An ergonomic risks assessment of manual and motor-manual pruning.

By Zimbili Bonisiwe Sibiya

Thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Forestry at the Faculty of AgriSciences, University of Stellenbosch.

Supervisor: Professor Pierre Ackerman
Co-supervisor: Mr Simon Ackerman

Department of Forest and Wood Science

Faculty of AgriSciences

March 2020

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof, that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: March 2020

Abstract

Mechanisation and modernisation in pruning operations for South Africa's forestry industry have advanced to keep abreast with best practices internationally. Commercially planted pine species in South Africa are not self-pruning, therefore, pruning activities are done extensively to produce clear wood and for fire protection or accessibility purposes. Although traditional handheld pruning tools have been used for decades, motor-manual pruning saws have recently been introduced to South African pruning operations. This has, however, raised the question what the ergonomic risks in manual and motor-manual pruning operations potentially expose workers to. Therefore, the study aimed to assess ergonomic risks that may be associated with the manual and motor-manual pruning operations of *Pinus patula* stands in Kwa-Zulu Natal (KZN), Midlands at 3.5 m and 2.0 m pruning lifts.

Convenience sampling of seven pruners was done to collect data on productivity (time study), workload (heart rate indices and productive heart rate), awkward postures (captured images during pruning operations) and body discomfort rating (Nordic Musculoskeletal map and the Likert scale) for ergonomic risks assessment. Statistica 64 and Excel functions were used to test for significant interactions between pruning method, pruning lift and worker and Games-Howell posthoc test for significant differences between the means of operations at a statistically significant level of 5.0 %. Awkward postures were assessed for deviation from the neutral plane of body posture. Body discomfort was analysed with Fisher's exact test for prevalence of discomfort per recording period, frequency of discomfort rating and discomfort per body part for each pruning operation. Machine utilisation was considered the same as the duration of exposure to operation due to the nature of the operation requiring availability of operator and machine to be executed successfully.

Results show that the interaction between the pruning lift, pruning method and pruner was significant for productivity, productive heart rate and body discomfort responses. Time study results showed that motor-manual (MM) operations produced the highest productivity compared to the manual (M) operations; however, the manual operations were the most efficient. Pruning operations fell under the "medium to heavy" workload classification with mean heart rates at work of 115, 113, 110 and 119 beats per min (beats.min^{-1}), for 2.0 m M, 2.0 m MM, 3.5 m M and 3.5 m MM respectively. Common postures adopted by workers were the shoulder and elbow abduction and extension, twisting and neck extension, ulnar deviation and bending of the back. High prevalence of discomfort was reported for manual (55 %) operations compared to MM (49 %) and 2.0 m pruning lift (61 %) and 3.5 m pruning lift (42 %). Pruning operations were rated as severe discomfort except for 3.5 m MM, which was rated as moderate discomfort. Some of the postures adopted by workers must be adjusted to avoid future health problems, such as high flexion of the back in the 2.0 m M and MM operations with a high prevalence of discomfort reported. Additionally, the duration of exposure to the operation and the repetitive nature of pruning operations are additional ergonomic risks identified in this study.

These results show promise as the first steps in investigating the effect of M and MM operations on Ergonomic and productivity of operations. However, it is recommended for this study to be repeated with a larger sample and with gender as an additional factor because that is much more thorough representation of the current pruning operation teams. Additionally, a thorough focus on musculoskeletal disorder since many workers have been in the field for several years.

Keywords: pruning, ergonomics, productivity, workload, discomfort and postures.

Opsomming

Meganisasie en modernisering van snoeibedrywighede vir die bosboubedryf in Suid-Afrika is gevorder om op hoogte te bly met die beste praktyke internasionaal. Kommersiële aangeplante dennespesies in Suid-Afrika snoei nie vanself nie; daarom word snoeiaktiwiteite breedvoerig gedoen om helder hout te produseer, en vir brandbeskerming of toeganklikheid. Alhoewel tradisionele hand-en-snoei-instrumente al dekades gebruik word, is motorsnoei-saag onlangs aan Suid-Afrikaanse snoeibedrywighede bekendgestel. Dit het egter die vraag laat ontstaan waartoe die ergonomiese risiko-handleiding en motorhandmatige snoeiwerk werkers moontlik blootstel. Daarom is die studie gemik op die bepaling van ergonomiese risiko's wat verband hou met die hand- en motorhandmatige snoeibewerkings van *Pinus patula* bos in Kwa-Zulu Natal (KZN), Midlands op 3.5 m en 2.0 m snoeihysbakke.

Gemakste steekproefneming van sewe snoeiers was gedoen om data oor produktiwiteit (tydstudie), werklading (hartslagindeks en produktiewe hartklop), ongemaklike posture (vasgelegde beelde tydens snoeioperasies) en liggaamsgemakstemming (Nordiese muskuloskeletale kaart en Likert-skaal) te versamel vir assessering van ergonomiese risiko's. Statistica 64 en Excel-funksies was gebruik om te toets vir beduidende interaksies tussen snoeimetode, snoeigraaf en werker, en Games-Howell posthoc-toets vir beduidende verskille tussen die bedieningsmetodes op 'n statisties beduidende vlak van 5.0 %. Ongemaklike houdings is beoordeel as afwyking van die neutrale vlak van liggaamshouding. Liggaamsongemak is geanaliseer met Fisher se presiese toets vir die voorkoms van ongemak per opnameperiode, frekwensie van ongemak-gradering en ongemak per liggaamsdeel vir elke snoeibedrywigheid. Die doeltreffendheid van die masjien word dieselfde beskou as die duur van die blootstelling aan die gebruik as gevolg van die aard van die werking wat die beskikbaarheid van die bestuurder en die masjien suksesvol moes uitvoer.

Resultate toon dat die interaksie tussen die snoeihef, die snoeimetode en snoeier betekenisvol was vir produktiwiteit, produktiewe hartklop en reaksies op liggaamsongemak. Resultate van die tydstudie het getoon dat motorhandleiding (MM) bedrywighede die hoogste produktiwiteit opgelewer het in vergelyking met die handleiding (M) bewerkings; die handbedrywighede was egter die doeltreffendste. Snoei-operasies val onder die gemiddelde tot swaar werklasklassifikasie met gemiddelde werkshartklop van 115, 113, 110 en 119 slae per minuut (slae.min-1), vir 2.0 m M, 2.0 m MM, 3.5 m M, en 3.5 m MM onderskeidelik. 'n Algemene liggaamshouding wat deur werkers aangeneem is, was die ontvoering en verlenging van die skouer en elmboog, draai en nekverlenging, afwyking van die ulna en buigingvan die rug. 'n Groot voorkoms van ongemak was gerapporteer by handmatige (M) (55%) operasies in vergelyking met MM (49%), en 2.0 m snoeihef (61%) en 3.5 m snoeihef (42%). Snoeibedrywighede is as ernstige ongemak beskou, behalwe vir 3.5 m MM, wat as matige ongemak beskou is. Sommige van die houdinge wat deur die werkers aangeneem was, moet aangepas word om toekomstige gesondheidsprobleme te vermy, soos hoë buiging van die rug in die 2.0 m M- en MM-bedrywighede, met 'n hoë voorkoms van ongemak wat aangemeld is. Boonop is die duur van die blootstelling aan die bedrywigheid en die herhalende aard van die snoeiobedrywighede addisionele ergonomiese risiko's is wat in hierdie studie geïdentifiseer was. Hierdie resultate toon belofte as die eerste stappe in die ondersoek na die effek van M- en MM-bewerkings op die ergonomiese risiko’s en produktiwiteit van snoeibedrywighede. Dit word egter aanbeveel dat hierdie studie herhaal word met 'n groter steekproef en met geslag as 'n addisionele faktor want dit is 'n baie deeglike weergawe van die huidige snoei-operasiespanne. Daarbenewens is daar 'n deeglike fokus op muskuloskeletale versteurings, aangesien baie van die werkers al 'n paar jare in die veld was.

Sleutelbegrippe: pruning, ergonomics, productivity, workload, discomfort and postures.

Isifinyezo
Ukusebenza ngomshini nokwenziwa kwemisebenzi ngesimanje emisebenzini yokuthena embonini yamahlathi yaseNingizimu Afrika sekuthuthukile ukuze kuqhubeke kuhlangane ngemikhuba emihle emhlabeni jikelele. Izinhlobo zikaphayini ezitshalelwe ukuthengiswa eNingizimu Afrika azizitheni. Ngakho-ke, imisebenzi yokuthena yenziwa kakhulu ukukhiqiza izinkuni ezinhle, kanye nezinjongo zokuvikela umlilo noma kungeneke kalula ehlathini. Yize kusetshenziswe amathuluzi endabuko okuphathwa ngesandla amashumi eminyaka, amasu okuthenga izithuthuthu asanda kwethulwa emisebenzini yokuthena yaseNingizimu Afrika. Lokhu-ke, kuphakamise umbuzo wokuthi yimiphi imisebenzi yezandla yokuphehlwa kwe-ergonomic kanye ne-motor-manual (MM) engase ichithe abasebenzi kuyo. Ngakho-ke, lolu cwaningo luhlose ukuhlola ubungozi be-ergonomic obungase buhlotshaniswe nomsebenzi wokuthena izihlahla ze-*Pinus patula* KwaZulu Natal (KZN), Midlands ngamamitha ayi-3.5 m kanye no-2.0 m.
Ukwenza isampula yokuqongelela, abasebenzi abayisikhombisa abavele bekhona, kwenziwa ukuqoqa idatha ekukhiqizeni (ngesikhathi sesifundo), umthamo womsebenzi (ukushisa kwenhliziyo kanye nenhliziyo ekhiqizayo), ukuma okungahambi kahle (izithombe ezithwetshuliwe ngesikhathi somsebenzi), isilinganiso sokungakhululeki komzimba (Imephu ye-Nordic Musculoskeletal kanye nesikali se-Likert) ukuhlolwa kwezingozi ze-ergonomic. I-Stistica 64 ne-Excel imisebenzi esetshenziselwe ukuhlola ukusebenzisana okuhle phakathi kwendlela yokuthena izihlahla, ukuphakamisa izihlahla kanye nomsebenzi, kanye nokuhlolwa kwe-Games-Howell posthoc ngomehluko omkhulu phakathi kwezindlela zokusebenza ngezinga eliphakeme ngokwezibalo ze-5.0 %. Ukuhlolwa okungahambi kahle kuhlolwe ukuze kuhlukaniswe ukuma komzimba okungathathi hlangothi. Ukungaphatheki kahle komzimba kwahlazinywa ngokuhlolwa okuqondile kukaFisher kokuthola ukungathandeki ngesikhathi ngasinye sokurekhoda, imvamisa yesilinganiso sokungaphatheki kahle, kanye nokungaphatheki kahle kwengxenye yomzimba womuntu ngamunye emsebenzini wokuthena. Ukusebenza kahle komshini kubhekwe kufana nesikhathi sokuchayeka ekusebenzeni ngenxa yohlobo lomsebenzi oludinga ukutholakala komsebenzi nomshini ukuthi wenziwe ngempumelelo.
Imiphumela ikhombisa ukuthi ukuxhumana phakathi kwephini yokuthena izihlahla, indlela yokuthena izihlahla kanye nomsebenzi kwakubalulekile ekukhiqizeni, ukushaya kwenhliziyo nokukhiqiza izimpendulo zokungakhululeki komzimba. Imiphumela yokutadisha isikhathi ikhombisa ukuthi ukusebenza kwe-motor-manual (MM) kukhiqize umkhiqizo ongcono kakhulu uma kuqhathaniswa nokusebenza kwemanuwali (M); kepha imisebenzi yezandla ibisebenza kahle kakhulu. Umsebenzi wokuthena wawela ngaphansi kokuhlukaniswa komthwalo osindayo kuya kwesilinganiso senhliziyo emsebenzini we-115, 113, 110 no-119 ukushaywa ngeminithi ngalinye (beats.min-1), ku-2.0 m M, 2.0 m MM, 3.5 m M, no-3.5 m MM ngokulandelana. Ukuma okujwayelekile okwamukelwa ngabasebenzi kwakungukuhlatshwa kwehlombe nokuwela, nokunwebeka, ukusontelana nokunwetshwa kwentamo, ukuphambuka kwe-ulnar nokugoba kweqolo. Kubikwe ukuthi kunenkinga enkulu yokungakhululeki komzimba kahle ngokusebenza kwezandla (55%) makukuqhathaniswa neMM (49%), kanye noluthena okuphakanyiswe amamitha awu-2.0 m (61%) nakuma mitha awu-3.5 m (42%). Umsebenzi wokuthena ulinganiswe njengobunzima obukhulu ngaphandle kwe-3.5 m MM, okulinganiswe njengokungahambi kahle okulinganiselwe. Ezinye zezinto ezimiselwe ukusetshenziswa kumele zilungiswe ukuze kugwenywe izinkinga zempilo zesikhathi esizayo, njengokuguququguquka okuphezulu komhlane ekusebenzeni kwe-2.0 m M ne-MM ngobunzima obukhulu bokuxhamazeka okubikiwe. Ngaphezu kwalokho, isikhathi sokuchayeka ekusebenzeni kanye nemvelo ephindaphindekayo yokusebenza ukuthena ziyingozi eyengeziwe ye-ergonomic ekhonjwe kulolu cwaningo.
Le miphumela ikhombisa ukuthembisa njengezinyathelo zokuqala zokuphenya imiphumela yokusebenza kwe-M ne-MM ku-Ergonomic nokukhiqizwa kwemisebenzi. Kodwa-ke,

kunconyelwe ukuthi lolu cwaningo luphinde luphindwe ngesampula enkulu kanye nobulili njengenye into eyengeziwe ngoba lokho kuvezwa ngokuphelele kwamaqembu wokusebenza kokuthena kwamanje. Ngaphezu kwalokho, ukugxila ngokuphelele ekuphazamisekeni kwesifo se-musculoskeletal njengoba abasebenzi abaningi baneminyaka eminingi benza lomsebenzi.

Amagama agqamile: ukuthena izihlahla, i-ergonomics, umkhiqizo, umthwalo, ukungakhululeki komzimba, kanye nokuma okungahambi kahle.

Dedication

This thesis is dedicated to:

- The change agents who want to change the world through research, innovation, creation and implementation to move humanity forward.
- My mother, who believes in the value of education.
- The hard-working forestry workers in field who trust our intentions with research, may we never disappoint you.

