, expressed as rate of productivity, energy required in kilojoules to harvest one kilogram of cane (Efficiency kJ), amount of cane harvested per litre of oxygen consumed (Efficiency kg), number of cutting strokes per minute and number of stalks cut per stroke, along with the level of significance in burnt cane for the short handle and long handle curved blade knives

Parameters	Short handle	Long handle	Significance
Rate of productivity (kg cane · min^{-1})	30.30±11.52	33.31±12.37	$p>0.05$
Efficiency kJ (kJ · kg^{-1} cane)	1.51±0.58	1.37±0.36	$p>0.05$
Efficiency kg (kg cane · L O_2^{-1})	16.43±8.61	16.43±4.49	$p>0.05$
Number of strokes per minute	34.42±6.87	31.72±5.37	$p>0.05$
Number of stalks per stroke	2.45±0.37	2.68±0.52	$p>0.05$

Despite there being no statistically significant differences ($p>0.05$) between the two knives, the trend in direction of the long handle curved blade knife demonstrated a higher rate of productivity, a lower energy expenditure required to cut one kilogram of cane, and similar amounts of cane were cut consuming a litre of oxygen. In addition, the use of the long handle curved blade knife, required fewer strokes to cut the cane and a greater number of stalks could be cut per stroke compared with the short handle curved blade knife. This is supported by studies by De Beer et al. (1994) and Morrison and Blake (1974) who showed that the long handle cane knife has overcome the disadvantageous features of the short handle knife.

Values for absolute energy expenditure ($kJ \cdot min^{-1}$) in the present study would imply that manual harvesting of sugarcane is a manual labour task that requires a high metabolic rate when referred against absolute energy expenditure data of other manual labour tasks as presented by Åstrand and Rodahl (1986). Figure 7 depicts the mean values for absolute energy expenditure ($kJ \cdot min^{-1}$) of other manual labour tasks, and compares these with the values of the present study, with regard to harvesting burnt and unburnt sugarcane, as well as harvesting burnt sugarcane with the short handle curved blade knife and the long handle curved blade knife. In the literature, energy expenditure is often described in terms of kilocalories per minute. To ease the interpretation of the values in Figure 7 the data were converted from kilocalories per minute to kilojoules per minute.

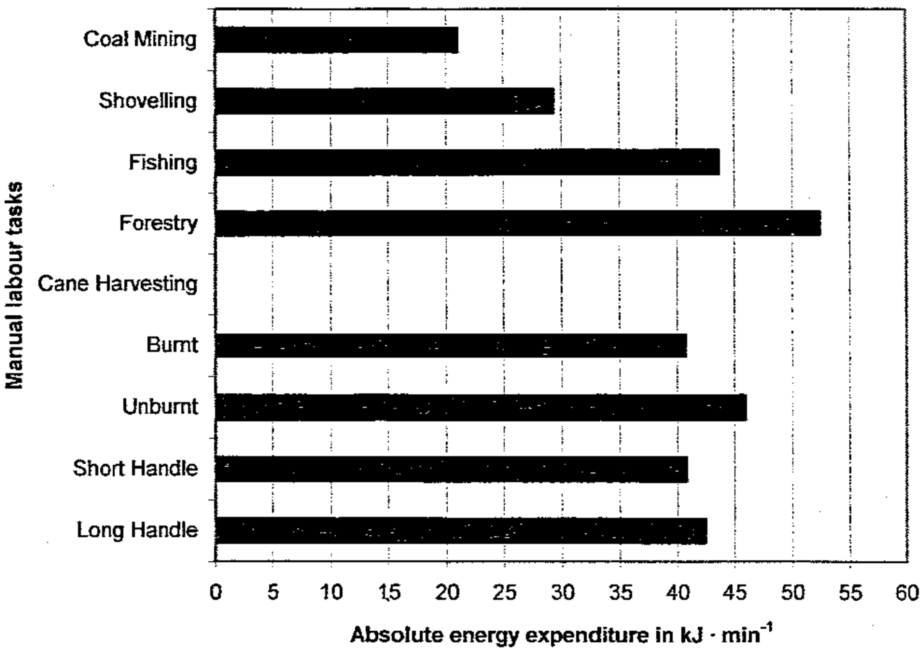


FIGURE 7. A comparison of means of absolute energy expenditures of different manual labour tasks and that found in manual cane harvesting in the present study (Adapted from Åstrand and Rodahl, 1986)

SUBJECT OBSERVATION AND UNOBTRUSIVE OBSERVATION INTERACTION

It is of interest to identify whether or not subject observation had an effect on the cane cutter's performance. The data were obtained from all conditions regarding cane cutters, i.e. short handle curved blade knife and long handle curved blade knife in burnt cane as well as short handle curved blade knife in burnt and unburnt cane.

PHYSIOLOGICAL PARAMETERS

Observation of the cane cutters during work, led to significant differences in relative oxygen consumption and relative energy expenditure as well as the mean heart rate response. The difference between subject observation and unobtrusive observation amounted to 6.14% for the relative oxygen consumption and 5.88% for the relative energy expenditure. The mean heart rate response of the cane cutters was 6.43% higher when observed. The absolute oxygen consumption (p=0.0551) and the absolute energy expenditure (p=0.0810) were both statistically reportable (Table 10).

TABLE 10. Means and standard deviations for absolute (Abs VO_2) and relative oxygen consumption (Rel VO_2), absolute (Abs EE) and relative energy expenditure (Rel EE), mean and peak heart rate (HR), along with the level of significance during subject observation and unobtrusive observation interaction

Physiological parameters	Observation	Unobtrusive observation	Significance
Abs VO_2 ($L \cdot min^{-1}$)	2.12±0.38	1.99±0.43	$p>0.05$
Rel VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	32.40±7.03	30.41±7.09	$p<0.05$
Abs EE ($kJ \cdot min^{-1}$)	44.28±8.00	41.78±9.08	$p>0.05$
Rel EE ($kJ \cdot min^{-1} \cdot kg^{-1}$)	0.68±0.15	0.64±0.15	$p<0.05$
Mean HR ($beats \cdot min^{-1}$)	123.73±15.33	115.78±15.15	$p<0.05$
Peak HR ($beats \cdot min^{-1}$)	134.27±15.91	128.82±16.97	$p>0.05$

WORKING EFFICIENCY

In line with the findings of Morrison and Blake (1974) and Spurr et al. (1975), the productivity of cane cutters during observation and measurement in the present study was found to be 11.86% higher than they sustained otherwise. Though the energy required in kilojoules to cut one kilogram of cane ($kJ \cdot kg^{-1}$ cane) was statistically insignificant ($p>0.05$), 6.94% less energy was expended, i.e. harvesting was more efficient during observation of the cane cutters. The amount of cane cut per litre of oxygen consumed (kg cane $\cdot$ $L\ O_2^{-1}$) was also statistically insignificant ($p>0.05$), out 9.65% more cane was cut during observation. Wyndham et al. (1964) proved that motivation was the most important independent factor in governing the output of South African miners. Table 11 indicates means and standard deviations for the above parameters of working efficiency. This contention appears to be supported by the findings of Åstrand and Rodahl (1986) that the test subject tends to be affected by the investigation itself.

TABLE 11. Means and standard deviations for working efficiency, expressed as rate of productivity, energy required in kilojoules to harvest one kilogram of cane (Efficiency kJ), amount of cane harvested per litre of oxygen consumed (Efficiency kg), along with the level of significance during subject observation and unobtrusive observation interaction

Parameters	Observation	Unobtrusive observation	Significance
Rate of productivity (kg cane $\cdot$ min^{-1})	30.68±10.78	27.04±11.24	$p<0.05$
Efficiency kJ ($kJ \cdot kg^{-1}$ cane)	1.61±0.60	1.73±0.64	$p>0.05$
Efficiency kg (kg cane $\cdot$ $L\ O_2^{-1}$)	15.23±7.67	13.76±4.77	$p>0.05$

With respect to metabolic cost, most studies in the literature report estimated values for oxygen consumption of cane cutters during manual cane harvesting. A distinction should be made between oxygen consumption (VO_2) and energy expenditure (kcal or kJ). Whilst mean oxygen consumption reported in the literature can be converted to energy expenditure for comparative purposes, individual or relative energy expenditure, where the energy expenditure is normalised to the cane cutter's body mass, was calculated with the present methodology. This is considered a more appropriate method, as both oxygen consumption and energy expenditure are reported, without loss of accuracy when use of mean oxygen consumption data are converted to mean energy expenditure data. Table 12 is a summary as found in the literature on the energy expenditure of cane cutters, the conditions of sugarcane, i.e. whether manual harvesting was performed in burnt and/or unburnt cane, along with the method of determining energy expenditure.