Acknowledgments

I wish to express my sincere gratitude and appreciation to the following persons and institutions:

- My supervisor, Prof. Pierre Ackerman for accepting my individuality and for being patient with me.
- NCT for sponsoring my studies and living expenses.
- Mondi for providing the study area, team and learning opportunity.
- Nonkululeko Ntinga for guidance, help and insight
- The Siyanqoba pruning team, ngyabonga kakhulu ukuzinikela nokuzikhandla kwenu.
- Stellenbosch University High performance Sports Department for assistance with heart rate equipment for data collection.
- Charles Swart for assisting in the study
- Genevieve Macquet for insight and guidance.
- The staff members and friends from student affairs for encouraging, supporting and reminding me of what matters.
- Every person who reminded me that it is okay and to trust the process-and all the hugs you gave me!
- My close friends who continuously cheered me up and inspired me.
- Myself, for persevering despite every obstacle that challenged me.
- My family (Sibiya's and Ngema's), for having my back and supporting me throughout.

Table of Contents

Table of Figures

List of Tables

1. Introduction

The mechanisation of South African forest operations has increased significantly during the last ten years. The main objectives being to improve productivity and the working environment to ensure enhanced safety and reduced exposure of workers to adverse working conditions (Längin and Immelman, 2011 and Williams and Ackerman, 2016). Forest operations are considered high-risk for human safety, therefore an understanding of ergonomic risks in operations is of utmost importance (ILO, 1998, Cohen, Clark, Silverstein, Sjostrom, and Spielholz, 2006).

In contrast to timber harvesting and primary transportation of timber, silvicultural operations are mostly still manually orientated in South Africa. There is however a move towards more mechanised operations, as in mulching, pitting, planting, pruning and slash management by several forestry companies in South Africa. The need to keep South African forest operations abreast with international best work practices greatly influences modernisation in silviculture namely; improved ergonomics, enhanced productivity, product quality, reduced exposure to monotonous work and reduced worker exposure to adverse elements in operations (Da Costa, 2013). With modernisation comes the mechanisation of work methods and tools used in these operations. It is, therefore, necessary to understand if the tools used are ergonomically sound, do not impact the worker and what potentially can be improved to make them ergonomically sound.

Pruning is fundamental to South African commercial plantations with even-aged stand silvicultural systems (Du Toit and Norris, 2011). Pruning of pine species is required since, unlike commercially grown Eucalyptus species, pines are not self-pruning. Pruning of stands is done for access purposes for fire protection, limiting dead knots and to produce clear wood. Traditional manual pruning saws are slowly being replaced by more modern tools, such as: manual pole-pruners, loppers, manual and battery-powered pruning shears, small pruning chainsaws and recently, motor-manual pole-pruners.

The motor-powered pole-pruner was introduced to South Africa in the early 2000s. Reasons for the introduction of mechanised equipment is to improve productivity and quality of the pruned trees over that produced by traditional pruning saws. Although it has long been recognised that high manual pruning is ergonomically questionable, there are currently no known South African related studies investigating the potential ergonomic impacts of the pole-pruner operations compared to the manual pruning saw. There have, however, been studies done investigating the ergonomic risks of manual pruning saws and electric shear pruners, (Shekwa, Chirwa, Ngulube and Ghebremariam, 2017). The most current study to date is the Brazilian study of *Pinus taeda* manual and motor-manual pruning operations. The study looked at the technical and cost evaluation (de Oliveira, Lopes, Malinovski, da Silva and Rodrigues, 2012) and a biomechanical evaluation (Lopes, Oliveira, Malinovski and da Silva, 2013) of manual pruning saws and motor-manual pole-pruners at first, second and third pruning of *P. taeda* stands.

From studies performed by Potočnik and Poje (2017), it is evident that more research needs to be executed on ergonomic assessments of pruning operations in general and various potentially suitable pruning equipment. South Africa's unique industrial plantation management system, in contrast to the northern hemisphere, requires intensive tree-based silviculture. Pruning is one of the critical parts of this management system. Even though the current research focuses on pruning for accessibility, it does open doors to encourage more research to be done on ergonomic assessment for pruning operations within Southern Africa to ensure that pruning activities are safer for operators.

1.1. Research question

Are there ergonomic risks associated with manual and motor-manual pruning operations of *Pinus patula* stands in the Midlands of KZN for 2.0 m and 3.5 m pruning lifts?

1.2. Research aims and objectives

Main objective: An ergonomics risk assessment of manual and motor-manual pruning operation of *P. patula* stands in the KZN Midlands in South Africa.
Sub-objectives:

- Determine productivity of manual and motor-manual pruning methods for the 2.0 m and 3.5 m pruning lifts.
- Assess the biomechanical effects on the worker of manual and motor-manual pruning method for the 2.0 m and 3.5 m pruning lifts by monitoring heart rates as a measure during pruning operations.
- Analyse and assess the psychophysical effects on the worker by manual and motor-manual pruning method for the 2.0 m and 3.5 m pruning lifts based on body discomfort rating responses.
- Assess observed adverse body postures adopted by workers using photos taken during pruning operations.

2. Literature Review

2.1. Background to ergonomics

Ergonomics has evolved and developed for decades as a unique discipline of its own and continues as technology advances (Karwowski, 2005). Dempsey, Wogalter and Hancock (2000) identified keywords related in the discipline that conveys the essence of the discipline as a dynamic and human-centred field. Dempsey, Wogalter and Hancock (2000) defined ergonomics as "the design and engineering of human-machine systems to enhance human performance". In addition, ergonomics at the workplace is applied to the design of work equipment and tasks and work organisation (McPhee, Scott and Kogi, 2009).

In 2000, the International Ergonomics Association (IEA) proposed three broad domains of specialisation in ergonomics, namely; physical, cognitive and organisational ergonomics to establish clear identification of recognised areas of the discipline. The focus is commonly placed on the physical ergonomics domain, which is concerned with human anatomical, anthropometric, physiological and biomechanical characteristics as they relate to physical activities (McPhee *et al.*, 2009). Ergonomics is synonymously used with other terms such as human factors, occupational health and safety and work-related musculoskeletal disorders as contributors to improving work conditions for human performance in the workplace. These terms are relevant topics within the physical ergonomics domain.

The common aim of the abovementioned terms is bettering the human condition in the workspace, ensuring that jobs are safe, healthier, but at the same time efficient (ILO, 1992; Stanton, 2005). Some authors argue that the aim of bettering human conditions may conflict with other aims of improving system effectiveness and efficiencies. However, this is a concern for the ergonomists and employing organisations to ensure that ethical concerns are accounted for to meet these aims (Stanton, 2005).

According to Christie (2012), ergonomics research has mostly focused on industrially advanced countries (IACs). Potočnik and Poje (2017) found that 95% of the published articles reviewed between the years 2005-2016 were from Europe, South America and North America. These findings confirm the dominance of the industrially developed countries in forest ergonomics research. Ergonomists need to collaborate and contribute to narrowing the gap in ergonomics and turn their priorities towards industrially developing countries (IDCs) because 75 % of humankind live and work in IDCs (Christie, 2012; Krueger, 2012). In 1995, Shanahvaz raised the concern that "the tendency of applying first-world ergonomics theory to third-world problems, without carefully and substantially modifying it to local conditions is not a constructive approach" (Scott, 2009). Ergonomics in IACs must take full consideration of the additional factors impacting ergonomics which may not reflect the working and living conditions of IDCs (Scott, 2009: Todd, 2011).

Ergonomists must work with and optimise what is in their countries to effect change in the direction of what ought to be and not wait for IACs' socio-economical, educational and political developments to emulate those of IDCs' (Scott, 2009). Therefore, guidelines specific to IDCs in occupational health and ergonomics can be applied based on the work by McPhee *et al.* (2009).

2.2. Ergonomics in forestry

Most forestry workers in South Africa are from underprivileged backgrounds and rural areas, with compromising living conditions, such as lack of access to clean water, poor nutritional intake and low income (Christie, 2001; Steenkamp, 2007). In extended studies of forestry ergonomics in harvesting operations, the relationship between worker nutritional status and demands of the work requires attention as it is a contributing factor to the operator's ability to work effectively (Scott, 2009). Forestry activities require substantial energy and many workers do not have adequate nutritional intake (Scott, 2009). Steenkamp (2008) found that nutrient supplementation improved the productivity of such activities. These negative compounding factors have a spiralling effect on the worker's performance and Scott (2009) urges that ergonomics input can and must play a role in reversing this negative spiral.

Potočnik and Poje (2017) identified a global increase in scientific publications in the field of occupational safety and health and ergonomics in the forestry industry. Thirty-five per cent of the studies addressed timber harvesting and 38 % timber extraction, while pre-harvesting operations, such as silviculture were only addressed in 12 % of the articles reviewed (Potočnik and Poje, 2017). South African studies in forest ergonomics focused mostly on harvesting operations (Phairah, Brink, Chirwa and Todd, 2016), heavy manual labour, such as timber extraction (James, 2006), manual peelers, stackers and chainsaw workers (Scott *et al.*, 2004). There is a dire need for local ergonomics research in order to sustainably support the mechanisation drive and to optimise existing mechanical harvesting systems and silvicultural systems.

2.3. The influence of modernisation and mechanisation

The increasing need for modernisation and mechanisation in the forestry industry has led to radical changes in the work methods of forestry operations (Phairah *et al.*, 2016). Although both terms have similar aims, modernisation does not necessarily refer to mechanisation (McEwan and Steenkamp, 2014). Modernisation refers to the change of an already existing system with the aim to improve or keep abreast with technological advancements (da Costa, 2013). Mechanisation, however, is a subset of modernisation (da Costa, 2013) and refers to the use of machines as tools to assist or replace the use of workforce in operations, intending to improve productivity and sustainability (Thompson, 2013).

On a global scale, mechanisation of forest harvesting operations has contributed to increasing productivity and improved working conditions (ergonomics), while decreasing the workforce required for specific tasks in operations (Błuszkowska and Nurek, 2014; Ackerman, Williams, Ackerman and Nati, 2016). Slappendel, Laird, Kawachi, Marshall and Cryer (1993) found that mechanisation reduces injury risk in many logging tasks with the notable exception of maintenance work. McEwan and Steenkamp (2014), however, contradicted this finding and identified that modernisation of silviculture activities reduced the number of people in-field and increased the probability of injury.

Da Costa (2013) outlines the factors positively influencing modernisation in silviculture as:

- The concept of decent work
- Keeping abreast of best practices in international forestry
- Improved ergonomic working conditions

- Eliminate safety risks, especially when using sharp tools
- Reduced exposure to harsh climatic conditions
- Reduced exposure to monotonous work
- A more stable and educated workforce
- Improved productivity and quality of silviculture operations.

McEwan and Steenkamp (2014) conceptualised the factors driving modernisation within South Africa based on the socio-economic status of workers as a result of migration patterns in the labour market. Workers from rural areas migrate to urban areas, leading to a "decrease" of available markets for silvicultural operations. A great contributor, however, is the social status of the worker concerning their socio-economic background. Many people, especially those with educational qualifications, are not willing to be involved in manually strenuous work. Other contributing factors are the HIV and AIDS status of the workers, which further influences productivity, labour turnover and absenteeism (Christie, 2001; Todd, 2011; McEwan and Steenkamp, 2014). However, this is a unique situation in IDCs due to the high level of basic skilled people in rural areas. Although Da Costa's approach focused on international relations and rightfully so, in the context of ergonomics, the drive for mechanisation should be more people focused. Especially considering that manually intensive silvicultural operations are ergonomically inferior and that they pose high risks in an already dangerous occupation (Scott, 2009).

Modernisation and mechanisation add value to the forestry industry, though its disadvantages must be acknowledged (Diamante-Camacho, 2012). For instance, the ergonomic risks and development of work-related musculoskeletal disorders (WMSDs) (Phairah *et al.*, 2016) and occupational health problems, such as back pain, adverse posture and overuse injuries remain a concern (Slappendel *et al.*, 1993). Mechanisation in forestry also leads to emission of pollutants into the natural environment, such as polycyclic aromatic hydrocarbons and oil spills on the ground (Klamerus-Iwan, Błońska, Lasota, Kalandyk and Waligórski, 2015).

Although there are disadvantages, modernisation of silvicultural operations is a necessity in forestry to improve the safety, productivity and poor health of current labour (McEwan and Steenkamp, 2014). The increasing drive in modernisation and mechanisation in silviculture resulted in existing and new innovative techniques for operations being identified, tested and implemented (McEwan and Steenkamp, 2014), which benefits modernisation as it can supply decent work. The industry is currently in an implementation phase whereby high-risk operations are being modernised, using appropriate technologies coupled with continual training, multi-skilling of workers, the improvement of supervisors and a continual focus on new practices to promote the wellbeing and productivity of silvicultural activities and workers (McEwan and Steenkamp, 2014).

2.4. Pruning operations in South Africa

Pruning operations in South Africa are extensively implemented in most sawtimber management regimes and contribute to the high costs, time-consuming and labour demanding activities in the industry (Shekwa *et al.*, 2017). The pine species grown in South Africa are not self-pruning as with some Eucalyptus species, which are. Therefore, timber growers prune pine stands for fire protection purposes, to prevent the formation of dead knots and to produce high-value clear wood (Kotze and du Toit, 2012). The global price incentive for clear wood still drives some timber growers to focus on the production of clear wood, but most growers, whether for sawtimber or pulpwood production will still do a pruning lift for fire protection (Kotze and du Toit, 2012).

Pruning lift is the height in metres to which workers must prune to from the live crown upwards. For *P. patula* in South Africa for example, a pruning lift approach is applied to ensure that at least 35 % of the live crown of the tree height remains after pruning (Kotze and du Toit, 2012). Therefore, for the first pruning of *P. patula,* Kotze and du Toit (2012) recommend a 1.0 to 2.0 m pruning lift when the stand is between ages 5-6 years old and diameter at breast height (DBH) is within the proposed range for its adequate growth. Second pruning can follow 2-3 years after first pruning with pruning lift of 3.0, 5.0 or 7.0 m. Finally, the pruning lift should be practical for the workers to handle a stick length of 1.0-8.5 m throughout the operation (Kotze and du Toit, 2012), because hard-to-reach pruning heights of trees cause ergonomic discomfort to workers, which increases on steep terrains (Shekwa *et al.*, 2017).

The selection of an ergonomically and financially appropriate tool has a significant impact on the quality of operations (Nutto, Malinovski, Brunsmeier and Schumacher, 2013; Shekwa *et al.*, 2017). Researchers (Ford, 1995; Kirk and Parker, 1996a; Nutto *et al*., 2013; de Oliveira *et al.*, 2012; Shekwa *et al.*, 2017) have studied manual pruning saws, chainsaws with ladders, manual loppers, manual and electric pruning shears and pole-pruners for their productivity, cost analysis, effectiveness, quality and workload and ergonomic risks .