TABLE 12. Previous studies focusing on the energy expenditure of cane cutters harvesting either burnt and/or unburnt cane along with different methodologies of calculating the energy expenditure

Country	Cane	Methodology	Author(s)
Rhodesia Australia	Unburnt & Burnt	Indirect calorimetry	Morrison & Blake (1974)
Colombia	Unburnt	Indirect calorimetry	Spurr et al. (1975)
Egypt	Unknown	Indirect calorimetry	Collins et al. (1976)
South Africa	Unknown	Extrapolation of heart rate	Lambert et al. (1994)
South Africa	Burnt & Unburnt	Indirect calorimetry	Present study

An attempt has been made in this chapter to integrate the complex and diverse nature of factors contributing to an adequate understanding of manual harvesting of sugarcane. These relate specifically to the differences in physiological responses and working efficiency to harvesting burnt and unburnt cane with either the short handle curved blade knife or the long handle curved blade knife, along with the effects of subject observation and unobtrusive observation on the performance of the cane cutter. The summary, conclusions and recommendations are elucidated in Chapter Five.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

AIMS OF THE STUDY

This study sought to examine the physiological demands and working efficiency of sugarcane cutters in burnt and unburnt cane, along with the effects of using the short handle curved blade knife and the long handle curved blade knife. The study took cognisance of the fact that sugarcane harvesting is a unique form of manual labour, because of the differences in cane varieties, hot and humid climatic conditions, skills in harvesting, different cane harvesting implements and the high intensity of the work involved. Thus, the present study integrated two different conditions for cane, namely burnt and unburnt, as well as the effects of implementing different cane knives.

The questions addressed aimed firstly at determining whether harvesting burnt and unburnt cane placed different demands on the physiological system of the cane cutter and whether the working efficiency was affected in the same manner.

Secondly, the study examined whether or not significant differences existed between harvesting burnt cane with the short handle curved blade cane knife and the long handle curved blade cane knife with respect to physiological parameters and selected measures of working efficiency.

Lastly, the study endeavoured to establish whether subject observation or unobtrusive observation interaction had a significant influence on the performance of the cane cutters.

METHODS

This study entailed three areas of research, namely:

HARVESTING BURNT AND UNBURNT CANE

Subjects comprised 15 professional male cane cutters, who used the short handle curved blade knife in burnt and unburnt cane. Physiological measures included absolute and relative oxygen consumption, absolute and relative energy expenditure, and mean and peak heart rates elicited during normal work *in situ*. The selected measures of the working efficiency were rate of productivity, energy required in kilojoules to cut one kilogram of cane, amount of cane cut per litre of oxygen consumed, number of cutting strokes per minute and number of stalks cut per stroke. The MetaMax I Ergospirometry System was implemented to measure the physiological parameters, along with the telemetric Polar Accurex Plus™ heart rate monitor for heart rate measures.

SHORT HANDLE CURVED BLADE AND THE LONG HANDLE CURVED BLADE IN BURNT CANE

All subjects used both the short handle curved blade and the long handle curved blade knife in burnt cane. Physiological measures included absolute and relative oxygen consumption, absolute and relative energy expenditure, and mean and peak heart rates elicited during normal work *in situ*. The selected measures used for establishing the working efficiency were rate of productivity, energy required in kilojoules to cut one kilogram of cane, amount of cane cut per litre of oxygen consumed, number of cutting strokes per minute and number of stalks cut per stroke. Use was made of the MetaMax I Ergospirometry System to measure the physiological parameters, as well as the telemetric Polar Accurex Plus™ heart rate monitor for heart rate measurements.

OBSERVATION AND UNOBTRUSIVE OBSERVATION INTERACTION

Subjects were either obtrusively observed or unobtrusively observed during the different testing conditions. Physiological measures included absolute and relative oxygen consumption, absolute and relative energy expenditure, and mean and maximal heart rate elicited during normal work *in situ*. The parameters for the working efficiency included rate of productivity, energy required in kilojoules to cut 1 kilogram of cane, amount of cane cut per 1 litre of oxygen, number of cutting strokes per minute and number of stalks cut per stroke. The MetaMax I Ergospirometry System was implemented to measure the physiological parameters through which the cane cutters were obtrusively observed. During unobtrusive observation interaction only the Polar Accurex Plus™ heart rate monitor was used and cane cutters continued harvesting cane for one hour without supervision.

RESULTS AND DISCUSSION

This study produced results illustrating that harvesting of burnt and unburnt cane are significantly different ($p<0.05$), unless otherwise indicated for the following measured physiological variables: average absolute oxygen consumption (Burnt = 1.95 $L \cdot min^{-1}$ versus Unburnt = 2.19 $L \cdot min^{-1}$) ($p<0.01$); average relative oxygen consumption (Burnt = 29.85 $ml \cdot kg^{-1} \cdot min^{-1}$ versus Unburnt = 33.42 $ml \cdot kg^{-1} \cdot min^{-1}$); calculated average absolute energy expenditure (Burnt = 40.76 $kJ \cdot min^{-1}$ versus Unburnt = 45.93 $kJ \cdot min^{-1}$); and, average relative energy expenditure (Burnt = 0.63 $kJ \cdot min^{-1} \cdot kg^{-1}$ versus Unburnt = 0.70 $kJ \cdot min^{-1} \cdot kg^{-1}$). Mean heart rate responses did not differ significantly ($p>0.05$) in harvesting burnt or unburnt cane (Burnt = 119.8 beats $\cdot min^{-1}$ versus Unburnt = 123.67 beats $\cdot min^{-1}$) as well as the peak heart rate responses (Burnt = 131.13 beats $\cdot min^{-1}$ versus Unburnt = 135.93 beats $\cdot min^{-1}$). Even so, these heart rate measures were demonstrative of a lesser degree of physical strain harvesting burnt cane than for unburnt cane. Ratings of perceived exertion (RPE) values recorded during harvesting burnt and unburnt cane did not differ significantly ($p>0.05$), suggesting that the subjective perceptions of strain experienced when harvesting burnt and unburnt cane were similar (Burnt = 11.71 versus Unburnt = 11.13).

The selected measures for establishing working efficiency were as follows: Rate of productivity in harvesting burnt cane was significantly higher ($p<0.01$) compared with harvesting unburnt cane (Burnt = 30.30 kg cane · min^{-1} versus Unburnt 22.98 kg cane · min^{-1}). Significantly less ($p<0.01$) energy was required to cut one kilogram of burnt cane than for unburnt cane (Burnt = 1.51 kJ · kg^{-1} cane versus Unburnt = 2.13 kJ · kg^{-1} cane). The amount of cane cut per litre of oxygen consumed was significantly higher ($p<0.01$) for burnt than for unburnt cane (Burnt = 16.43 kg cane · L O_2^{-1} versus Unburnt = 10.62 kg cane · L O_2^{-1}). The above-mentioned parameters for working efficiency were all highly significant ($p<0.01$). The number of cane cutting strokes per minute to cut the stalks in burnt cane was significantly higher ($p<0.05$) than for unburnt cane (Burnt = 34.42 versus Unburnt = 25.45). The number of stalks cut per stroke for burnt cane was significantly lower ($p<0.05$) than that for unburnt cane (Burnt = 2.45 versus Unburnt = 2.55). Despite the values for the number of cane cutting strokes per minute and the number of stalks cut per stroke in favour of unburnt cane, the results in general lend credence to the fact that cutting burnt cane surpasses harvesting unburnt cane with regard to physiological parameters and working efficiency of the cane cutters.

The study and comparison of the short handle curved blade knife (SH) and the long handle curved blade knife (LH) in burnt cane demonstrated no significant differences ($p>0.05$) with respect to either physiological parameters, and selected measures of working efficiency.

The following physiological measures were reported to be lower for harvesting burnt cane with the short handle curved blade knife compared with the long handle curved blade knife: average absolute oxygen consumption (SH = 1.95 L · min^{-1} versus LH = 2.02 L · min^{-1}); average relative oxygen consumption (SH = 29.85 ml · kg^{-1} · min^{-1} versus LH = 30.95 ml · kg^{-1} · min^{-1}); average absolute energy expenditure (SH = 40.76 kJ · min^{-1} versus LH = 42.40 kJ · min^{-1}); and average relative energy expenditure (SH = 0.63 kJ · min^{-1} · kg^{-1} versus LH = 0.65 kJ · min^{-1} · kg^{-1}). Furthermore mean heart rate measures recorded were higher using the short handle curved blade knife compared with the long handle curved blade knife (SH = 119.8 beats · min^{-1} versus LH = 115.80 beats · min^{-1}), as were the average peak heart rate measures (SH = 131.13 beats · min^{-1} versus LH = 127.57 beats · min^{-1}. Ratings of perceived exertion (RPE) values were significantly different ($p<0.05$) between the different harvesting knives. Cane cutters rated 11.71 for the use of the short handle curved blade knife and 10.58 for the long handle curved blade knife, suggesting that the cane cutters' subjective perception of strain experienced harvesting burnt cane with the short handle curved blade knife was that it was more strenuous than using the long handle curved blade knife.

Though the selected measures for working efficiency for the comparison of the short handle curved blade knife with the long handle curved blade knife did not significantly differ ($p>0.05$), the following measures were all in favour of using the long handle curved blade knife: Rate of productivity (SH = 30.30 kg cane · min^{-1} versus LH = 33.31 kg cane · min^{-1}), energy required to cut one kilogram of burnt cane (SH = 1.51 kJ · kg^{-1} cane versus LH = 1.37 kJ · kg^{-1} cane); similar amounts of cane were cut per litre of oxygen consumed (SH = 16.43 kg cane · L O_2^{-1} versus LH = 16.43 kg cane · L O_2^{-1}); number of cane cutting strokes per minute to cut the stalks (SH = 34.42 versus LH = 31.72); and number of stalks cut per stroke (SH = 2.45 versus LH = 2.68).

It would therefore be reasonable to speculate that the choice of cane knives appears to depend largely on the preference of the cane cutter for a specific knife. No known studies to date have reported on the use of different manual cane harvesting implements with regard to their effects on the cane cutters' physiological system and the selected measures for working efficiency.

The effect of observation and unobtrusive observation interaction on the cane cutters' physiological system during cane harvesting revealed significant differences ($p<0.05$) in relative oxygen consumption, relative energy expenditure, as well as the mean heart rate responses. All remaining physiological parameters were statistically insignificant ($p>0.05$). The following measures were higher during the experimental condition when cane cutters were observed: average absolute oxygen consumption (Observation = 2.12 $L \cdot min^{-1}$ versus Unobtrusive observation = 1.99 $L \cdot min^{-1}$); average relative oxygen consumption (Observation = 32.40 $ml \cdot kg^{-1} \cdot min^{-1}$ versus Unobtrusive observation = 30.41 $ml \cdot kg^{-1} \cdot min^{-1}$); average absolute energy expenditure (Observation = 44.28 $kJ \cdot min^{-1}$ versus Unobtrusive observation = 41.78 $kJ \cdot min^{-1}$); and, average relative energy expenditure (Observation = 0.68 $kJ \cdot min^{-1} \cdot kg^{-1}$ versus Unobtrusive observation = 0.64 $kJ \cdot min^{-1} \cdot kg^{-1}$). Mean heart rate measures recorded for cane harvesting during observation and unobtrusive observation were 123.73 beats $\cdot min^{-1}$ and 115.78 beats $\cdot min^{-1}$, respectively, and the average peak heart rate responses during observation and unobtrusive observation 134.27 beats $\cdot min^{-1}$ and 128.82 beats $\cdot min^{-1}$, respectively.

Only the rates of productivity of the cane cutters recorded during observation and unobtrusive observation were significantly different ($p<0.05$). Other selected measures for the working efficiency, though not statistically different ($p>0.05$) were higher during observation compared with the experimental condition of unobtrusive observation. The following values were yielded: rate of productivity (Observation = 30.68 kg cane $\cdot min^{-1}$ versus Unobtrusive observation = 27.04 kg cane $\cdot min^{-1}$); energy required to cut one kilogram of cane (Observation = 1.61 kJ · kg^{-1} cane versus Unobtrusive observation = 1.73 kJ · kg^{-1} cane); and amount of cane cut per litre of oxygen consumed (Observation = 15.23 kg cane · L O_2^{-1} versus Unobtrusive observation = 13.76 kg cane · L O_2^{-1}). This concurs with earlier research findings.

CONCLUSIONS

PHYSIOLOGICAL PARAMETERS: BURNT AND UNBURNT SUGARCANE

Harvesting burnt cane was characterised by the cane cutters' average lower absolute and relative oxygen consumptions, average lower absolute and relative energy expenditures, as well as lower mean and peak heart rate responses compared with harvesting unburnt cane. This indicates that harvesting burnt cane surpasses harvesting unburnt cane. The ratings of perceived exertion (RPE) responses were not significantly different between burnt and unburnt cane.

WORKING EFFICIENCY: BURNT AND UNBURNT SUGARCANE

Cane cutters exhibited a higher rate of productivity and more cane could be cut per litre of oxygen consumed in harvesting burnt cane, and were characterised by requiring less energy to cut one kilogram of burnt than unburnt cane. The number of cane cutting strokes required to cut the stalks of burnt cane was significantly higher than for unburnt cane. More stalks were cut per cane cutting stroke for unburnt than burnt cane.

PHYSIOLOGICAL PARAMETERS: SHORT HANDLE CURVED BLADE KNIFE VERSUS LONG HANDLE CURVED BLADE KNIFE

No significant differences existed between the use of the short handle curved blade and long handle curved blade knife in harvesting burnt cane. With regard to the ratings of perceived exertion (RPE) responses a significant difference was apparent in favour of the long handle curved blade knife.

WORKING EFFICIENCY: SHORT HANDLE CURVED BLADE KNIFE VERSUS LONG HANDLE CURVED BLADE KNIFE

No significant differences existed between the use of the short handle curved blade and long handle curved blade knife in burnt cane.

PHYSIOLOGICAL PARAMETERS: OBSERVATION AND UNOBTRUSIVE OBSERVATION INTERACTION

Observation of the cane cutters during work reflected a higher average relative oxygen consumption, higher average relative energy expenditure, and a higher mean heart rate response than during the unobtrusive observation interaction.

WORKING EFFICIENCY: OBSERVATION AND UNOBTRUSIVE OBSERVATION INTERACTION

During observation, the cane cutters performed significantly better, showing an increased rate of productivity, compared with the experimental condition where they were not being observed.

Though statistically insignificant, harvesting was more efficient during observation of the cane cutters with their expending less energy to cut one kilogram of cane while the amount of cane cut per litre of oxygen consumed was 9.65% more than during the unobtrusive observation interaction. In the light of these results the following conclusions can be drawn:

HYPOTHESIS ONE: A TENTATIVE REJECTION OF THE NULL HYPOTHESIS

The findings of this study lead one to tentatively accept the alternative hypothesis ($p<0.05$) as follows:

A difference exists between harvesting burnt and unburnt sugarcane with regard to selected physiological parameters, where the following values were lower for harvesting burnt cane: absolute and relative oxygen consumption; and absolute and relative energy expenditure.

HYPOTHESIS TWO: A TENTATIVE REJECTION OF THE NULL HYPOTHESIS

The findings of this study lead one to tentatively accept the alternative hypothesis ($p<0.05$) as follows:

A significant difference exists between harvesting burnt and unburnt sugarcane with regard to selected measures for working efficiency, where the following values were in favour of harvesting burnt cane: rate of productivity; energy required in kilojoules to cut one kilogram of cane; and the amount of cane cut per litre of oxygen consumed. In unburnt cane, the number of cutting strokes per minute was less and the number of stalks cut per stroke was higher.

HYPOTHESIS THREE: A TENTATIVE ACCEPTANCE OF THE NULL HYPOTHESIS

The findings of this study lead one to tentatively accept the null hypothesis as there were no significant differences ($p>0.05$) between the short handle curved blade knife and the long handle curved blade knife with regard to physiological parameters during cane harvesting, where the following parameters were similar for cane cutters, namely absolute and relative oxygen consumption; absolute and relative energy expenditure; mean and peak heart rate responses.

HYPOTHESIS FOUR: A TENTATIVE ACCEPTANCE OF THE NULL HYPOTHESIS

The findings of this study lead one to tentatively accept the null hypothesis ($p>0.05$) as follows:

There is no significant difference between the use of the short handle curved blade knife and the long handle curved blade knife in burnt cane with regard to selected measures for establishing working efficiency. The following values were statistically insignificant, namely rate of productivity; energy required in kilojoules to cut one kilogram of cane; amount of cane cut per litre of oxygen consumed, number of cutting strokes per minute and number of stalks cut per stroke.

HYPOTHESIS FIVE: A TENTATIVE REJECTION OF THE NULL HYPOTHESIS

The findings of this study lead one to tentatively accept the alternative hypothesis ($p<0.05$) as follows:

A difference exists between subject observation and unobtrusive observation interaction with regard to selected physiological parameters, where the following values were higher when subjects were observed: relative oxygen consumption, relative energy expenditure and mean heart rate. Absolute oxygen consumption, absolute energy expenditure and peak heart rate responses were also higher during observation, though not significantly.

RECOMMENDATIONS

The present study appears to have been largely successful in presenting an informed understanding of those factors having an influence on the cane cutter's performance of work.

The following recommendations should be considered for future research:

1. Observations should be carried out using the same variety of cane, or at least cane of similar thickness. In addition, all cane should preferably be straight, whether burnt or unburnt, to minimise variables.

2. The period for collecting data on energy expenditure concerning different cane knives should be increased, to ensure measurements that are more accurate. It was observed that the cutting rate, early in the morning (05h00) was higher than that during mid-morning (10h00), which could lead to significant differences in the outcome.

3. A more comprehensive study in which labour productivity could be compared with the quality of harvesting sugarcane in terms of the Cane Testing Services (CTS) analysis, i.e. sucrose content, percentage ash and percentage fibre, should be undertaken.

4. Further consideration should be given to heart rate extrapolated findings, because of the unknown demands of cane cutting on the cane cutter.