Traditional pruning saws have been used for decades and different types of saws have been designed to increase productivity, improve quality of pruning and reduce ergonomic risks to the worker (Ford, 1995; Kirk and Parker, 1996b). The advantages of traditional manual saws are that they are easy to handle and light in weight, require little training, are cost-effective and lower risks of injury (Ford, 1995; Nutto *et al.,* 2013; Shekwa *et al.*, 2017). However, manual pruning tools lead to high workloads that reach the upper physical and mental limits of the body. Ford (1995) found that manual pruners experience significantly more body discomfort during the workday as compared to the high ladder chainsaw pruners. A study by Kirk and Parker (1996a) evaluated ergonomic risks in manual pruning of Douglas fir in New Zealand. They found that first lift manual pruning constitutes a “medium to heavy” workload, while Nutto *et al*. (2013) found manual pruning to be “very hard work”. Furthermore, manual pruning requires strenuous and repetitive wrist and elbow motions, which can lead to workers suffering from tennis elbow (epicondylitis). Nutto *et al.* (2013) also found a prevalence of absenteeism of at least two days a month due to the strenuous nature of the work. Outcomes suggest that some of the risks identified in the study could be mitigated by potentially replacing manual with motor-manual pruning methods.

Motor-manual tools can reduce physical workloads and improve productivity in pre-harvesting operations (Bačić, Šušnjar, Pandur, Šporčić and Landekić, 2018). Pole-pruner saws are ideal for extensions and pruning operations extending to heights of more than 5.0 m (Schnepf and Schwandt, 2006) and with the motor-powered and chainsaw, are more productive compared to manual saws (de Oliveira *et al.*, 2012).

The pole-pruner, however, requires extensive training, more personal protective wear due to its high-injury risk and to adhere to occupational health and safety regulations (Kirk and Parker, 1996a; de Oliveira *et al.*, 2012). The maintenance and repair, refuelling and sharpening is time-consuming and require additional costs, making the motor-manual pole pruner more expensive (Schnepf and Schwandt, 2006). De Oliveira *et al.* (2012), however, concluded that the production cost, high quality of work and ergonomic benefits of the motor-manual pruning operations are technically and economically viable.

2.5. Productivity in pruning operations

Productivity studies in forest operations have been well-investigated internationally. These studies (Toupin, LeBel, Dubeau, Imbeau and Bouthillier, 2007; de Oliveira *et al.*, 2012; Nutto *et al*., 2013; Williams and Ackerman, 2016; Shekwa *et al.*, 2017) are aimed at improving forest operations, predicting productivity and sometimes the cost of operations due to mechanisation and modernisation. Although the productivity of pruning operations can be generalised specifically to the equipment, there are various contributing factors unique to specific conditions, namely operator experience and motivation, terrain conditions, shift timing, maintenance practices, work objective, tree form, species and tree branchiness (Martin, 2016).

Time studies have been widely used by researchers across the forestry industry to determine the productivity of operations or comparing systems to improve productivity and machine utilisation (Längin, Ackerman and Olsen, 2010). Time study is a standard tool used for the measurement of work to determine a standard time it should take to complete a task (Ackerman, Gleasure, Ackerman, and Shuttleworth, 2014).

All forestry activities have several smaller processes referred to as elements in the time study (Martin, 2016). These elements are broken down into basic functional steps which can be measured throughout a typical work cycle (Ackerman *et al.*, 2014). Elements such as delays (resting breaks, maintenance and repair, refuelling and other) that interrupt the productivity flow need to be measured to capture the most accurate representation of work rate (Nakagawa, Hamatsu, Saitou and Ishida, 2007). The Forest Operations Productivity Initiative in South Africa (Ackerman, Ackerman, Spong, and Terblanche, 2019) developed robust and internationally aligned time study standards and elements for use by the forestry industry.

South African and international studies investigated the productivity of different pruning tools such as manual pruning saw (different types), pruning shears, chainsaw and ladder and motor-manual pole-pruners. Shekwa *et al.* (2017) studied the productivity of the manual pruning saw and an electric pruning shear in 2.0 m pruning lift operations in *Pinus elliottii* stands in Mpumalanga, South Africa. In this study, they found that the electric pruning shear yielded higher productivity compared to the manual saw. These findings are complemented by the study of Nutto *et al.* (2013) who compared the productivity of three different pruning tools (Limmat handsaw, P100 manual pruning shear and the F3010 electric pruning shear). The electric shear yielded the highest productivity, the manual shear the second highest and the lowest being the handsaw. De Oliveira *et al.* (2012) however, compared three different pruning tools and pruning lifts, in which the manual operation had the lowest productivity compared to the motor-manual operations, which were similar to the findings by Ford (1995). However, Ford (1995) compared the manual saw to a small pruning chainsaw with the assistance of a ladder to reach high pruning lifts. Giefing and Złota (2007) studied the efficiency of four different types of pruning saws (Dauner saw, Bushman saw, Hengst saw and the Deutsche model saw) in Poznań, Poland. The findings concluded that the Dauner saw was the most effective and productive compared to the others, with an average pruning time per tree of 2.5 min. In all these studies, the difference is influenced by various factors, such as the pruning tool, branch diameter, ground slope, pruning lift, maintenance time of each piece of equipment due to design, length of the tool to reach desired pruning lift heights and environmental conditions.

With these findings, it must be noted that the influence of branch diameter has a significant effect on the productivity of the pruning operations based on the type of tool applied (Montowska and Pospiech, 2007 and Shekwa, *et al.*, 2017). Additionally, productivity can be affected by the ergonomic discomfort created due to hard-to-reach pruning heights and terrain influences, e.g. slope differences but manual saws are found to be less sensitive to slope grades (Nutto *et al.*, 2013; Shekwa *et al.*, 2017). In all comparable studies mentioned above, the manual saw was found to be the least productive compared to other pruning tools such as semi-mechanised and motor-powered tools that produced higher productivity.

2.6. Ergonomic analysis methods

Methods that offer a structured approach to the analysis and evaluation of the design problems in the field were developed for scientists and ergonomists to implement for the various aims of bettering the human condition in the workspace (Stanton, 2005). The methods, namely, physical, psychophysiological, behavioural-cognitive, team methods, environmental and macro ergonomics, are designed to align with the aim of the ergonomics discipline. The focus will be placed on the physical and psychophysiological method, which is the approach taken for the current study and falls under the physical domain (McPhee *et al.*, 2009).

Physical methods are analysis and evaluation of the musculoskeletal factors by measuring discomfort, observation of posture, analysis of workplace risks, measurement of work effort and fatigue, assessing lower back disorder and predicting upper-extremity injury risks. While the psychophysiological methods analyse and evaluate human psychophysiology by measuring heart rate and heart rate variability, event-related potentials, galvanic skin response, blood pressure, respiration rate, eyelid movements and muscle activity (Stanton, 2005). These methods assist in narrowing the ergonomic assessment to studies only focusing on a particular method, for example, workload (heart rate), observation of postures and reporting of body discomfort, work-related musculoskeletal disorder studies, which have gained great focus in the ergonomics field.

Biomechanical (heart rate) measures give an objective indication of the mechanical demands on the body and relate to physical activity (Karwowski, 2005). The psychophysical (discomfort and awkward postures) approach, on the other hand, is a subjective measure and may indicate the influence of the demands relative to the existing capacity (Dickerson, Martin and Chaffin, 2006; Fischer and Dickerson, 2014). Dickerson *et al.* (2006) and Fischer and Dickerson (2014) agree that the biomechanical inputs are more specific compared to the psychophysical responses, which represent an integration of the sensory feedback and can be more indicative of overall exposure. Recent studies using the psychophysical approach found that there is evidence to support the notion that relationships exist between psychophysical responses and physical stimuli across body domains and task complexities. However, some of the studies focused more on individual body parts than the full body (Fischer and Dickerson, 2014).

2.6.1. Heart rate as a measure of workload

Changes in cardiac activity are one of the five physiological measures used to measure workload by measuring heart rate and heart rate variability (Miller, 2001). Physiological workload is a parameter used to show the pressure that the worker encounters during work, based on heartbeat frequency (Vitalis, Gaskin and Jeffrey, 1984). Physical work is performed due to muscle action, which leads to aerobic combustion as muscles use oxygen to convert food into mechanical energy. High energy demand leads to high oxygen demand and therefore increased blood circulation. Workload increases as heart rate increases, making heart rate a reliable measure for workload during active task periods (Vitalis *et al.*, 1984; Smith, Wilson and Sirois, 1983; Sullman and Byers, 2000; Kirk and Sullman, 2001; Toupin *et al.*, 2007; Caliskan and Caglar, 2010). However, these changes can be influenced by environmental factors, such as terrain surface, weather conditions, tools, work method, pace of work, stand characteristics (undergrowth, or stand density) and psychophysiological factors, such as emotions, heat and work pace, resulting in higher physiological workloads (Parker and Kirk, 1994; Ford, 1995; Kirk, Sullman and Parker, 1998; Yoopat, Toicharoen, Glinsukon, Vanwonterghem and Louhevaara, 2002; Bates and Schneider, 2008; Nutto *et al.*, 2013; Kolus, Dubé, Imbeau, Labib and Dubeau, 2014; Shekwa *et al.*, 2017; Dubé, Imbeau, Dubeau and Auger, 2019).

Heart rate transmitters have been used in a number of studies (Parker and Kirk, 1994; Kirk and Parker, 1996a; Sullman and Byers, 2000; Kirk and Sullman, 2001; Nutto *et al.*, 2013; Shekwa *et al.*, 2017; Bačić *et al.*, 2018) to investigate workload based on heart rate data. The advantages of using heart rates are that it is objective and non-invasive (Shakouri, Ikuma, Aghazadeh and Nahmens, 2018). The equipment can be worn as an accessory and data is recorded externally and is less expensive compared to maximal oxygen uptake (VO_{2max}), which measures the amount of physiological work a person can execute (Wu and Wang, 2010). Therefore, measuring workload using heart rate data has been the preferred method.

Assessing workload using the HR indices has been implemented within forestry ergonomics research over the years. The heart rate indices are relative heart rate (RHR %) or heart rate reserve, average heart rate, the ratio of HR_{work} to $HR_{resting}$ and 50% level HR reserve. HR is recorded throughout the working day of a specific operation or the intended study time. The challenge with the HR indices is the recording of resting HR. The ideal resting HR is recorded in a state where the workers are relaxed, sitting or lying down and not ill (American College of Cardiology, 2014). This approach is not always easily achievable due to ancillary activities such as possibly walking long distances to work, which can increase the heart rate by the time they get into field. A proposed compromise is to allow a 10 to 15-minute rest period where workers can sit while recording HR (Vitalis *et al.*, 1984; Parker and Kirk, 1996a; Sullman and Byers, 2000; Toupin *et al.*, 2007).

Relative heart rate percentage (RHR%) is one of the most used indices to determine a comparable measure of heart rate strain (physical strain) among workers (Vitalis *et al.*, 1984; Kirk and Parker, 1996a; Sullman and Byers, 2000; Garet, Boudet, Coudert, Montaurier, Vermorel and Chamoux, 2005; Toupin *et al.*, 2007; Caliskan and Caglar, 2010). The use of the relative HR index at work was shown to be comparable to oxygen consumption (VO_2) and to have a significant relationship in measuring work metabolism in forestry workload studies (Dubé, Imbeau, Dubeau, Auger and Leone, 2015). The recommended aerobic capacity level index for prolonged continuous physical work over an eight-hour work period without being fatigued is 40% or lower (Sullman and Byers, 2000; Caliskan and Caglar, 2010; Dubé *et al.*, 2015). This value is significant to ensure that workers are working at a sustainable rate without overworking themselves.

The age-predicted maximum HR is an influential parameter in the RHR % equation. The universally accepted age-predicted maximum HR is calculated by subtracting the operator's age from 220 beats.min^{-1} (Gellish, Goslin, Olson, McDonald, Russi and Moudgil, 2007; Dubé *et al.*, 2015). Gellish *et al.* (2007) and Dubé *et al.* (2015) analysed the validity of this method and its suitability to be an actual representative value of maximum heart rate of individuals. Gellish *et* *al.* (2007), however, argued that the age-predicted maximum HR overestimates the actual value of maximum HR in young people and underestimates the maximum HR of older people. Dubé *et al.* (2015) reviewed other sources and concluded that the traditionally used 220-age equation compared to the equation proposed by Gellish *et al.* (2007) are both comparable to the participant's true maximum HR when executing metabolic aerobic capacity predictions; therefore, neither is superior to the other.

The ratio of HR_{work} to $HR_{resting}$ and the 50 % level of HR reserve is also a recommended relative measure of strain applied by researchers to measure workload in various ergonomics and workload related studies (Kirk and Sullman, 2001; Sullman and Byers, 2000). The 50 % level of the working HR has been accepted as a simple and efficient estimate of physical strain by Lammert (1972), Kirk and Parker (1996a) and further implemented by Sullman and Byers (2000) and Kirk and Sullman (2001). Diament *et al.* (1986) proposed the implementation of the ratio of working HR to resting HR as another measure of physical strain (Parker and Kirk, 1994). If the resulting number of this value is one or more, the work can be classified as hard-continuous work (Lammert, 1972; Parker and Kirk, 1994).

Previous work investigating physiological strain in forestry operations found physical workload averages of 44.79 % in chainsaw operations (Caliskan and Caglar, 2010), some harvesting activities as "medium to heavy" work (40.9 RHR %) (Yilmaz, Eroğlu, Cihan and Kayacan, 2013) and cable hauler/choker-setters as moderate workload (Kirk and Sullman, 2001). Pruning specific studies classified *Eucalyptus* plantation manual operations as "middle hard work" to "very hard," and operating motor-powered tool as "hard work" (Nutto *et al.*, 2013). Kirk and Parker (1996a) classified manual pruning of Douglas fir as a moderate workload activity, with a heart rate of 112 beats.min^{-1}. Ford (1995) found physiological workloads of 38.8 % and 39.3 % for chainsaw pruners (using ladders) and manual pruners, respectively. The physiological workload and strain of the pruning operations should be expected to range from "moderate hard work" to "hard work".

2.6.2. Body discomfort rating as a measure of psychophysical assessment

Psychophysics is the study of the relationship between stimuli and sensations (Fox, 1993; Ayoub and Dempsey, 1999). The psychophysical approach used in manual work studies elicits perceived exertion or discomfort ratings from subjects performing specific tasks and have been used to, "establish recommended capacity thresholds for specified task demands" (Fischer and Dickerson, 2012). The results can be used to select task conditions with the lowest perceived exertion or discomfort (Ayoub and Dempsey, 1999). Precise and complete instructions are critical to the integrity and validity of a psychophysical experiment (Rodrick and Karwowski, 2006) and efforts must be made to ensure that the participants completely understand what was expected of them. The Hawthorne effect is one of the most considered disadvantages of this method.

The Hawthorne effect describes the modification of the behaviour of participants in a social experiment, because they know they are being studied, unwittingly distorting the research findings (Payne and Payne, 2004). Some researchers addressed this phenomenon by increasing the control they have over the study with a control group (Payne and Payne, 2004). Fenety and Walker (2002) took precautions to reduce the Hawthorne effect by extending the invitation to not only the participants of the study as directed to but to the "entire directory assistance operations staff". They did not give preferences to volunteers of the study with respect to breaks, salary, or shift arrangements. Although this may have been applicable to this study (Fenety and Walker, 2002), it is not always feasible for other studies. Shekwa *et al.* (2017) acknowledged the phenomena as a contributing factor to differences in his study's results but did not necessarily address its effect. The study design and full "shift length observations" can be applied to assume that the Hawthorne effect is not applicable (Rabie, 2015).

Mechanical exposure to operations is a factor that aggravates occupational musculoskeletal disorders (Vasseljen, Holte and Westgaard, 2001; Gallo and Mazzetto, 2013; Wanave and Bhadke, 2013; Phairah *et al.*, 2016; Shekwa *et al.*, 2017). Musculoskeletal pain and discomfort is a good predictor of any overexertion, a build-up of fatigue and tissue damages (Ford, 1995) and serve as warnings to alert damage to, or limitations of the body. Stressors on the musculoskeletal system can lead to inflammation of affected muscles and joints and perceived pain and discomfort in those body parts alert the person of the body's state and allow them to adjust their behaviour accordingly (Ford, 1995). These can be a result of awkward postures workers adopted during operations.

Work-related musculoskeletal disorders (WMSDs) have become one of the greatest occupational concerns to date (Vos, Flaxman, et al., 2012). WMSDs is a broad term used to refer to occupational-related injuries, pain, discomfort, sprain, strain, soreness and chronic pain. These can be grouped as disorders with symptoms associated with muscles, joints, tendons, ligaments, nerves, bones, spinal discs and connective tissue of the musculoskeletal system aggravated or caused by work-related factors (Kumaraveloo, Sakthiaseelan and Kolstrup, 2018). Risk factors for WMSDs can be classified into four categories, namely genetic, morphological, psychological and biomechanical (Phairah, 2014). The genetic and morphological risk factors are non-manipulatable, in that they cannot be manually altered or improved (Kumar, 2001).

The biomechanical category is the most common risk factor associated with WMSDs. Commonly identified physical work-related risk factors include repetitive work, force applied on work object or activity, awkward working postures, heavy physical workload, exposure to vibration and noise, duration of work task (exposure to work), fatigue, work organisation, psychosocial and work environment (Gallo and Mazzetto, 2013; Fox and Smith, 2014; Phairah *et al.*, 2016; Kumaraveloo *et al.*, 2018). Repetitive work is prevalent in forestry operations, leading to workers adopting static, cyclic and overloaded postures affecting the musculoskeletal system (Lopes, Britto, and Rodrigues, 2019).

Awkward postures are postures adopted during work activities, whereby workers deviate from the neutral position of the body part (Moore, Torma-Krajewski and Steiner, 2011). The neutral working body position is when the muscles are at their resting length and joints are aligned in their neutral working natural state. Awkward postures affect muscle activity, whereby muscle contractions are actively sustained or passively compressed (Ford, 1995). Therefore, worker adopt awkward postures when doing repetitive tasks which, when used for prolonged periods result in fatigue, pain or discomfort, reduction of the workers' ability to concentrate and increased risk of accidents, injuries and biomechanical overload (Keyserling, Brouwer, and Silverstein, 1992; Slappendel *et al.*, 1993). The adoption of static, cyclic and overloaded postures leading to health risks to the musculoskeletal system is quite common in forestry operations (Lopes *et al.*, 2019) and remains a concern regardless of the advancement in mechanisation (Phairah *et al.*, 2016; Potočnik and Poje, 2017). Work postures often contribute to strains that have far-reaching long-term effects but have no immediate impact on the worker's behaviour or injury rates (Phairah *et al.*, 2016).

Activities in pruning operations require engagement of the upper body, arms, legs, torso and muscular strength for carrying equipment which can easily lead to inappropriate postures (Gallo and Mazzetto, 2013; Phairah *et al.*, 2016; Cremasco, Giustetto, Caffaro, Colantoni, Cavallo and Grigolato, 2019; Lopes *et al.*, 2019). Identifying the occurrence of postural discomfort is essential for the prevention of biomechanical overload risks in the workplace (Cremasco *et al.*, 2019). Therefore, methods have been developed to assess posture for prevention of injuries, accidents and to decrease the risks of WMSDs. The most commonly used assessments for awkward postures are the Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA) and the Ovako Working Analysis System (OWAS). These methods are useful and practical measures for postural risk assessment in various agricultural and forestry studies on WMSDs or ergonomics assessments (McAtamney and Nigel Corlett, 1993; de Oliveira *et al.,* 2012*;* Wanave and Bhadke, 2013; Phairah, 2014; Cremasco *et al.*, 2019).

Self-report and observational methods can be applied for the subjective assessment of discomfort in which tools such as the Nordic musculoskeletal questionnaires and body part discomfort (BPD) surveys can be used (Ford, 1995; Sullman and Byers, 2000; Shekwa *et al.*, 2017). The methods are subjective but are the cheapest and quickest way to assess musculoskeletal disorders or prevalence of discomfort. The workers can subjectively assess and rate their discomfort based on the Likert scale using the body part discomfort diagram (Ford, 1995).

Although these methods have gained popularity for their advantages of cost-effectiveness and flexibility in a wide range of workplaces, they have some disadvantages to be considered. For instance, the observer may be subject to "intra- and inter-observer variability when choosing between categories of exposure level" (David, 2005) which influences the suitability of the assessment of static or repetitive jobs (Van Der Beek and Frings-Dresen, 1998). Even though a number of these methods use hypothetical scoring systems to determine factors, these scoring systems are limited to how different factors should be weighted, or interactions between factors should be quantified. In this study (Van Der Beek and Frings-Dresen, 1998), the self-report measurement is applied. Workers rate their discomfort based on the Nordic musculoskeletal questionnaire for body discomfort rating and postural observation checklist applied by Keyserling *et al.*, (1992). Observation-based measurements are acceptable measures due to cost-effectiveness, require less human capital and time and provide exactness best matched to the needs of the current assessment (David, 2005).

A study by Lopes *et al.* (2013) of biomechanical evaluation of manual and semi-mechanised pruning activities, postures adopted by workers were considered normal. However, in the manual pruning operations, workers usually adopt postures that extended arms above shoulder level. Furthermore, it was identified that the increase in pruning heights in manual operations lead to higher stress on the L5-S1 column disc. Although the hip was the articulation affected the most in this study, it does not cause damage to the worker's health (Lopes *et al.*, 2013). However, occupational health problems, such as back pain and overuse injuries remain a major concern.

2.7. Summary

Although researchers have done exceptional work within the Ergonomics discipline, there is still a lot more research needed to reduce the risks within the forestry industry. Manual operations are still prevalent and practised in the industrially developing countries, despite the increase in

mechanisation and modernisation. Understanding ergonomic risks with advancements in equipment implemented in the industry is a necessity for the wellbeing of the workers in the field.
Pruning operations in South Africa will remain relevant in the industry due to its importance within forest management. Although the advancement of suitable tools to increase productivity and ergonomics have been explored in the past years, many operations still implement manual pruning. The use of traditional manual pruning saws remains the least productive compared to modernised and motor-manual tools. The future of manual pruning saws may not be assured after all.

Biomechanical measures in ergonomics research give an objective indication of the mechanical demands on the body; therefore, heart rate data is an indicative measure for workload. Heart rate indices are supporting measures to compare heart rate values, decreasing the individuality variability in workload measurements. The psychophysical estimates are subjective and may indicate the influence of the physiological demands, relative to the existing capacity. Even though workers may be blind to their subjective indicators of discomfort, adverse body postures observed can indicate the potential ergonomic risk workers may be experiencing without being aware of it.

3. Study design and methodologies

3.1. Study site

The study was conducted in the KZN Midlands, in two *Pinus patula* compartments in close proximity of each other and with similar terrain conditions (Table 1). The compartments are at an altitude of 1 530 m and 1 330 m above sea level, with mean annual rainfall between 950 mm and 1 046 mm, which mostly occurs during summer months and a mean annual temperature between 13°C and 15°C. Both compartments consist of the Magwa soil type with compartment 2 having Inanda soil type as well.

Compartment sizes were considered large enough for the execution of the study. The first pruning study was in trees six years old and second pruning study was in trees eight years old. The study was completed between 30 July and 30 August 2018. The intention was to avoid disruption from potential fire season incidents and summer rainfall.

Table 1. A summary of the terrain conditions of both compartments at which the study was conducted.

Parameter	Compartment 1	Compartment 2
Species	*Pinus patula*	*Pinus patula*
Area (ha)	13	41.8
Stand age at pruning (yrs)	6	8
Stocking (Stems/ha^{-1})	1333	1333
Spacing (m)	3.0 x 2.5	3.0 x 2.5
*Slope Condition (%)	Level (0-11 %)	Level (0 -11 %)
*Ground Conditions (1 (very good) to5 (very poor))	3 (Moderate)	3 (Moderate)
Ground Roughness Class(1 (smooth) to 5 (very rough))	3 (Uneven)	2 (Slightly uneven)
Mean diameter at breast height (DBH) (cm)	10.71	16.47
Mean height (m)	6.5	10.9

*The National Terrain Classification System for Forestry extracted from Erasmus (1994).

3.2. Ethical considerations

The research was designed and conducted following Stellenbosch University Research Policy, Section 7 (Senate Research Ethics Committee, 2013). Ethical clearance was approved on the 4th of July 2018 (Addendum A), for the study to be conducted. Each participant received a consent form which was extracted and amended from the Stellenbosch University REC guidelines and templates. The consent form (Addendum B) was translated to isiZulu; the participants' home language, to avoid language barriers. A thorough discussion of the consent form regarding the aim of the study and the participants' role, was held before commencement of study and each participant signed a consent form.

3.3. Sampling of study participants

Convenience sampling was used in this study, which is a non-probability sampling method in which participants were ready and easily accessible during time of study (Etikan, Musa and Alkassim, 2016). In this case, a trained team of motor-manual pruning workers was available.

This method is advantageous because it is convenient, inexpensive and time-efficient (Etikan *et al.*, 2016). However, sampling bias is one of the key disadvantages of this method; therefore, medical screening of participants was done to reduce sampling bias, a procedure administered by the sponsoring company's wellness department. The medical screening was also done to ensure that the participants were physically and mentally able to do the job required, efficiently and would not endanger themselves or others (Kew, 2002). Information regarding the participant's medical status was not made known to the researcher, except key reasons pertaining to study data collection, such as heart rate irregularities. For this study, the participants had to meet the following requirements to reduce sampling biases to general job fitness further:

1. Physically able to do the task (no apparent physical anomalies related to the task).
2. Should have no injuries, or be recovering from injuries, that can affect ability to perform the task.
3. Should not have musculoskeletal conditions or impairments that may limit mobility.
4. Should not be suffering from a heart or lung disorder/disease.

3.4. Pilot study

A field visit and pilot study were undertaken to select potential worksites and to observe the pruning operation to ensure adequate preparedness for data collection. To verify suitability and effectiveness of heart rate monitors, two students wore the monitors over a period of eight days. The data received was analysed for suitability of data analysis for this study. Workers also had one week of additional exposure to each of the pruning methods (manual and motor-manual) to ensure that any potential body discomfort experienced was not due to inactivity or lack of exposure to operation.

3.5. Study design

Table 2 outlines the study design implemented for collecting heart rate (HR), body discomfort ratings (BDR) and time study (TS) data for each worker for both manual and motor-manual operations. Only two workers were studied per day due to the limited number of trained time study officials available. BDR ratings were recorded four times per shift (sometimes three if shift ended before lunchtime).

Table 2. Study design for the manual (M) and motor-manual (MM) pruning methods at 2.0 m and 3.5 m pruning lifts. Highlighted tables refer to time study data recording.

Pruning lift	**Both 2.0 m and 3.5 m pruning lift operations**							
Workers	**A**		**B**		**C**		**D**	
Pruning method	**M**	**MM**	**M**	**MM**	**M**	**MM**	**M**	**MM**
Day 1	HR, BDR and TS		HR, BDR and TS		HR and BDR		HR and BDR	
Day 2	HR and BDR		HR and BDR		HR, BDR and TS		HR, BDR and TS	
Day 3		HR, BDR and TS		HR, BDR and TS		HR and BDR		HR and BDR
Day 4		HR and BDR		HR and BDR		HR, BDR and TS		HR, BDR and TS

3.6. Pruning operations

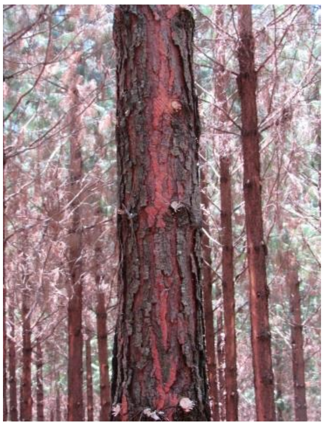
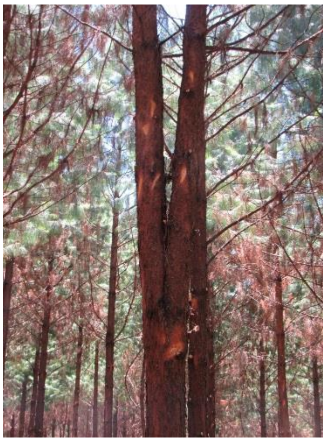
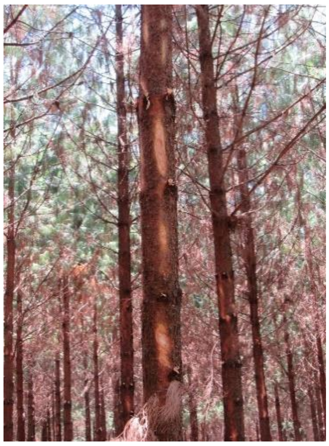
Compartment 1 was pruned from ground level up to 2.0 m (first prune) and A2 from its first prune (2.0 m) up to 3.5 m pruning lift (second prune). The work task refers to the number of trees each operator must prune before the end of the shift. The standard work task was given by the supervisors for each operation whereby 150, 300, 180 and 370 trees for 2.0 m M, 2.0 m MM, 3.5 m M and 3.5 m MM, respectively, had to be pruned by each operator.