5. Future researchers in this field may wish to devote attention to a more adequate explanation of the following:

5.1 A replication of this study with attention given to the effects of different postural positions during cane harvesting. It is conceivable that the energy expenditure and heart rate responses will differ when either a more upright stance is taken or if the cane cutter bends down lower (forward flexion of the trunk);

5.2 a biomechanical analysis of the cane cutters using the short handle curved blade knife and the long handle curved blade knife;

5.3 an ergonomic evaluation of the short handle curved blade knife and the long handle curved blade knife, as proposed by Kadefores et al. (1993).

REFERENCES

AMERICAN COLLEGE OF SPORTS MEDICINE (1995). *Guidelines for Exercise Testing and Prescription*. Fifth edition. USA: Lea & Febiger.

ÅSTRAND I (1967) Degree of strain during building work as related to individual aerobic work capacity. *Ergonomics*, 10(3): 293-303, May.

ÅSTRAND I; GUHARAY A; & WAHREN J (1968). Circulatory responses to arm exercise with different arm positions. *Journal of Applied Physiology*, 25(5): 528-532, November.

ÅSTRAND P-O & RODAHL K (1986). *Textbook of Work Physiology*. Third edition. New York: McGraw-Hill.

BALLOR DL; BURKE LM; KNUDSON DV; OLSON JR & MONTOYE HJ (1989). Comparison of three methods of estimating energy expenditure: Caltrac, heart rate; and video analysis. *Research Quarterly for Exercise and Sport*, 60(4): 362-368, December.

BANISTER EW & BROWN SR (1968). The relative energy requirements of physical activity. In HB Falls (ed.), *Exercise Physiology*. New York: Academic Press.

BARNES AC (1964). Harvesting the cane. *The sugar cane* (pp. 291-323). New York: Interscience Publishers.

BMDP Statistical Software Package (1993), Version 7.0.

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

BRIDGER RS (1995). Physiology, Workload, and Work capacity. *Introduction to Ergonomics* (pp. 193-213). New York: McGraw-Hill.

BRIDGER RS; CABION N; GOEDECKE J; RICKARD S; SCHABORT E; WESTGARTH-TAYLOR C & LAMBERT MI (1997). Physiological and subjective measures of workload when shoveling with a conventional and two-handled ("levered") shovel. *Ergonomics*, 40(11): 1212-1219, November.

BROOKS GA & MERCIER J (1994). Balance of carbohydrate and lipid utilization during exercise: the "crossover" concept. *Journal of Applied Physiology*, 76(6): 2253-2261, June.

BROOKS GA; FAHEY TD & WHITE TP (1996). *Exercise physiology.* Second edition. London: Mayfield Publishing.

BROOKS RC (1983). Improving cane cutters' productivity. Proceedings of the South African Sugar Technologist's Association (June 1983), pp. 165-166.

BRUKNER P & KHAN K (2001). *Clinical Sports Medicine.* Second edition. Sydney: McGraw-Hill.

CAPODAGLIO P (2002). The use of subjective rating of exertion in ergonomics. *Giornale Italiano Medicina del Lavoro ed Ergonomia*, 24(1): 84-89, January-March.

CICCIARELLA CF (1997). Research in physical education, exercise science, and sport: An introduction. Scottsdale, AZ: Gorsuch & Scarisbrick.

COETSEE MF (1998/99). Validation of the Cortex MetaMax portable ergospirometry system. *South African Journal for Sport, Physical Education and Recreation*, 21(1): 11-19.

COLLINS KJ; BROTHERHOOD RJ; DAVIES CTM; DORÉ C; HACKETT AJ; IMMS FJ; MUSGROVE J; WEINER JS; AMIN MA; EL KARIM M; ISHMAIL HM; OMER AHS & SUKKAR MY (1976). Physiological performance and work capacity of Sudanese cane cutters with *Schistosoma mansoni* infection. *The American Journal of Tropical Medicine and Hygiene*, 25(3): 410-421, May.

DAVIES CTM (1973). Relationship of maximum aerobic power output to productivity and absenteeism of East African sugar cane workers. *British Journal for Industrial Medicine*, 30(2): 146-154, April.

DAVIES CTM; BROTHERHOOD JR; COLLINS KJ; DORÉ C; IMMS F; MUSGROVE J; WEINER JS; AMIN MA; ISMAIL HM; EL KARIM M; OMER AH & SUKKAR MY (1976). Energy expenditure and physiological performance of Sudanese cane cutters. *British Journal of Industrial Medicine*, 33(3): 181-186, August.

DE BEER AG; HUDSON C; MEYER E & SEIGMUND B (1994). Green cane harvesting and trash management. Green cane harvesting and trash management workshop, Mauritius and Réunion, 5-14 October.

DE BEER G & PURCHASE B (1997). The effect of field mechanization on factory performance. International Society of Sugar Cane Technologists Workshop, Veracruz, Mexico, 24-28 November.

DEIVANAYAGAM S & AYOUB MM (1979). Prediction of endurance time alternating workload tasks. *Ergonomics*, 22(3): 279-290, March.

DEVIENNE MF (2003). Intérêt de la surveillance de la dépense énergétique par télémétrie application en physiologie humaine, intérêt en pathologie. *Annales de Biologie Clinique*, 61(2): 199-201, March-April.

deVRIES HA & HOUSH TJ (1994). *Physiology of Exercise: For Physical Education, Athletics and Exercise science.* Fifth edition. Madison: WCB Brown & Benchmark.

DUL J & WEERDMEESTER B (1993). *Ergonomics for Beginners.* London: Taylor & Francis.

DURNIN JVGA & WOMERSLEY (1974). Body fat assessed from total body density and its estimation from skinfold thickness: measurement on 481 men and women aged 16 to 72 years. *British Journal of Nutrition*, 32(1): 77-97, July.

DURNIN JVGA (1991). Assessment of physical activity during leisure and work. In C Bouchard, RJ Shepard, T Stephans, JR Sutton & BD McPherson (eds.), *Exercise, fitness, and health: A consensus of current knowledge* (pp. 63-70). Champaign, IL: Human Kinetics.

EKLUND J & FREIVALDS A (1993). Hand tools for the 1990s. *Applied Ergonomics*, 24(3): 146-147, June.

FREIVALDS A & KIM YJ (1990). Blade size and weight effects in shovel design. *Applied Ergonomics*, 21(1): 39-42, March.

GAESSER GA & BROOKS GA (1975). Muscular efficiency during steady-rate exercise: effects of speed and work rate. *Journal of Applied Physiology*, 38(6): 1132-1139, June.

GALLAGHER S (1991). Acceptable weight and physiological costs of performing manual handling tasks in restricted postures. *Ergonomics*, 34(7): 939-952, July.

GALLAGHER S (1999). Ergonomics issues in mining. In W Karwowski & WS Marras (eds.), *The Occupational Ergonomics Handbook* (pp. 1893-1915). London: CRC Press.

GREEN MS; LUZ Y; JUCHA E; COCOS M & ROSENBERG N (1986). Factors affecting ambulatory heart rate in industrial workers. *Ergonomics*, 29(8): 1017-1027, August.

HAGEN KB; VIK T; MYHR NE; OPSAHL PA & HARMS-RINGDAHL K (1993). Physical workload, perceived exertion, and output of cut wood as related to age in motor-manual cutting. *Ergonomics*, 36(5): 479-488, May.

HANSSON JE (1968). Physiological methods studies in Swedish industry. *Nordisk Hygienisk Tidskrift*, 49(2): 55-57.

THE HARRISON COLLECTION (1995). Empangeni Art and Cultural Museum, Cnr of Turnbull Street and Main Road, Empangeni 3880, South Africa. Curator: Ms Kovacs, Grand Opening: December 1995.

HOUSTEN ME (1995). *Biochemistry Primer for Exercise Science*. Champaign, IL: Human Kinetics.

ILLOVO (2004). World of Sugar [online]. Available: http://www.illovo.co.za.

IMMINK MDC; FLORES CR; VITERI FE & SIBRIAN R (1987). Body Composition of Guatemalan Sugarcane cutters, Worker Productivity and Different Work Settings and Conditions. *Human Biology*, 59(5): 827-836, October.

JØRGENSEN K (1985). Permissible loads based on energy expenditure measurements. *Ergonomics*, 28(1): 365-369, January.

KADEFORS R; ARESKOUG A; DAHLMAN S; KILBOM Å; SPERLING L; WIKSTRÖM L & ÖSTER J (1993). An approach to ergonomics evaluation of hand tools. *Applied Ergonomics*, 24(3): 203-211, June.

KENNIS: Die Eerste Afrikaanse Ensiklopedie in Kleur (1980). Vol. 7, pp. 1300-1303. Kaapstad: Human & Rousseau.

KILBOM Å (1990). Measurement and assessment of dynamic work. In JR Wilson and EN Corlett (eds.). *Evaluation of Human Work* (pp. 517-540). London: Taylor & Francis.

KUKKONEN-HARJULA K & RAURAMAA R (1984). Oxygen consumption of lumberjacks in logging with a power-saw. *Ergonomics*, 27(1): 59-65, January.

KURUMATANI N; YAMAGUCHI B; DEJIMA M; ENOMOTO Y & MORIYAMA T (1992). Aerobic capacity of forestry workers and physical demands of forestry operations. *European Journal of Applied Occupational Physiology*, 64(6): 546-551.

LADOUCIER R & CARRIER C (1983). Awareness and control of pain. *Perceptual and Motor Skills*, 56(2): 405-406, April.

LAMBERT MI; CHEEVERS EJ & COOPOO Y (1994). Relationship between energy expenditure and productivity of sugar cane cutters and stackers. *Occupational Medicine*, 44(4): 190-194, September.

LEHMANN G; MÜLLER EA & SPITZER H (1950). Der Kalorienbedarf bei gewerblicher Arbeit. *Arbeitsphysiologie*, 14(2): 166-235.

McARDLE WD; KATCH FI & KATCH VL (1991). *Exercise Physiology: Energy, Nutrition, and Human Performance.* Third edition. Philadelphia: Lea & Febiger.

MCHUNU MS (1999). Personal interview with the Training's Officer from the Training Department, Experiment Station, 20 August. Mount Edgecombe: South African Sugar Association.

MEDBO JI; MAMEN A; WELDE B; VON HEIMBURG E; & STOKKE R (2002). Examination of the MetaMax I and II oxygen analysers during exercise studies in the laboratory. *Scandinavian Journal of Clinical and Laboratory Investigation*, 62(8): 585-98.

MEEMEDUMA D & DHAMRAWARDENE N (1994). An improved green cane harvesting knife. ISSCT agricultural engineering workshop on green cane harvesting and trash management, Mauritius and Réunion, 5-14 October 1994.

MEIJER GA; WESTERTERP KR; KOPER H & 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, June.

MEYER T; DAVISON RC & KINDERMANN W (2005). Ambulatory gas exchange measurements: current status and future options. *International Journal of Sports Medicine*, 26 Suppl 1: S19-27, February.

MEYER T; GEORG T; BECKER C & KINDERMANN W (2001). Reliability of gas exchange measurements from two different spiroergometry systems. *International Journal of Sports Medicine*, 22(8): 593-597, November.

MOORE H (1977). Cane cutting: Burnt or trashed. South African Sugar Association Experiment Station: *Agricultural Training Department Instructor's Guide* (pp. 1-40).

MORRISON JF & BLAKE GTW (1974). Physiological Observations on Cane Cutters. *European Journal of Applied Physiology and Occupational Physiology*, 33(3): 247-254.

MURGATROYD PR; SHETTY PS & PRENTICE AM (1993). Techniques for the Measurement of Human Energy Expenditure: A Practical Guide. *International Journal of Obesity and Related Metabolic Disorders*, 17(10): 549-568, October.

NAIDU S (2001). Price of recoverable value (RV) in cane. *The Cane Grower*, 8(1): 4, April.

OKAPI South Africa (Pty) Ltd (n.d.) - Brochure. Manufacturers and Distributors of Quality "OKAPI" Knives. 46/48 Green Street, Isithebe, KwaZulu-Natal, Republic of South Africa.

OLIVIER SC & SCOTT PA (1993). Physiological, perceptual and attitudinal responses to identically matched workloads in field and laboratory testing conditions. *South African Journal for Research in Sport, Physical Education and Recreation*, 16(1): 63-72.

PAL AK & SINHA DK (1994). The energy cost of metalliferous mining operations in relation to the aerobic capacity of Indian miners. *Ergonomics*, 37(6): 1047-1054, June.

PHOOLCHUND HN (1991). Aspects of occupational health in the sugar cane industry. *The Journal of the Society of Occupational Medicine*, 41(3): 133-136, Autumn.

PLOWMAN SA & SMITH DL (1997). Aerobic metabolism during exercise. *Exercise Physiology for Health, Fitness, and Performance*. Boston: Allyn & Bacon.

ROBERGS RA & ROBERTS SO (1997). *Exercise Physiology*. Massachusetts: WCB McGraw-Hill.

RODAHL K; VOKAC Z; FUGGELI P; VAAGE O & MAEHLUM S (1974). Circulatory strain, estimated energy output and catecholamine excretion in Norwegian coastal fishermen. *Ergonomics*, 17(5): 585-602, September.

ROHDAHL K (1989). Methods for the assessment of physical work capacity and physical work load. *The Physiology of Work* (pp. 51-84). London: Taylor & Francis.

ROHMERT W (1987). Physiological and psychological work load measurement and analysis. In G Salvendy (ed.), *Handbook of Human Factors* (pp. 402-427). New York: John Wiley & Sons.

SALOKHE VM & MAMANSARI DU (1995). Physical workload during selected farm operations. *Journal of Human Ergology*, 24(2): 161-169, December.

SCHULZ H; HELLE S; & HECK H (1997). The validity of the telemetric system CORTEX X1 in the ventilatory and gas exchange measurement during exercise. *International Journal of Sport Science*, 18(6):454-457, August.

SCOTT PA (1985). The rating of perception of exertion in a multi-ethnic society: A review of the problem and some preliminary solutions. Proceedings of the First Annual Conference of the Ergonomic Society of Southern Africa. CSIR, Pretoria (February), 16: 1-4.

SCOTT PA (1990). The development of a psychophysical scale for evaluating self-perceived strain. Unpublished Ph.D. (Human Movement Science) dissertation. Stellenbosch: University of Stellenbosch.

SIETSEMA KE; DALY JA & WASSERMAN K (1989). Early dynamics of O_2 uptake and heart rate as affected by exercise work rate. *Journal of Applied Physiology*, 67(6): 2535-2541, December.

SOUTH AFRICAN CANE GROWER'S ASSOCIATION (2002). Labour utilisation and cost survey: 2000/01 Season, (pp. 1-11).

SOUTH AFRICAN SUGAR ASSOCIATION (2004). Overview of the sugar industry sugar [online]. Available: http://www.sasa.org.za.

SOUTH AFRICAN SUGARCANE RESEARCH INSTITUTE (2004a). Harvesting: Cane quality. *Senior Certificate Course in Sugarcane Agriculture*, (pp. 1-10).

SOUTH AFRICAN SUGARCANE RESEARCH INSTITUTE (2004b). Harvesting: Estimating and manual cutting. *Senior Certificate Course in Sugarcane Agriculture*, (pp. 1-10).

SOUTH AFRICAN SUGARCANE RESEARCH INSTITUTE (2004c). Varieties: Botany: The structure, propagation and physiology of the cane plant. *Senior Certificate Course in Sugarcane Agriculture*, (pp. 1-18).

SPURR GB; BARAC-NIETO M & MAKSUD MG (1975). Energy expenditure cutting sugarcane. *Journal of Applied Physiology*, 59(6): 990-996, December.

SPURR GB; BARAC-NIETO M & MAKSUD MG (1977). Productivity and maximal oxygen consumption in sugar cane cutters. *American Journal of Clinical Nutrition*, 30(3): 316-321, March.

Sugar Knowledge International (1998). How sugar is made – The history of sugar [online]. Available: http://www.sucrose.com.

Sugarcane Agronomy Research Department (1992). *SSMC Agronomy Annual Report, SSMC Field Operations Manual*, pp. 1-13.

SUN M & HILL JO (1993). A method for measuring mechanical work and work efficiency during human activities. Journal of *Biomechanics*, 26(3): 229-241, March.

THOMPSON DL; TOWNSEND KM; BOUGHEY R; PATTERSON K & BASSETT DR (1998). Substrate use during and following moderate- and low-intensity exercise: Implications for weight control. *The European Journal of Applied Physiology and Occupational Physiology*, 78(1): 43-49, June.

VANDER AJ; SHERMAN JH & LUCIANO DS (1994). *Human physiology: The mechanisms of body function.* Sixth edition. New York: McGraw-Hill.

VOSS R (1999, July 1). Sugar cane knives [e-mail to M de L Smit], [online]. Available e-mail: mdelsmit@yahoo.com.

VOSS R (2000). Personal interview with the Export and Financial Manager, 7 August. Mandini: Okapi cane knife manufacturers.

WÊRELDSPEKTRUM (1982). Ensiklopedie Afrikana, Vol. 27, pp. 22-27. Johannesburg: Perskor.

WIXLEY JH (2001). Prospects for the season 2001/2002 season. *The Cane Grower*, 8(1): 1, April.

WYNDHAM CH & COOKE HM (1964). The influence of quality of supervision on the production of men engaged in moderately hard physical work. *Ergonomics*, 7: 139-149.

WYNDHAM CH; COOKE HM; MUNRO A & MARITZ JS (1964). The contribution of physiological factors to the performance of moderately heavy physical work. *Ergonomics*, 7: 121-137.

XU F & RHODES EC (1999). Oxygen uptake kinetics during exercise. *Sports Medicine*, 27(5): 313-327, May.