Study workers were required to do the following:

- Remove all branches from a prescribed height to a specified height using two different pruning saws.
- Remove weeds that hinder accessibility into the plantation.
- Slashing and redistribution of natural regeneration of trees between rows.
- Remove forks or multi-stems on trees.

The quality of the pruning was assessed through observation of pruned trees during enumeration using the company's pruning quality control sheet in Table 3.

Table 3. Damage to trees, pruning quality control categories extracted from Mondi Forests © presentation.

Category – none (1) (no cambium exposed even if the bark is scored)	Category – slight (2) (minor cuts and small areas of cambium exposed; the small surface area affected)
	
Category – moderate (3) (cambium exposed in several places, cuts up to 15 cm in length)	Category – severe (4) (large areas of cambium exposed, cuts 20 cm and longer or ringbarked at knot whorls)
	

3.7. Pruning equipment

A Husqvarna 525P5S pole-pruner was used for the motor-manual pruning with an adjustable length suitable for both pruning lifts. The machines were a month old at the time of the study. The pole-pruners have a lifespan of 12-15 months, depending on the frequency of use. A saw-head mounted onto a wooden shaft was used for the manual pruning. The pruning equipment used throughout the study is shown in Figure 1.

Figure 1. A - 3.5 m M manual saw, B - shortened wooden shaft for 2.0 m M pruning and C - Husqvarna motor-manual pole-pruner for 3.5 m pruning lift. Photo credit: Charles Swart.

The technical features of the pruning equipment are presented in Table 4. The length of the manual chainsaw was measured in field. The pole pruner features were obtained from the Husqvarna website (Husqvarna, 2019).

Table 4. Technical features of pruning equipment.

Features	**Husqvarna pole pruner**	**Manual Chainsaw**
Weight (kg)	6.4 (excluding cutting equipment)	Blade (0.084 -0.179)
Length (cm)	243 -347 (can reach up to 5 m)	25 -350
Power output (kW)	1.0	
Cylinder displacement (cm^3)	25.4	
Vibration Daily exposure A (8) ($m.s^{-2}$)	0.9	

3.8. Data collection

The flowchart (Figure 2) shows the data collection process. This process was found to be the most logical to achieve the objectives of the study within the study period during shift hours. While the workers were setting up, the researcher recorded weather conditions and assessed terrain conditions. The diameter at breast height (DBH) and height (m) measurements of a sample of the pruned trees were recorded.

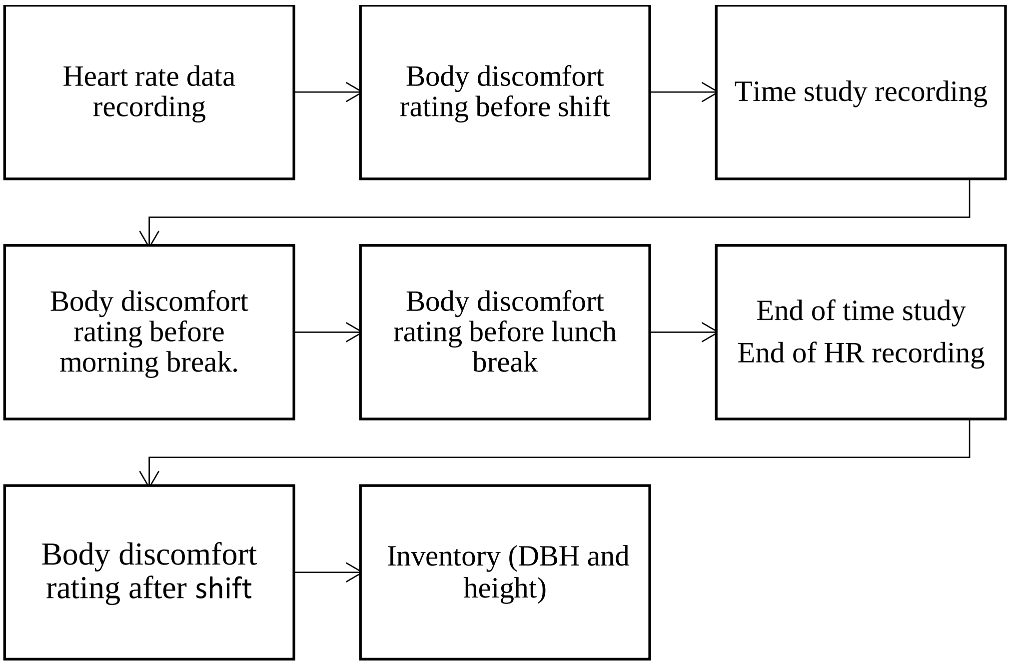


Figure 2. A flow-chart of methods followed for data collection in the field.

3.8.1. *Time study*

The time study was performed throughout the shift period and only once per operator for each pruning operation, using the Work-Study + software installed on a Samsung tablet. The time study elements that were considered in the study are presented in Table 5. The elements were considered in both pruning methods and lifts, however, the refuel delay was not relevant to the manual pruning method.

Table 5. Time Study elements for pruning work cycle (Ackerman *et al.*, 2019).

Elements	Break Points	Detail required
Pruning (physical action of pruning the branches)	Begins when the operator starts to prune the first branch until the last branch is pruned and the workers move to the next tree.	Time (t)
Move (Physical movement of the operator)	Begins once the last branch has been pruned until when the operator reaches the next tree to inspect the operation.	Time (t) and distance (d) for movement
Delays		
Refuel	From when saw stops due to fuel starvation (or needs fuel to top-up) to when the current operation resumes (whatever the operation was previously).	Time (t)
Repair Time	From when saw stops for repair to when current operation resumes (whatever the operation was previously).	Time (t) for repairs
Maintenance time	From when saw stops for maintenance to when current operation resumes (whatever the operation was previously)	Time (t) for maintenance
Other workplace time (delays such as planning, rests, work preparation, tea breaks/lunch breaks)	From when work stops due to delay to when current operation resumes (whatever the operation was previously).	Time and reason for delays (t)

3.8.2. Heart rate

The Polar H10 Heart Rate transmitter was used to monitor heart rate. The transmitter can accumulate 360 hours of data in "off-season" mode (Bluetooth disconnected) (Polar Electro Oy, 2008). Each worker had an HR-transmitter with their research code name on it and wore the same transmitter throughout the study period. The workers wore the HR-transmitters as soon as they got to the field. Transmitters were charged every second night to sustain battery life and transmitter straps washed after every shift for hygiene purposes. The transmitter recorded heart rates every five seconds; data was retrieved using the Polar Training Software and saved in a csv format to be used in Microsoft Excel.

3.8.3. Body discomfort

The Nordic musculoskeletal disorder body discomfort map and amended Likert scale were used to ascertain body discomfort (Addendum C). This method is favoured because it is cheap and quick to execute and has been tested to be effective for assessing worker's discomfort (Ford, 1995). Figure 3 is the body discomfort map workers used to identify regions of their body and rate discomfort accordingly. The Likert rating scale used was amended by adding "No-discomfort" as 0 and 4 as "unbearable discomfort".

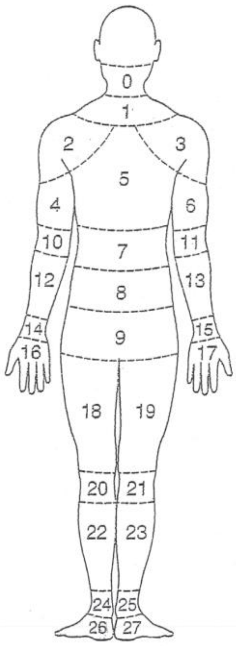


Figure 3. The Nordic musculoskeletal disorder body discomfort map. Extracted from Ford (1995).

Each worker had a clipboard assigned with their study code name on it along with an instructions page, body discomfort map and multiple copies of the rating scale attached to it. Workers were given clear instructions before each data collection session and effort was made to ensure that they understood their role in this study which is critical for the integrity and validity of the psychophysical experiment (Fox and Smith, 2014). The workers were asked to rate the severity of their discomfort using the Body Discomfort Map (BDM) on four occasions (recording periods): before the shift start, before morning break, before lunch break and after the shift. This helped keep a record of any discomfort the workers may have had before the task started and could be explained by other factors. Additionally, it allowed the assessment of relative changes in discomfort throughout the day. If the task was completed before lunchtime, the discomfort rating was recorded under the "after shift" recording period. Lastly, images of the workers were taken during operations to observe and identify awkward postures adopted during pruning operations.

3.9. Other data collection

The Samsung tablet with a 16-megapixel camera was used to capture images of the workers during the pruning operations. A Kestrel 3000 pocket weather meter was used to record the weather (temperature, wind speed and relative humidity) conditions each morning during the study because it is portable and convenient. A DBH tape and Vertex IV were used to measure the DBH of a sample of the pruned trees and the heights of the trees for stand inventory. Rectangular sampling method was applied for inventory and sampling was limited to 60 DBH and 20 height recordings.

3.10. Data Analysis

The statistical software Statistica 64 was used to analyse collected data. All analyses were based on testing for differences between pruning methods, workers and pruning lifts, as well as any potential interactions between factors. Analysis of variance (ANOVA) was done only for time study and heart rate data. The three-way ANOVA analysis included workers A, B, E and F, only because the 2.0 m manual data of worker C and D were not recorded due to their absence at times during the study. Assumptions for ANOVA analysis (normality, homogeneity and independence) were tested. A transformation of the data was done using the BoxKox data transformer due to a large number of observations in the data sets. The Games-Howell posthoc test was implemented when the assumption of homogeneity was violated and to identify significant differences between means. The Games-Howell posthoc test was favourable in this analysis because the sample sizes of the observations are different.

3.10.1. Time study

Productivity indicators were calculated using Microsoft Excel functions. Total trees pruned was the sum of trees an operator pruned, determined by individual counts and tested if it aligned with time study data. The time per tree (min) refers to the time to prune a tree. Productive time refers to the total time excluding all delays. Productivity was then calculated using Equation 1 for each operation with the unit, trees per productive machine hours (PMH) for motor-manual operations and productive hours (PH) for manual operations.

$$Productivity\left(\frac{tree}{PMH}\right) = \left(\frac{60}{time\ per\ tree\ (\mathrm{min})}\right) \qquad \text{Equation (1)}$$

Basic statistics was used to summarize the productivity per operator. A three-way factorial ANOVA was implemented, in which worker C and D were not included due to the lack of data for their 2.0 m pruning lift. However, for the two-way ANOVA analysis of the method and pruning lift, operator C and D's were included in the analysis.

Efficiency of a machine refers to machine utilisation for the intended purpose throughout operation and was calculated using Equation 2 proposed in the time study standards for the South African forestry industry (Ackerman *et al.*, 2014)

$$Machine\ utilisation\ (\%) = \left(\frac{Productive\ time\ (min)}{Total\ study\ time\ (min)}\right) \qquad \text{Equation (2)}$$

3.10.2. *Heart rate*

Heart rate (HR) was recorded for the full workday for each operator. However, only data that fell within the time-study period was used for analysis. Maximum, average and minimum HR for each operator was recorded for each pruning operation. HR indices were used to determine the scale of workload. HR_{work} included all micro pauses, tea breaks and other delays. Productive heart rate refers to the HR recorded during the productive time (when the worker is performing the task) of the time study. As it was difficult to attain HR_{rest} at the start of work, due to reasons mentioned in the literature review, a rest period of between 30 and 45 min was allowed during the workday in which the minimum HR was recorded as the resting HR of the operator; this approach was also followed by Cheţa, Marcu and Borz, (2018). Relative HR_{work} was calculated using Equation 3.

$$RHR\ (\%) = \frac{HR_{work} - HR_{rest}}{HR_{max} - HR_{rest}} \times 100 \qquad \text{Equation (3)}$$

Where:
HR_{work} is average heart rate measured during work
HR_{rest} as measured during rest break
HR_{max} is 220 - age

The 50% level heart rate reserve (HRr) was determined using Equation 4 by Lammert (1972).

$$HRr = \frac{HR_{max} - HR_{rest}}{2} \qquad \text{Equation (4)}$$

The ratio of HR_{work} to HR_{rest} was obtained using Equation 5 by Diament *et al.*, (1968)

$$Ratio = \frac{HR_{work}}{HR_{rest}} \qquad \text{Equation (5)}$$

Table 6 (Yilmaz *et al.*, 2013) was used to classify physiological workload.

Table 6. Physiological workload levels extracted from Yilmaz *et al.* (2013).

Work Level	Heartbeat (beats.min^{-1})	Physiological workload (RHR %)
Light	70-90	0-36
Medium	90-110	36-78
Heavy	110-130	78-114
Very heavy	130-150	114-150
Extremely heavy	150-170	>150

3.10.3. *Body discomfort and awkward postures*

The number and type of body discomforts were recorded for each pruning method throughout the study. The data was classified into contingency tables in Statistica 64 based on pruning method, pruning lift and recording period for reported discomfort per body part and discomfort rating. Fisher's exact test was applied to test for statistical significance.

Awkward postures captured were analysed and identified based on deviations from the normal plane, as shown in Figures 4-7 (Moore *et al.*, 2011). Identified awkward postures were compared to the body discomfort results for its risk to musculoskeletal disorders.

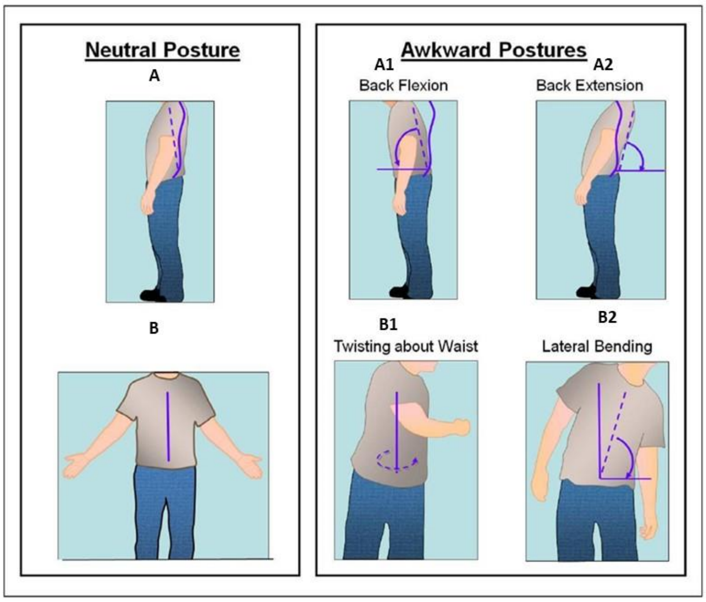


Figure 4. Neutral posture of the back (A and B), with awkward postures that deviate from neutral plane (A1-A2 and B1-B2).

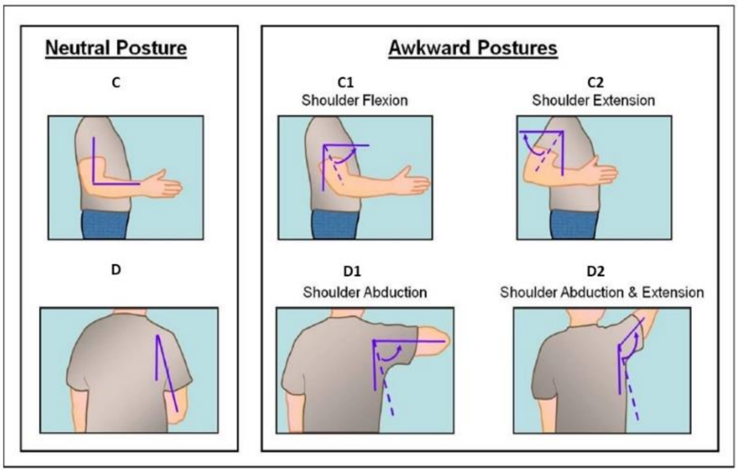


Figure 5. Neutral posture of the shoulders (C and D), with awkward postures that deviate from neutral plane (C1-C2 and D1-D2). D2 can also be referred to as a reaching out posture (Moore *et al.*, 2011).

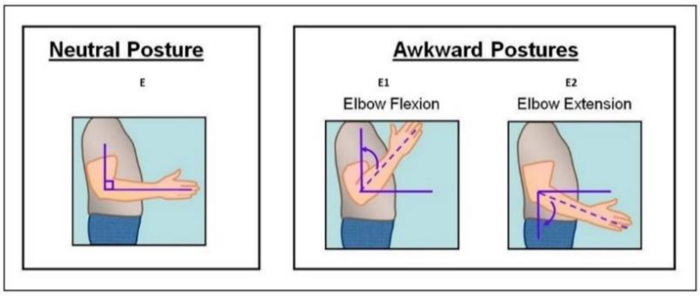


Figure 6. Neutral posture of the elbow (E), with awkward postures that deviate from neutral plane (E1-E2).

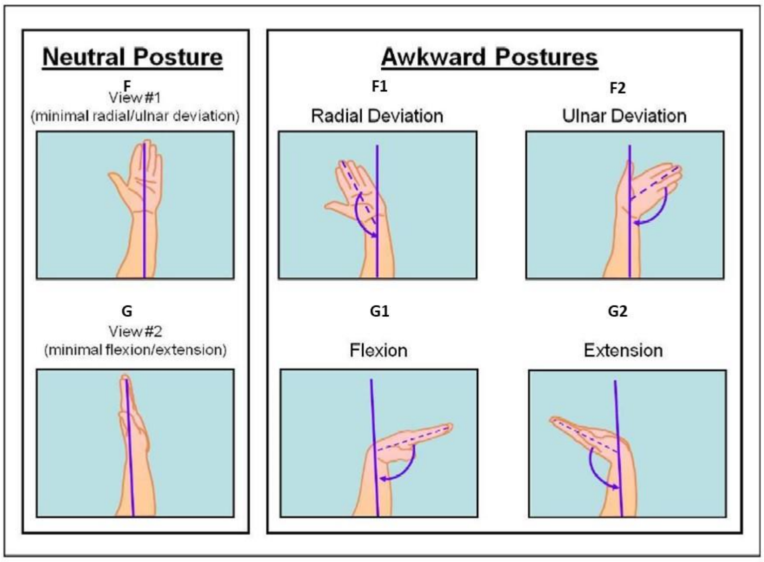


Figure 7. Neutral postures of the wrist (F and G), with awkward postures that deviate from neutral plane (F1-F2 and G1-G2).

4. Results

4.1. Study Site

Table 7 shows temperature (°C), relative humidity (%) and wind speed (km/h) recorded during the study period (July-August 2018). The mean recorded temperature differs between compartments by 3°C, relative humidity by 5.0 % and mean wind speed for both compartments.

Table 7. Temperature, humidity and wind speed for both compartments 1 and 2.

	Compartment 1 (2.0 m pruning lift)			Compartment 2 (3.5 m pruning lift)		
	Temperature (°C)	Humidity (%)	Wind speed (km.h^{-1})	Temperature (°C)	Humidity (%)	Wind speed (km.h^{-1})
Mean	13	67	3	11	62	3
SD	2	9	1	4	31	2
Min	8	60	2	5	4	1
Max	15	84	5	17	86	6

4.2. Study participants

The team identified for the study initially consisted of seven males and one female. The female worker was not included in the actual study to avoid gender bias in the study. The remaining seven participants were each allocated a coded identifier ranging from A to G for anonymity purposes. Their physiological attributes are presented in Table 8, which may have an impact on their abilities to perform their tasks and the impact the operation method has on their physical body. Workers had two weeks' prior experience with manual pruning.

Table 8. Workers' physical attributes.

Operator	Age (yrs.)	Experience (months)*	Height (cm)	Weight (kg)	Theo. Max (beats.min^{-1})
A	33	48	1.69	60.8	187
B	25	7	1.63	62.2	195
C	35	24	1.8	71.5	185
D	29	24	1.68	65.4	191
E	27	48	1.73	74.8	193
F	28	7	1.56	50.5	192
G	39	7	1.74	77.3	181

*Months of experience refer to the use of the motor-manual pole-pruner only.

Ultimately, during the medical screening participant G was found to have an irregular heart rate. As a result, participant G's heart rate (HR) data was not used in the study. Participant G, however, continued as a participant of the study. Participants C and D withdrew from the study during the 2.0 m manual pruning work, i.e. after the 3.5 m pruning lift trials. The researcher did not question their reasons nor was an attempt made to persuade them to reconsider. No injuries occurred during the study, however, at the end of the 2.0 m manual data collection, worker F consistently complained of lower back pain and the supervisor was informed about taking the necessary steps to assist the worker.

4.3. Quality of pruning

The 2.0 m motor-manual (2.0 m MM) pruning operation had the highest frequency of damage and the 2.0 m manual (2.0 m M) operation produced the lowest frequency of damage (Table 9). The 3.5 m motor-manual (3.5 m MM) operation resulted in more damaged trees compared to 3.5 m manual (3.5 m M) operations. Figure 8 is an example of slightly damaged tree and incomplete pruning. Overall there is mostly "no damage" to the trees based on the categorisation of tree damage (Mondi Forests ©).

Table 9. Frequency (%) of damaged trees observed for a pruned sample of trees. MM refers to the motor-manual pruning method, while M refers to the manual pruning method.

Pruning operations	None	Slight	Moderate	Severe
2.0 m M	100%	0%	0%	0%
2.0 m MM	64%	32%	3%	1%
3.5 m M	100%	0%	0%	0%
3.5 m MM	83%	15%	3%	0%

Figure 8. Example of damaged trees and incomplete pruning in 2.0 m motor-manual pruning operation.

4.4. Productivity of Pruning Operations

Table 10 shows basic time study statistics for the total number of trees pruned, study time, productive time, time per tree, productivity and operation efficiency. The total study time included all delays (resting breaks, maintenance and refuelling), while the productivity calculation excluded delays representing productive work. The 2.0 m MM pruning operation had the longest mean total study time of 383 min, followed by 2.0 m M (309 min), 3.5 m MM (256 min) and the 3.5 m M having the shortest total study time. The 3.5 m MM (136 trees/PMH) had the highest mean productivity, followed by 2.0 m MM (71 trees/PMH) and the 2.0 m M had the lowest productivity. However, 2.0 m M pruning operation had the highest operation efficiency (83 %) followed by the 3.5 m M (76 %) and the 2.0 m MM (71 %) had the lowest.

Table 10. Summary of productivity for the pruning operations for the 2.0 m and 3.5 m pruning operations.

		2.0 m M	2.0 m MM	3.5 m M	3.5 m MM
Total trees pruned		439	1667	983	2166
Study Time (min)	**Mean**	309	383	249	256
	SD	63.73	50.08	43.88	26.75
	Min	231	282	197	228
	Max	386	410	322	300
Productive time (min)	**Mean**	257	277	190	182
	SD	56	31	35	22
	Min	180	216	153	158
	Max	311	303	255	220
Time per tree (min)	**Mean**	2.25	0.99	1.11	0.50
	SD	1.15	0.37	0.49	0.19
	Min	0.47	0.05	0.06	0.12
	Max	8.08	3.50	4.00	2.02
Productivity (Trees/P(M)H	**Mean**	34	71	66	136
	SD	19	43	47	48
	Min	7	17	15	30
	Max	127	1178	1060	505
Efficiency (%)		**83%**	**72%**	**76%**	**71%**

Weighted mean productivity per worker by pruning lift and pruning method is shown in Figure 9. The 2.0 m M and 3.5 m M operations differ significantly, with 3.5 m M yielding the best productivity. There is a significant difference between the 2.0 m MM pruning and the 3.5 m MM pruning operation with the 3.5 m lift producing higher productivity. Only the productivity means of the 3.5 m M and the 2.0 m MM do not differ significantly, but the 2.0 m M operation differed significantly from 3.5 m MM lift.

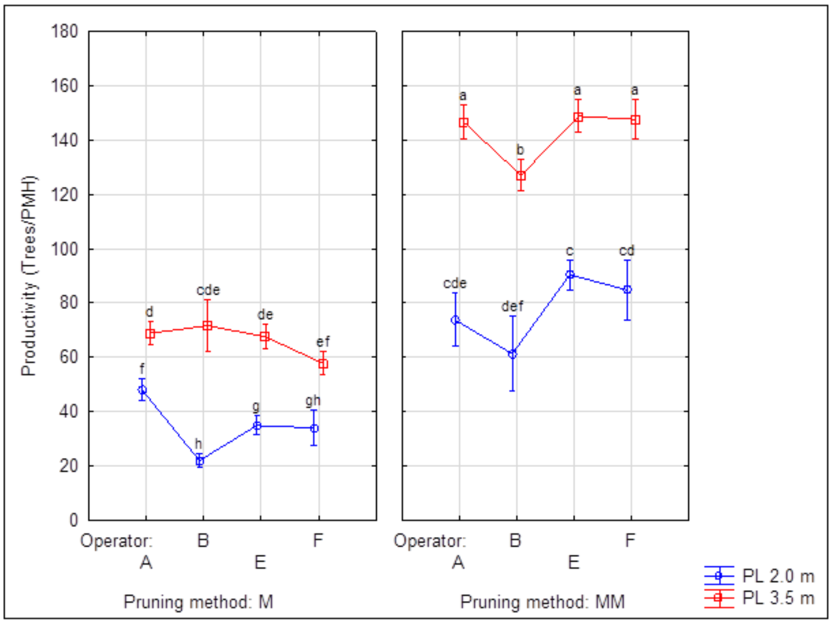


Figure 9. Weighted mean productivity of participants and significant differences (a-h), pruning method (M and MM) and pruning lift (PL 2.0 m and 3.5 m).

In Figure 10, individual worker performance is excluded in order to achieve a clearer picture of productivity performance between just pruning method and pruning lift. The two-way ANOVA analysed the interaction between the pruning lift and pruning method, which proved to be significant. All four (2.0 m M, 2.0 m MM, 3.5 m M and 3.5 m MM) pruning operations differ significantly. The 3.5 m MM pruning operation proved to be the most productive, followed by 2.0 m MM, 3.5 m M and the lowest productivity yield in the 2.0 m M operations. The differences were significant at $p < 0.001$.

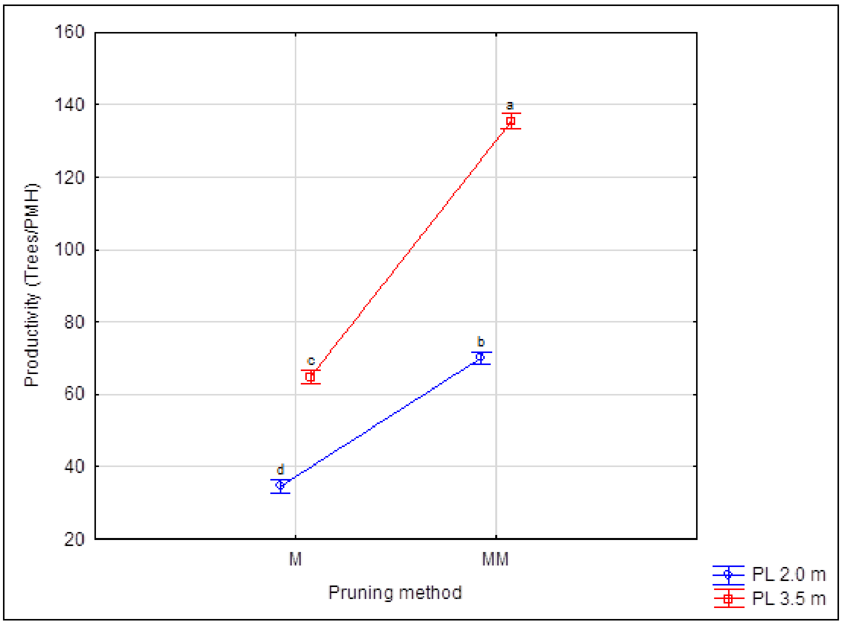


Figure 10. Results of the two-way ANOVA for the productivity of the pruning method and pruning lift.

4.5. Heart rate results

4.5.1. Heart rate indices

Overall heart rate indices for each pruning operation based on total recorded heart rate values are shown in Table 11. Mean HR_{work} for the workers and ranged from 110 beats.min^{-1} to 119 beats.min^{-1} (range of ± 18 and SD of 21). Motor-manual operations had the highest mean HR_{work} compared to the manual operations for both pruning lifts. The mean relative heart rate (RHR %) index ranged between 30 % and 40 % of aerobic capacity level recommended for prolonged continuous work with the 2.0 m M exceeding the threshold by 7%. Manual operations had higher RHR values of 47 % ± 15 % for 2.0 m pruning lifts and 40 % ± 7% for 3.5 m pruning lift compared to the motor-manual operations with 3.5 m pruning lift (38 % ± 11%) being 4% higher than the 2.0 m (34 % ± 8%) pruning lift operations.