ZARPELON F (1997). Engineering and energy workshop on factory design. International Society of Sugar Cane Technologists Workshop, Faisalabad, Pakistan, 23-28 February.

APPENDIX A

INFORMED CONSENT INFORMATION FORM

(ENGLISH & ZULU)

UNIVERSITY OF ZULULAND

DEPARTMENT
OF
HUMAN MOVEMENT SCIENCE

✉ X1001 KwaDlangezwa 3886 South Africa ✆ 035 9026388 🖷 035 9026386

INFORMED CONSENT INFORMATION FORM

The research work you are about to take part in, is for a Master's degree in the Department of Human Movement Science. The study aims to determine the energy expenditure and working efficiency of cane cutters in burnt and unburnt sugarcane and the effects of implementing different cane harvesting knives on the performance of the cane cutter. The following will be required from you:

Anthropometric measures

Stature and body mass will be determined using calibrated scales. Percentage of body fat will be assessed by the measurement of skinfolds at four selected sites including triceps, subscapular, biceps and suprailiac.

Physiological parameters

Oxygen consumption and energy expenditure will continuously be measured via telemetry by means of the portable MetaMax I Ergospirometry System, along with continuous heart rate monitoring using the telemetric Polar Accurex Plus™ heart rate monitor during cane harvesting.

The activity recording will be conducted on six consecutive occasions that will include the implementation of both the short and long handle curved blade knives harvesting burnt and unburnt sugarcane. The six consecutive occasions will be divided into three testing periods of 30 minutes each and three testing periods of 1 hour each, for each subject. Therefore, each subject will undergo a total of six testing procedures, four sessions with a short handle curved blade knife in burnt and unburnt sugarcane, and two sessions with a long handle curved blade knife harvesting burnt sugarcane.

To ensure that all subjects are familiar with both the short and long handle curved blade knives, you will be questioned concerning the use of and the preference for either the short or long handle curved blade cane knife. Additional training sessions for at least one week (40 hours) for those who required it would be implemented; until improved skill is demonstrated with a specific cane knife. This is necessary in order to accustom you to what is required and to ensure that the data collected is accurate. You will also be questioned on your average work experience in cane harvesting and your preference for harvesting burnt and unburnt sugarcane.

The risks you may encounter during these experimental conditions are similar to those experienced during cane cutting. However, there exists the possibility of certain changes occurring during the test. These may include laboured breathing, an elevated heart rate, post-test muscle stiffness and feelings of fatigue and/or exhaustion. Every effort will be made to minimise these risks during all testing procedures. Your prompt reporting of feelings with effort during the testing procedures itself are of great importance. You are responsible to disclose such information when requested by the researchers.

As you are volunteering for this experiment, you shall not be paid for your participation. However, you will accrue useful personal information on your capacity for cane cutting, your energy expenditure and working efficiency during cane cutting, providing an understanding of a cane cutter's tolerance for sustained effort harvesting burnt and unburnt sugarcane as well as the use of different cane harvesting implements.

You are assured of complete confidentiality and anonymity with respect to the use of the data obtained. Do note that the data may be stored and used for a different purpose in the future without obtaining further consent.

Questions about the procedures used in the research are encouraged. The Induna and a native Zulu speaking research assistant, will be available to you during all contact sessions and testing procedures. Your permission to perform these tests is voluntary. You are free to deny consent or stop the testing at any point, if you so desire.

In conclusion you will be providing a valuable service to the advancement of our knowledge of human performance within the cane cutting area.

Your participation will be greatly appreciated.

Yours sincerely

MDL Müller

UNIVERSITY OF ZULULAND

DEPARTMENT
OF
HUMAN MOVEMENT SCIENCE

X1001 KwaDlangezwa 3886 South Africa 035 9026388 035 9026386

IFOMU LOKUVUMA OKWAZISIWE

Ucwaningo ozozibandakanya kulo manje luwumsebenzi weqhuzu lezemfundo leMasters ophikweni lokuzivocavoca nokunyakaziswa komzimba eNyuvesi yakwaZulu. Izinhloso zalolu cwaningo ukuthola ukusebenza kanye nenani lamandla asetshenziswa uma kugawulwa umoba oshisiwe nongashisiwe nomuthelela ukusebenzisa ocelemba abangafani okungaba nayo emsebenzini womgawuli womoba. Nakhu okuzocelwa kuwe:

Ukukalwa komzimba

Ubude kanye nesisindo kuyokalwa ngesikalo esigcinwa sikala ngokushaya emhlolweni. Inani lamafutha emzimbeni liyokalwa ezindaweni ezine ezikhethiwe esingabala ingalo (ngemuva), ihlombe, ingalo (ngaphambili) kanye nasokhalo.

Ukukalwa kokusebenza komzimba

Ukuhlolwa kwamandla asetshenziswayo ngesikhathi kusetshenzwa kuyokwenziwa ngomshini ophathekayo i-MetaMax I Ergospirometry. Izinga lokushaya kwenhliziyo liyoqoshwa ngesikhathi usebenza kusetshenziswa umshini ophathekayo i-Polar Accurex Plus™.

Ukuhlolwa kuyokwenziwa izikhathi eziyisithupha ezilandelanayo kubhekwa ukusetshenziswa kocelemba omfishane onokudla okugobile kanye nonesibambo eside kuqhathaniswa umoba oshisiwe nongashisiwe. Lezi zikhathi eziyisithupha zizohlukaniswa zibe izikhathi ezintathu eziyimizuzu engamashumi amathathu nezinye ezintathu ezizothatha ihora umuntu ngamunye. Ngakho-ke, umuntu nomuntu uyohlolwa izikhawu eziyisithupha, kwezine zazo uyobe usebenzisa ucelemba omfishane okudla kwawo okugobile ugawula umoba oshisiwe nongashisiwe kuthi kwezimbili zokugcina uyobe usebenzisa ucelemba omude okudla kwawo okugobile ugawula umoba oshisiwe.

Ukuze kuqinisekiswe ukuthi bonke abantu bayajwayela ukugawula ngocelemba omfishane kanye nomude okudla kwawo okugobile, uzobuzwa ngokusebenzisa labo celemba nanokuthi uthanda muphi phakathi kwayo yomibili. Uqeqesho olwengeziwe luyonikezwa labo ababonakala beludinga. Lolu qeqesho luyokwenziwa isikhathi esingangesonto okungamahora angamashumi amane kuze kubonakale izimpawu zokuba ngcono ekugawuleni ngalowo celemba. Lokhu kubalulekile ukuze ujwayele ukugawula ngalowo celemba odingekayo nokuthi ucwaningo lungachemi. Uzophinde ubuzwe isilinganiso sesikhathi osusisebenze ugawula umoba kanye nokuthi uthanda ukugawula muphi umoba phakathi koshisiwe nongashisiwe.

Izingozi ongazithola kwenziwa lolu cwaningo ziyafana nalezo ongazithola uma usebenza ugawula umoba. Kungenzeka kodwa kube nezinguquko emzimbeni ezihambisana nokuhlolwa. Lezi zinguquko kungaba ukuphefumulela phezulu, ukushaya kwenhliziyo ngokushesha, ukutubeka kwezicubu kanye nokukhathala njalo ngezikhathi zokuhlolwa. Kuyokwenziwa imizamo ukuthi kwehliswe lezi zingozi.

Kuyobaluleka kakhulu ukuthi usazise indlela ozizwa ngayo ngesikhathi sokuhlolwa. Kukuwena futhi kusezandleni zakho ukuthi lolo lwazi ulinikeze abacwaningi uma beludinga.

Ngeke uze ukhokhelwe ngokuzibandakanya kulolu cwaningo ngoba uvumé ngokuzithandela. Kodwa uyothola ukwaziswa ngamandla owasebenzisa uma usebenza, lokho okosinika ulwazi ngokuthi umgawuli kamoba ubekezela kanjani uma esebenzisa ithuluzi lokugawula elehlukile, egawula umoba oshisiwe nongashisiwe kanye nomthelela wokusebenzisa ucelemba wokugawula ohlukile kunojwayelekile.

Uyaqinisekiswa ukuthi yonke into izogcinwa iyimfihlo kanti futhi negama lakho lizovikeleka uma sekusetshenziswa ulwazi olutholakale kulolu cwaningo. Okumele ukwazi ukuthi ulwazi olutholakele lungagcinwa futhi lusetshenziselwe izidingo ezahlukahlukene ngaphandle kokucela imvume kuwe kuqala.

Imibuzo mayelana nezindlela ezizosetshenziswa kulolu cwaningo yamukelekile futhi iyagqugquzelwa kakhulu. Induna kanye nomsizi wami okhuluma ulimi lwendabuko lwesiZulu bazobe bekhona zonke izikhathi zokuhlolwa ukukusiza. Ukuzibandakanya kwakho nalolu cwaningo okokuzithandela. Uvumelekile ukuyeka noma inini uma uzwa ungasathandi ukuzibandakanya nalolu cwaningo.

Ekuvaleni uyobe futhi unikeza usizo olukhulu ekuqhubekeni nokuqonda okwazisiwe mayelana nomsebenzi wokugawula umoba.

Ukuzibandakanya kwakho nalolu cwaningo kuyojatshulelwa kakhulu.

Ozithobayo

MDL Müller

APPENDIX B

SUBJECT INFORMED CONSENT FORM

(ENGLISH & ZULU)

SUBJECT INFORMED CONSENT FORM

I, ____,

having been fully informed of the nature of the research entitled: "Energy expenditure and working efficiency of South African sugarcane cutters", do hereby give my consent to act as a subject in the abovenamed research.

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

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

I have read the aforegoing and understand it. Any questions which may have occurred to me have been answered to my satisfaction.

SUBJECT (OR LEGAL REPRESENTATIVE)

PRINT NAME	SIGNATURE	DATE

PERSON ADMINISTERING INFORMED CONSENT

PRINT NAME	SIGNATURE	DATE

WITNESS

PRINT NAME	SIGNATURE	DATE

PROJECT SUPERVISOR

PRINT NAME	SIGNATURE	DATE

UKUVUMA OKWAZISIWE

Mina ____

emva kokuthi sengaziswe ngokugcwele ngengqikithi yocwaningo olusihloko esithi: "Inani lamandla nokusebenza okuyikho kwabagawuli bakamoba baseningizimu Afrika", ngiyavuma ngokuzithandela ukuzibandakanya nalolu cwaningo.

Ngiziqonda ngokugcwele izindlela ezibandakanyekayo kulolu cwaningo kanye nezingozi nosizo engizoluthola njengoba kuchazwe kimi ngolomo nangombhalo obhalwe phansi. Ekuvumeni kwami ukuzibandakanya nalolu cwaningo, ngiyalisusa igunya lokuhlawulisa abacwaningi kanye neNyuvesi yakwaZulu kukho konke ukulimala engingakuthola ngokuzibandakanya kulolu cwaningo. Lokhu kuyobopha izindlalifa zami kanye nabangimeleyo. Ngiyaqonda ukuthi kubalulekile ukuthi ngibikele abacwaningi ngokushesha ngezimpawu zokungaphatheki kahle.

Ngiyaqonda futhi ukuthi ngingayeka ukuzibandakanya nalolu cwaningo noma nini. Ngiyaqonda futhi ukuthi igama lami liyovikeleka ngaso sonke isikhathi futhi ngiyavuma ukuthi ulwazi olutholiwe lusetshenziswe ekushicileleni noma yini.

Sengifunde futhi ngezwa konke okungenhla. Nginikeziwe ithuba lokubuza imibuzo futhi yonke iphendulwe nganeliseka.

UMGAWULI

IGAMA	SAYINA	USUKU

UMUNTU OSAYINISA IFOMU LOKUVUMA OKWAZISIWE

IGAMA	SAYINA	USUKU

UFAKAZI

IGAMA	SAYINA	USUKU

OBUKELELA UCWANINGO

IGAMA	SAYINA	USUKU

APPENDIX C

INSTRUCTIONS FOR THE UNIVERSAL RPE SCALE

(ENGLISH & ZULU)

You are about to participate in a study, harvesting sugarcane under different experimental conditions. While you are working, we will be assessing various physiological functions. At the same time we want you to try and estimate how hard you feel the physical demands are; that is we want you to rate the degree of perceived exertion you are experiencing while working.

You will be asked to point to or call out a number and/or the diagram on the scale presented, which corresponds to your rating of perceived exertion. You will be asked to give three specific ratings:

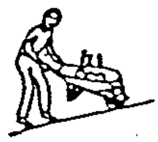
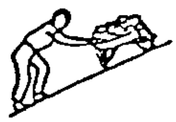
The first rating will be a local muscular rating pertaining to feelings or sensations of strain in the exercising muscles and joints (i.e. arms and/or legs).

The second rating involves sensations or feelings within the cardiorespiratory system (i.e. heart rate and breathing).

The third and final rating requires an overall or general evaluation. This will involve an integration of the previous two ratings with whatever weighing you deem appropriate.

Try to assess your ratings as honestly and objectively as possible. Do not underestimate the degree of exertion you feel, but there again, do not overestimate it either. Try to estimate it as accurately as possible.

When you are asked to rate your perception of the physical demands being imposed on you, you should do so by giving the numerical value and/or diagram on the scale in front of you which indicates your evaluation of you local, central and overall perceived exertion respectively, at that particular moment. A rating of 6 or the corresponding diagram, corresponds with feelings of exertion while standing quietly, and a rating of 20 or the corresponding diagram, reflects maximal exerting for you (Adapted from Scott, 1990).

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

Usuzozibandakanya nocwaningo oluzobheka ukugawulwa komoba ngaphansi kwezimo ezahlukahlukene. Ngenkathi usebenza sizobe sibheka ukusebenza komzimba. Ngesikhathi esifanayo sizocela usilinganisele ngezidingo (amandla) zalo msebenzi owenzayo, ngamanye amazwi sizocela ukuthi usitshele ukuthi uzwa ukuthi usebenzisa amandla angakanani ukuze wenze lo msebenzi owenzayo.

Uzocelwa ukuthi ukhombe noma ubize inamba ne/noma isithombe gama kulomfanekiso gama ozowukhonjiswa lokho okuzobe kumele amandla ocabanga ukuthi uyawasebenzisa ukwenza lo msebenzi owenzayo. Uzonikezwa ithuba lokuba unikeze izilinganiso ezintathu:

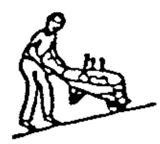
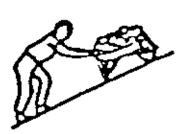
Okokuqala, uzobuzwa ngokukhathala okuhambisana nemizwa yokukhathala emzimbeni jikelele ikakhulukazi ezicubini ozisebenzisayo kanye namalunga omzimba (izingalo kanye/noma imilenze).

Okwesibili, uzobuzwa ukuthi uzizwa kanjani mayelana nokusebenza kwenhliziyo (ukushaya kwenhliziyo nezinga lokuphefumula).

Okwesithathu nokokugcina kuzodinga ukuba usho ukuthi uzizwa kanjani-ke wena ngokuphelele. Lokhu kuyobandakanya ukuhlanganisa lokhu okubili engizokubuza khona kuqala kanye nokunye ocabanga ukuthi kungabaluleka.

Zama ukuthi uhlole indlela ozizwa ngayo ngokwethembeka nokungachemi. Ungasho isilinganiso esingaphansi kwento oyizwayo ufuna ukuthenga amehlo ami, ungasho isilinganiso esingaphezu kwento oyizwayo. Zama ukuthi uhlabe esikhonkosini sonke isikhathi.

Uma ubuzwa ukuthi ulinganise amandla adingwa yilo msebenzi owenzayo, kufanele ukwenze lokho ngokunikeza inamba noma isithombe gama kulo mfanekiso gama ozobe ubekwe phambi kwakho ozosinikeza isithombe sokuthi uzwa ukuthi angakanani amandla adingwa umsebenzi owenzayo ngaleso sikhathi. Uma ukhomba inamba ewu-6 noma isithombe gama esihambisana naye, lokho kuhambisana namandla adingeka uma umile ungenzi lutho kuthi inamba ewu-20 noma isithombe gama esihambisana naye simele ukuzikhandla noma ukukhipha amandla onke ukwenza lowo msebenzi owenzayo (Adapted from Scott, 1990).

INAMBA	INCAZELO	ISITHOMBE GAMA
6		
7	KULULA KAKHULU	
8		
9	KULULA	
10		
11	KULULA NGOKULINGENE	
12		
13	KUTHANDA UKUBA NZIMA	
14		
15	KUNZIMA	
16		
17	KUNZIMA IMPELA	
18		
19	KUNZIMA KAKHULU	
20		

APPENDIX D

CALORIC EQUIVALENTS FOR THE RANGE OF NON-PROTEIN RESPIRATORY QUOTIENT (RQ) VALUES

RQ	$kcal \cdot L\ O_2^{-1}$	% kcal Carbohydrate	% kcal Fat
1.00	5.047	100.00	0.00
0.99	5.035	96.80	3.18
0.98	5.022	93.60	6.37
0.97	5.010	90.40	9.58
0.96	4.998	87.20	12.80
0.95	4.985	84.00	16.00
0.94	4.973	80.70	19.30
0.93	4.961	77.40	22.60
0.92	4.948	74.10	25.90
0.91	4.936	70.80	29.20
0.90	4.924	67.50	32.50
0.89	4.911	64.20	35.80
0.88	4.899	60.80	39.20
0.87	4.887	57.50	42.50
0.86	4.875	54.10	45.90
0.85	4.862	50.70	49.30
0.84	4.850	47.20	52.80
0.83	4.838	43.80	56.20
0.82	4.825	40.30	50.70
0.81	4.813	36.90	63.10
0.80	4.801	33.40	66.60
0.79	4.788	29.90	70.10
0.78	4.776	26.30	73.70
0.77	4.764	22.30	77.20
0.76	4.751	19.20	80.80
0.75	4.739	15.60	84.40
0.74	4.727	12.00	88.00
0.73	4.714	8.40	91.60
0.72	4.702	4.76	95.20
0.71	4.690	1.10	98.90
0.707	4.686	0.00	100.00