A one-way ANOVA of the HR indices, with worker applied as a blocking factor, showed no significant differences between HR_{work}, HR_{rest}, RHR and the HR_{work}/HR_{rest} ratio indices for all the pruning operations. However, HR_{work}/50 % level differ significantly for each of the operations.

Table 11. Summary of HR indices for each operation for all study participants.

		2.0 m M	2.0 m MM	3.5 m M	3.5 m MM
Mean HR	**Mean**	115	113	110	119
	SD	21	19	18	21
	Min	67	66	67	67
	Max	172	189	160	189
Resting HR	**Mean**	70	63	62	64
	SD	8	7	10	13
	Min	63	53	51	55
	Max	82	74	77	83
RHR (%)	**Mean**	47%	34%	40%	38%
	SD	15%	8%	7%	11%
	Min	31%	23%	33%	19%
	Max	63%	43%	52%	54%
50% level of HR reserve	**Mean**	160.8	132.1	135.6	134.8
	SD	36.1	54.5	56.0	56.4
	Min	126.5	59.0	57.5	57.0
	Max	202.5	178.0	178.5	178.0
HR_{work}/50 % level	**Mean**	0.7	0.9	0.8	0.9
	SD	0.6	0.3	0.3	0.4
	Min	0.5	0.3	0.4	0.5
	Max	0.8	1.1	1.2	1.2
Ratio (HR_{work}/HR_{rest})	**Mean**	1.80	1.68	1.83	1.79
	SD	0.19	0.15	0.16	0.28
	Min	1.59	1.43	1.66	1.25
	Max	2.06	1.89	2.11	2.04

4.5.2. Productive heart rate

Productive heart rate refers to the HR recorded during the productive time (when the worker is performing the task) of the time study. The interaction between the three main effects was significant (Figure 11) with p-value < 0.05 and significant differences per workers summarised (Table 12).

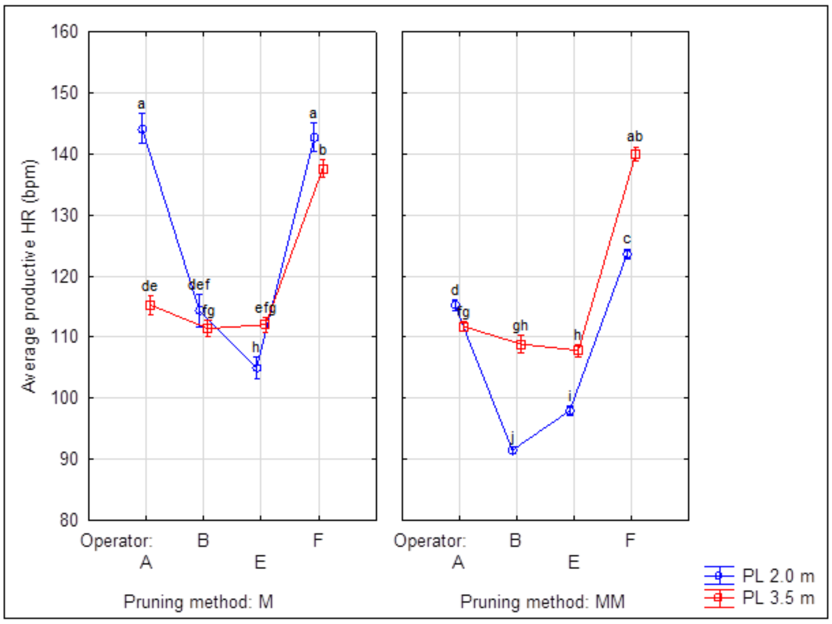


Figure 11. Three-way ANOVA of the three effects (pruning method, pruning lift and worker) considered for the analysis of the mean productive HR.

Table 12. Summary of significance interpretation of Figure 11.

Pruning Methods	
Manual operations:	**Motor-manual operations**
The mean productive HR for both 2.0 m and 3.5 m pruning lifts differ significantly between workers.	The mean productive HR for both 2.0 m and 3.5 m pruning lifts differ significantly between workers.
Pruning Lifts	
2.0 m Pruning Lift:	**3.5 m Pruning Lift**
Worker A- differ significantly for M and MM Worker B- differ significantly for M and MM Worker E- differ significantly for M and MM Worker F- differ significantly for M and MM	Worker A- differ significantly for M and MM Worker B- no significant difference between M and MM Worker E- differ significantly for M and MM Worker F- no significant difference between M and MM

Figure 12 gives a general overview of the interaction of the pruning method and pruning lifts and includes all the Worker (A-F) mean productive HR. The two-way ANOVA for the interaction of the pruning method and pruning lift for the productive mean HR is significant. Furthermore, mean productive HR differ significantly between the operations (2.0 m M. 2.0 m MM, 3.5 m M and 3.5 m MM). The 2.0 m M operation had a higher productive HR_{work} (128 beats.min^{-1}) compared to the 3.5 m M operation (110 beats.min^{-1}). Motor-manual 3.5 m operation had a higher HR_{work} (113 beats.min^{-1}) compared to the 2.0 m MM pruning operation (106 beats.min^{-1}).

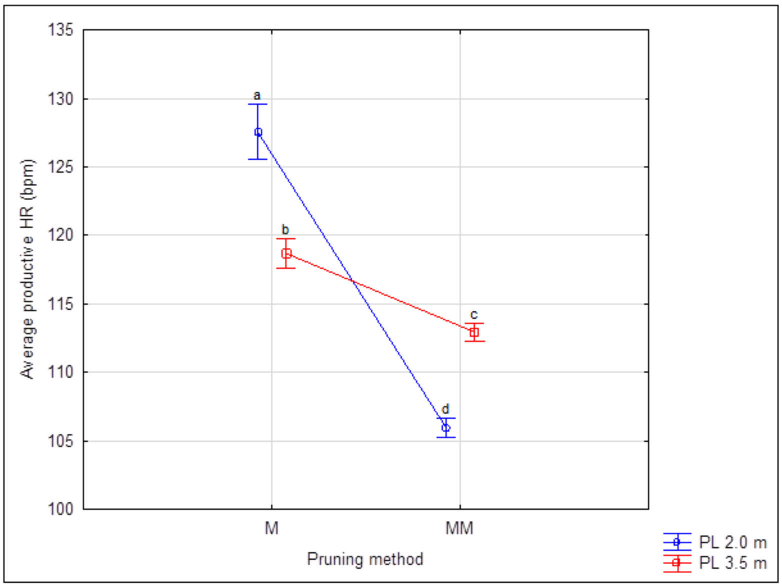


Figure 12. Two-way ANOVA of the interaction of the pruning method and pruning lift effects considered for the analysis of the productive mean HR.

4.6. Psychophysical assessment: awkward postures and body discomfort

4.6.1. Observation of postures

Figures 13-16 show awkward postures adopted by workers during the pruning operations. The most common awkward postures adopted in all the operations are shoulder abduction and extension. Frequent occurrences of neck extensions observed in 3.5 m M and 3.5 m MM operations and high flexion (bending) of back and flexion of elbow and shoulder in the 2.0 m M and 2.0 m MM operations. Ulnar deviation and radial deviation were observed in all the pruning operations.

Figure 16 show some of the awkward postures adopted by workers during 2.0 m M pruning operation. Awkward posture deviating from the neutral plane were identified as: (A)-shoulder abduction and extension, (B)-ulnar deviation of the left wrist and radial deviation of the right wrist, (C)-extreme flexion of the back and (D)-shoulder extension, slight flexion of back and bent left knee. For the 2.0 m MM operations, identified awkward postures in Figure 17 were identified as: (E)-moderate flexion of back, right shoulder abduction and left shoulder extension and flexion, (F)- left shoulder extension and neck flexion, (G)- right elbow extension, left wrist ulnar deviation and shoulder flexion and (H)-twisting of waist and neck.

Figures 18 and 19 show awkward postures adopted in the 3.5 m M and 3.5 m MM pruning operations. The identified postures for the 3.5 m M in Figure 18 are: (I)- left shoulder abduction and extension and right elbow flexion, (J)-right arm elbow and shoulder extension, extension of neck, (K)-ulnar deviation of left wrist, right shoulder extension and neck twist and extension and (L)-twisting of neck and back and right elbow extension. For the 3.5 m MM in Figure 19, postures were identified as: (M)-left shoulder abduction and extension, extension of neck and right elbow flexion, right ulnar deviation, (N)-right shoulder extensions, back and neck extension, (O) -lateral back extension, shoulder and elbow extension and radial deviation on right wrist and (P)-twisting of waist and neck with extension, right elbow and shoulder extension and right wrist radial deviation.

Figure 13. Awkward postures adopted by workers during 2.0 m M pruning operation.

Figure 14. Awkward postures adopted by workers during 2.0 m MM pruning operations.

Figure 15. Awkward Postures adopted by workers during 3.5 m M pruning operations.

Figure 16. Awkward postures adopted in 3.5 m MM pruning operations.

4.6.2. Prevalence of discomfort

Body discomfort results are presented for the body parts 0-17 (Figure 3), which were the only body parts in which discomfort was reported. A total of 838 discomfort reports from the workers were recorded during the study period for each pruning operation. Prevalence of discomfort (Yes) is shown for the pruning method (Figure 17), pruning lift (Figure 18) and recording period (Figure 19). Figure 18, for example, for the manual operations, shows that of the 81 responses recorded no discomfort.

Prevalence of discomfort for the pruning method does not differ significantly (Figure 17); however, there is a significant difference in the prevalence of discomfort between the 2.0 m and 3.5 m pruning lifts (Figure 18). Prevalence of discomfort reported for the recording periods differ significantly, with the highest prevalence reported after the shift (Figure 19).

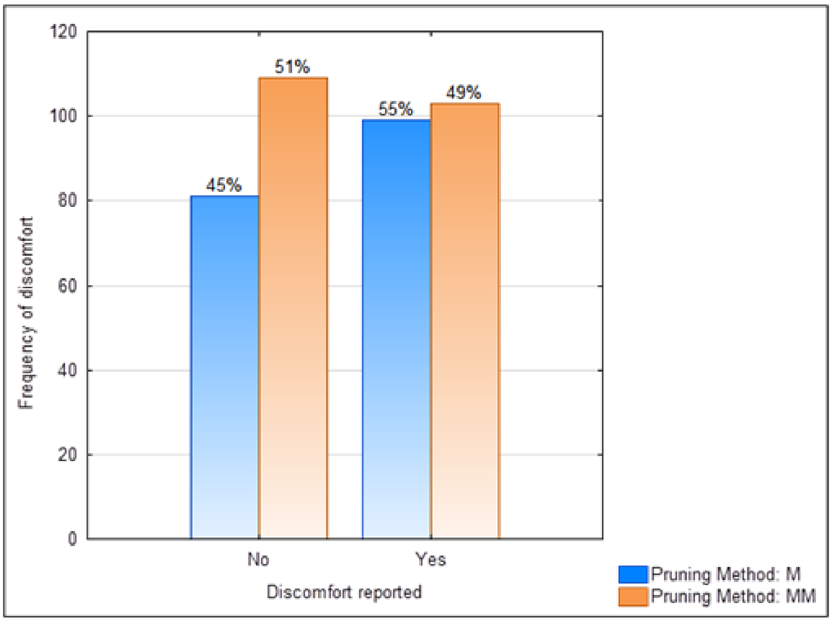


Figure 17. Frequency of responses for discomfort reported (Yes) or no discomfort (No) reported for both M and MM operations regardless of the pruning lift.

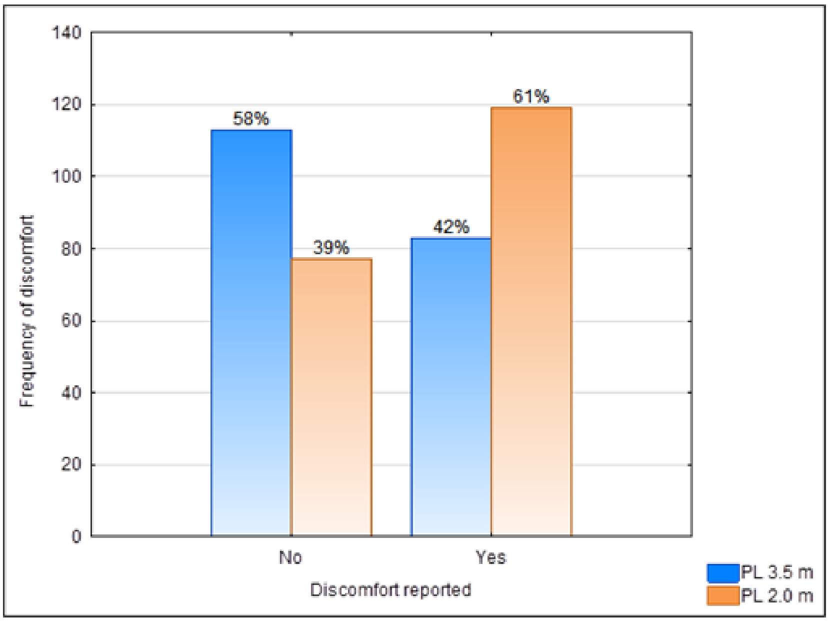


Figure 18. Frequency distribution of discomfort reported throughout the study for 2.0 m and 3.5 m pruning lift for pruning operations, regardless of pruning method.

The prevalence of discomfort BS was mostly reported for the 3.5 m MM (29 %), 2.0 m M 29 %) and 2.0 m MM (28 %) (Figure 19). Worker reported the most discomfort before the MB (37 %) for the 2.0 m M operation and the AS (39 %). Discomfort reported before the lunch break (LB) was the highest in the 2.0 m MM (45 %) followed by the 3.5 m MM (23 %) operation.

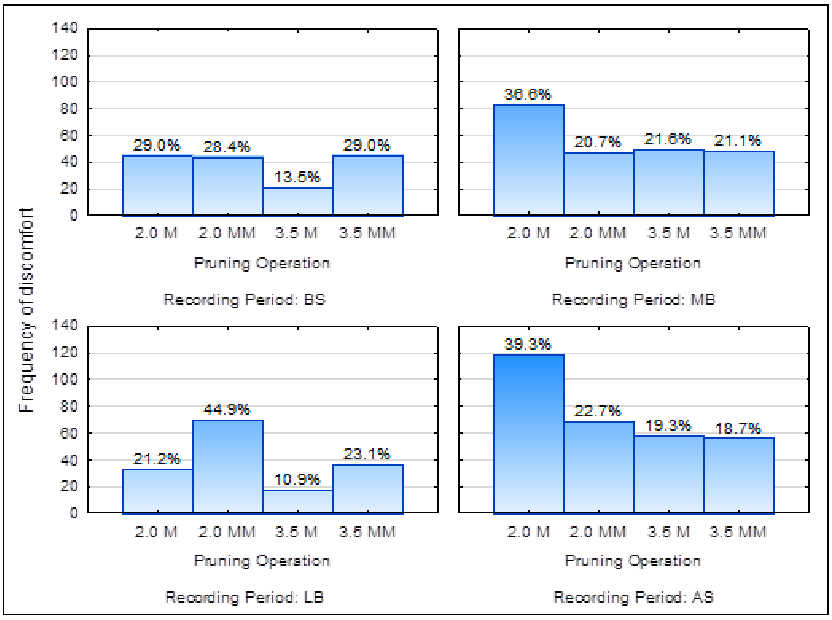


Figure 19. Discomfort reported for pruning operation for each recording period. Where: BS is before shift, MB is morning break, LB is lunch break and AS is after shift.