Adapted from Robergs and Roberts, 1997

APPENDIX E

METAMAX I ERGOSPIROMETRY SYSTEM PRINTOUT

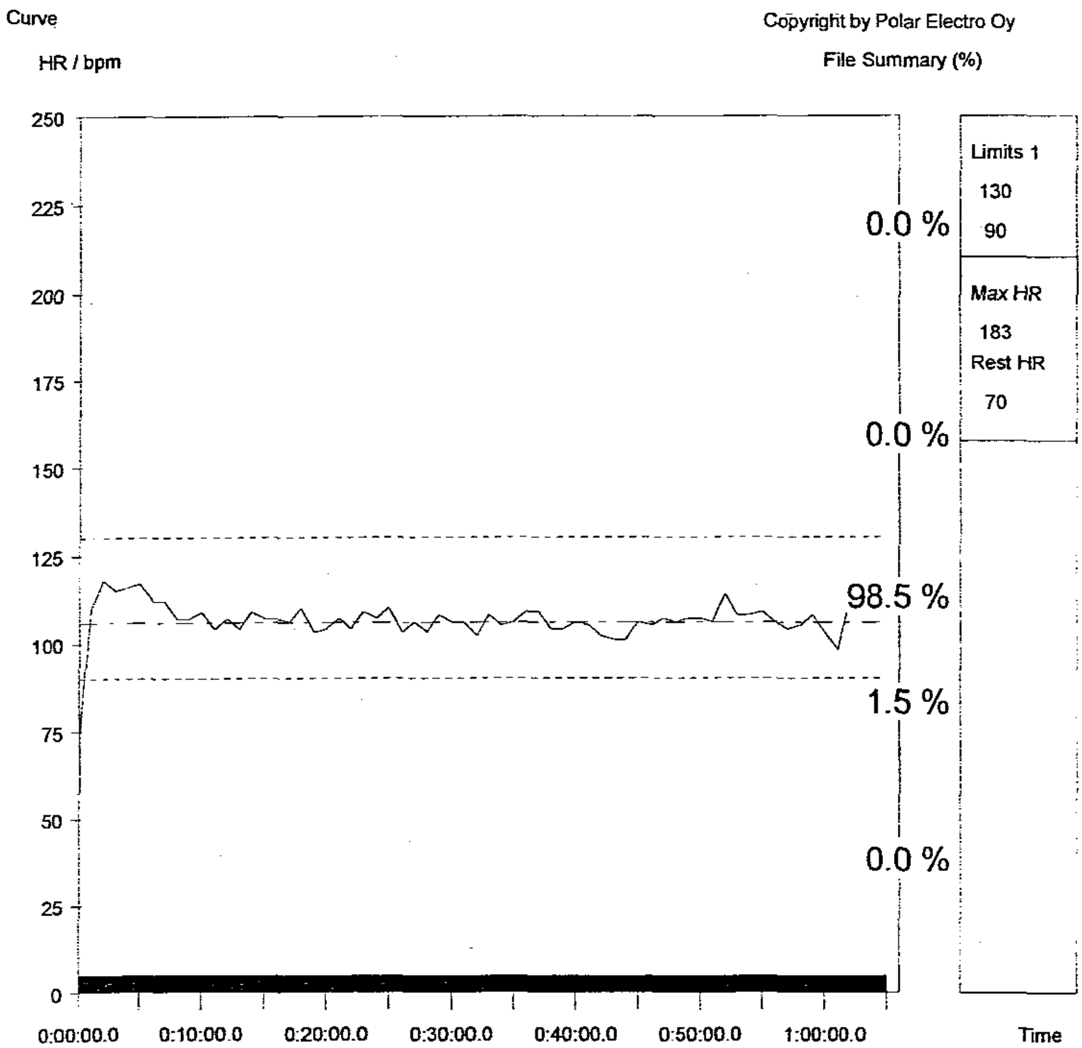
Name: August Magaia	Birth date: 05.08.1966	Date: 09.10.2000 05:49
Sex: Male	Height: 181 [cm]	Weight: 71.40 [kg]

MetaMax Ergospirometry Test

Time [h:m:s]	sV'O2 [l/min]	spec. V'O2 [ml/min/kg]	R	sV'CO2 [l/min]	V'E [l/min]	Fb [1/min]	VT [l]	fc [1/min]	Eq. O2
00:00:00	0.19	2.70	0.00	0.00	1.03	4	0.15	87	2.67
00:01:00	1.79	25.10	0.15	0.31	9.89	15	0.60	79	5.24
00:02:00	0.68	9.48	0.95	0.42	12.54	20	0.64	91	28.85
00:03:00	1.34	18.81	0.83	1.11	29.50	27	1.08	106	21.91
00:04:00	2.00	27.98	0.83	1.66	43.63	34	1.30	116	21.89
00:05:00	2.34	32.84	0.86	2.01	50.73	31	1.66	123	21.64
00:06:00	2.43	34.02	0.90	2.18	53.69	31	1.72	119	22.09
00:07:00	2.10	29.41	0.92	1.92	47.11	27	1.74	102	22.46
00:08:00	1.97	27.56	0.94	1.86	46.80	29	1.61	116	23.78
00:09:00	2.25	31.57	0.96	2.15	55.32	36	1.52	125	24.55
00:10:00	2.44	34.11	0.93	2.25	56.56	35	1.63	117	23.22
00:11:00	2.27	31.77	0.95	2.16	52.96	30	1.76	116	23.35
00:12:00	2.30	32.16	0.94	2.17	52.77	34	1.58	118	22.98
00:13:00	2.32	32.47	0.96	2.22	54.75	35	1.59	121	23.61
00:14:00	2.28	32.00	0.96	2.20	55.28	35	1.57	120	24.20
00:15:00	2.27	31.81	0.96	2.18	54.43	35	1.58	121	23.95
00:16:00	2.18	30.54	0.96	2.09	51.74	32	1.63	116	23.73
00:17:00	2.12	29.68	0.97	2.05	52.48	38	1.39	118	24.77
00:18:00	2.21	30.96	0.96	2.13	54.37	41	1.33	124	24.60
00:19:00	2.38	33.31	0.96	2.29	57.73	39	1.49	133	24.26
00:20:00	2.48	34.73	0.98	2.43	62.27	42	1.50	129	25.13
00:21:00	2.30	32.21	0.96	2.20	56.25	39	1.46	120	24.46
00:22:00	2.33	32.70	0.95	2.23	55.90	38	1.48	132	23.93
00:23:00	2.48	34.70	0.97	2.39	60.83	41	1.48	127	24.54
00:24:00	2.50	35.00	0.95	2.38	59.63	40	1.49	132	23.85
00:25:00	2.36	33.10	0.95	2.26	56.77	37	1.52	124	24.00
00:26:00	2.38	33.31	0.96	2.28	58.21	40	1.47	118	24.46
00:27:00	2.21	30.92	0.98	2.17	56.41	41	1.38	117	25.55
00:28:00	2.20	30.82	0.96	2.12	55.33	42	1.32	131	25.14
00:29:00	2.42	33.85	0.95	2.30	59.16	41	1.46	123	24.49
00:30:00	2.32	32.54	0.97	2.26	58.33	40	1.46	121	25.10
00:31:00	2.33	32.70	0.97	2.26	58.91	42	1.39	122	25.23
00:32:00	2.29	32.04	0.97	2.21	57.62	44	1.33	125	25.20
00:33:00	2.36	33.09	0.96	2.26	57.44	40	1.43	132	24.31
00:34:00	2.41	33.73	0.98	2.35	61.19	44	1.39	119	25.41

APPENDIX F

POLAR ACCUREX PLUS™ HEART RATE PRINTOUT



Curve
Copyright by Polar Electro Oy
HR / bpm
File Summary (%)
250
225
200
175
150
125
100
75
50
25
0
0.0 %
0.0 %
98.5 %
1.5 %
0.0 %
Limits 1
130
90
Max HR
183
Rest HR
70
0:00:00.0
0:10:00.0
0:20:00.0
0:30:00.0
0:40:00.0
0:50:00.0
1:00:00.0
Time

Listing (1/1)

Person: Mahlatini Malwane
Exercise: 2000/10/27 6:18:22 60s
Date: 10/27/2000
Time: 6:18:22.0

Final Time: 1:05:15.1 HR 111

Time	Heart Rate Values											
00:00	72	110	118	115	116	117	112	112	107	107	109	104
00:12	107	104	109	107	107	106	110	103	104	107	104	109
00:24	107	110	103	106	103	108	106	106	102	108	105	106
00:36	109	109	104	104	106	105	102	101	101	106	105	107
00:48	106	107	107	106	114	108	108	109	106	104	105	108
01:00	103	98	111	108	109	111						