4.6.3. Frequency of Discomfort rating

The frequency of discomfort rating for each pruning operation and recording period is presented in Figure 20. Worker rated the 2.0 m M, 2.0 m MM and 3.5 m M operations as causing severe discomfort (DR 3) and moderate discomfort rating for 3.5 m MM, which differs from severe discomfort by 3 %.

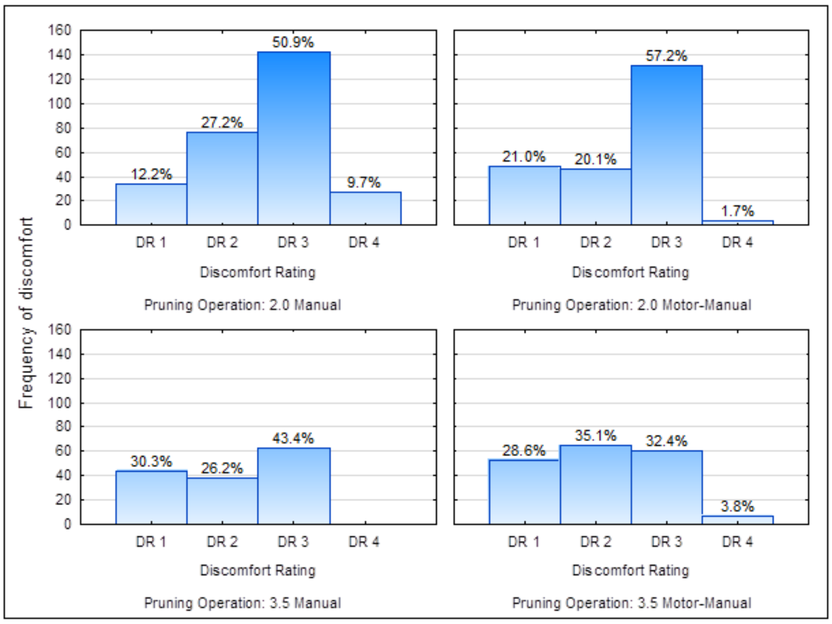


Figure 20. Frequency of discomfort rating for each pruning operation. Where: DR 0 = No Discomfort, DR 1 = Mild Discomfort, DR 2 = Moderate Discomfort, DR 3 = Severe Discomfort, DR 4 = Unbearable Discomfort.

4.6.4. Body part discomfort

Table 13 is a summary of the operations that have the most effect on each body part for each pruning operation (Figure 21), recording period (Figure 22) and discomfort rating (Figure 23). Fisher's exact test analysis was significant for pruning operation, recording period and discomfort rating for each body part.

Table 13. Summary of highest discomfort reported per body part for pruning operation, discomfort rating and recording period.

Body part	Pruning operation	Discomfort Rating	Recording Period
BP 0 (Upper neck)	3.5 MM (38 %) and 3.5 M (27%)	DR 3 (41 %) and DR 4 (5%)	BS (28%) and AS (28%)
BP 1 (Lower neck)	3.5 MM (31%) and 2.0 MM (26 %)	DR 3 (43 %) and DR 4 (3 %).	AS (31 %), BS and MB (26%)
BP 2 (left shoulder)	3.5 MM (44%) and 2.0 M (31%)	DR 3 (41 %) and 1% DR 4.	AS (35 %), MB (28%) and BS (27%).
BP 3 (right shoulder)	3.5 MM (42%) and 2.0 M (27%)	DR 3 (42 %) and DR 4 (3%)	AS (32 %), MB (27%) and BS (28%)
BP 4 (left upper arm)	2.0 M (34%) and 2.0 MM (34%)	DR 3 (43 %) and DR 4 (2%).	MB and AS (34 %)
BP 5 (upper back)	3.5 M (44%) and 3.5 MM	DR 3 (52 %) and DR2 (30 %)	AS (44 %), MB (26 %).
BP 6 (right upper arm)	2.0 M (35%) and 2.0 MM (34%)	DR 3 (42 %) and 2 % DR 4	MB (35 %) and AS (34 %)
BP 7 (waist)	2.0 M (68%) and2.0 MM (25%)	DR 3 (58 %) and DR 4 (20 %)	AS (40 %), BS (25%) and MB (23 %).
BP 8 (lower back)	2.0 M (49%) and 2.0 MM (35%)	DR 3 (58 %) and DR 4 (14 %)	AS (39 %), LB and MB (21%)
BP 9 (bottom/hips)	2.0 M (44%) and 2.0 MM (30 %)	DR 3 (56 %) and DR 4 (14 %)	AS (39 %), MB and LB (21 %)
BP 10 (left elbow)	2.0 M (56%) and 2.0 MM (33%)	DR 3 (78 %) and DR 1 and 2 (11 %)	AS (67 %) and (22 %)
BP 11 (right elbow)	2.0 MM (47%) and 2.0 M (40%)	DR 3 (67 %) and DR 2 (20 %)	AS (60 %) and LB (27 %)
BP 12 (left lower arm)	2.0 MM (47%) and 2.0 M (40%)	DR 3 (63 %) and DR 1 and 2 (19 %)	AS (44 %) and LB (38 %)
BP 13 (right lower arm)	2.0 MM (47%) and 2.0 M (40%)	DR 3 (59 %) and DR 2 (24 %)	AS (47%), LB (29 %) and MB (24 %)
BP 14 (left wrist)	2.0 M (75 %) and 3.5 M (25 %)	DR 3 (75 %) and DR 1 (25 %)	LB (25 %) and AS (75 %).
BP 15 (right wrist)	2.0 M (80 %) and 3.5 M (20 %)	DR 3 (80 %) and DR 1 (20 %)	LB (20 %) and AS (80 %).
BP 16 (left hand)	2.0 M (44 %) and 3.5 M (56 %)	DR 1 (56 %) and DR 3 (44 %)	MB and AS (33 %)
BP 17 (right hand)	2.0 M (38 %), 3.5 M (38 %) and 2.0 MM (25%)	DR 3 (63 %) and DR 1 (38 %)	LB (38 %), MB and AS (25 %).

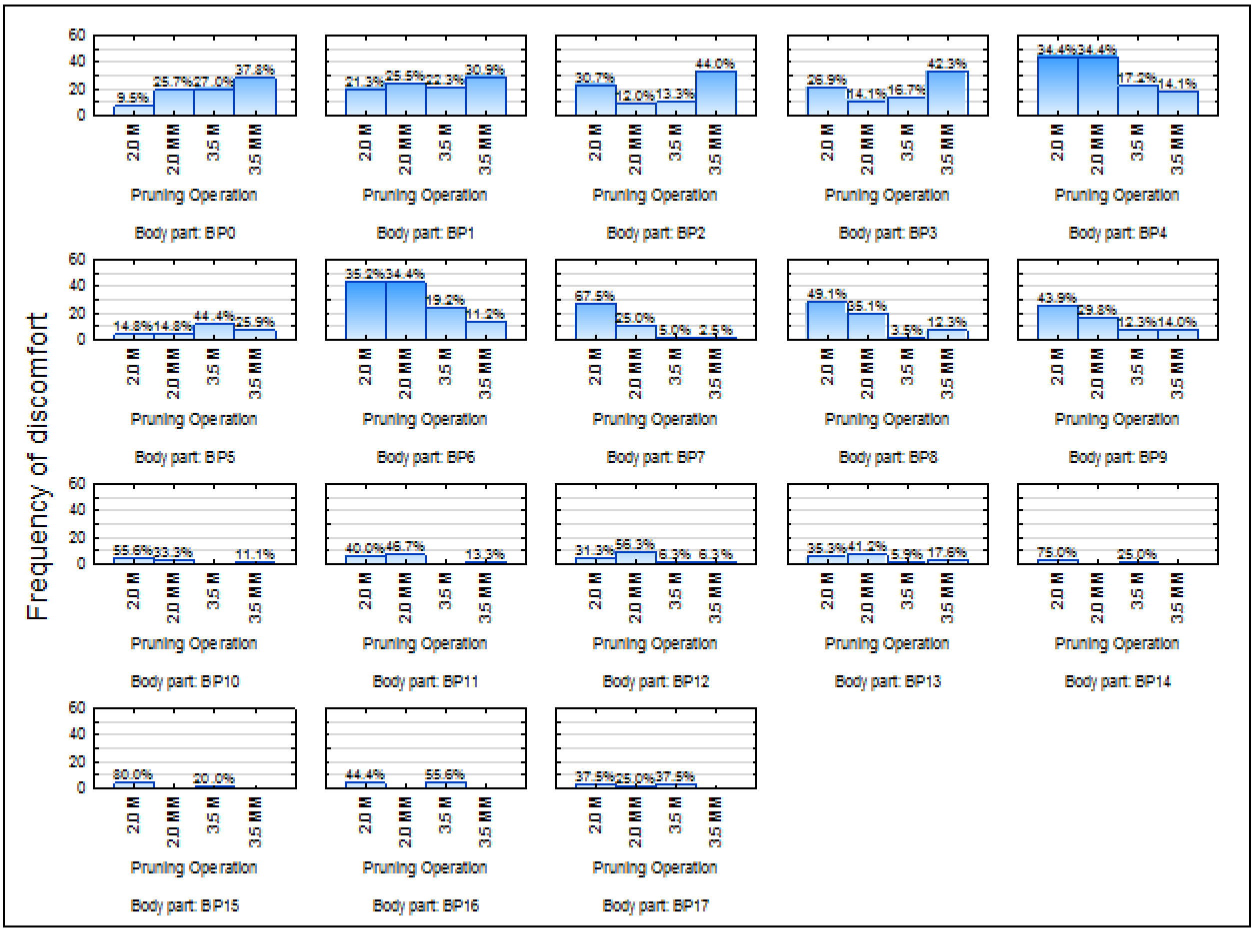


Figure 21. Body discomfort rating for each operation for body parts 1-17. Fisher's exact test p-value < 0.01.

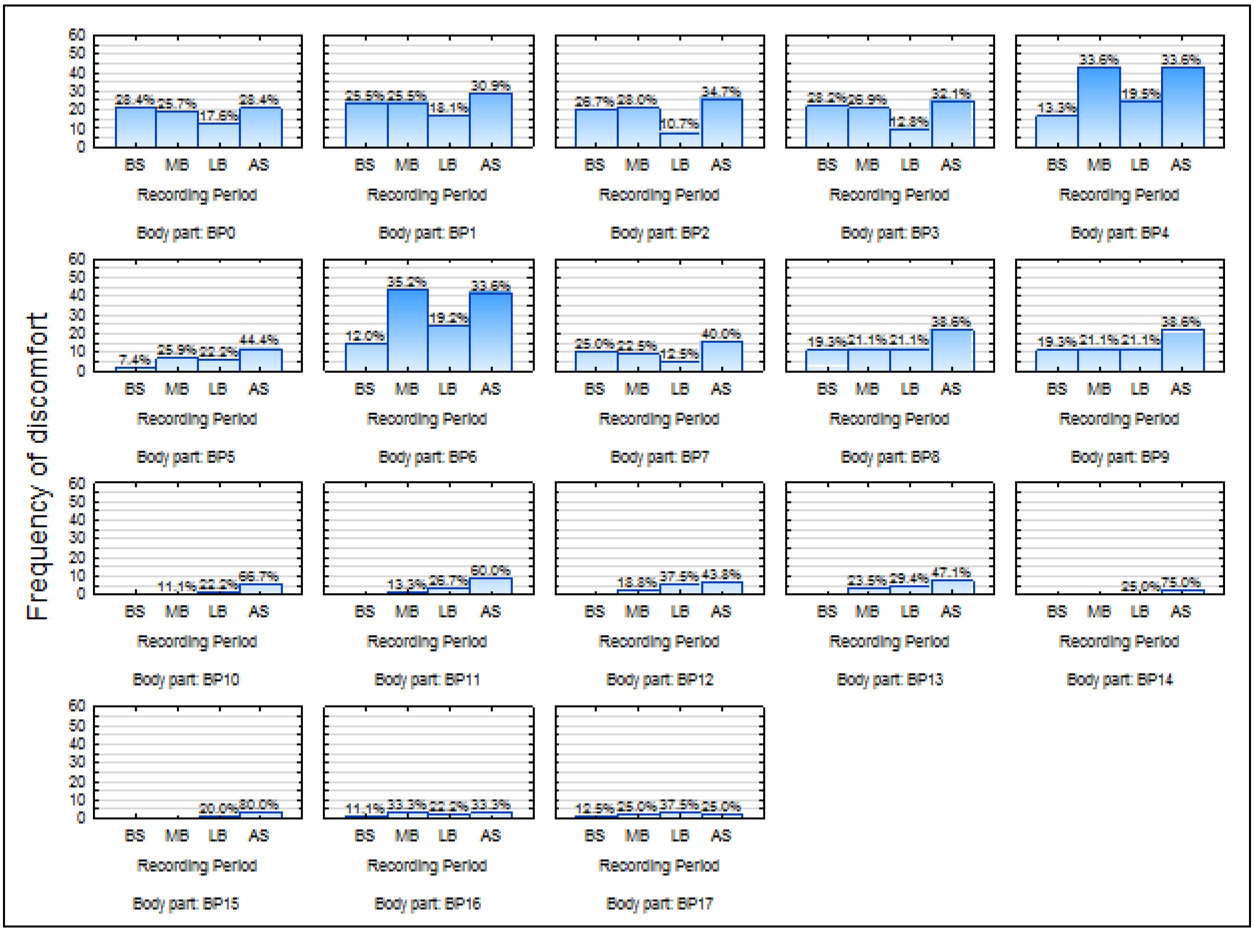


Figure 22. Body discomfort rating for recording period for body parts 1-17). Fisher's exact test p-value = 0.03.

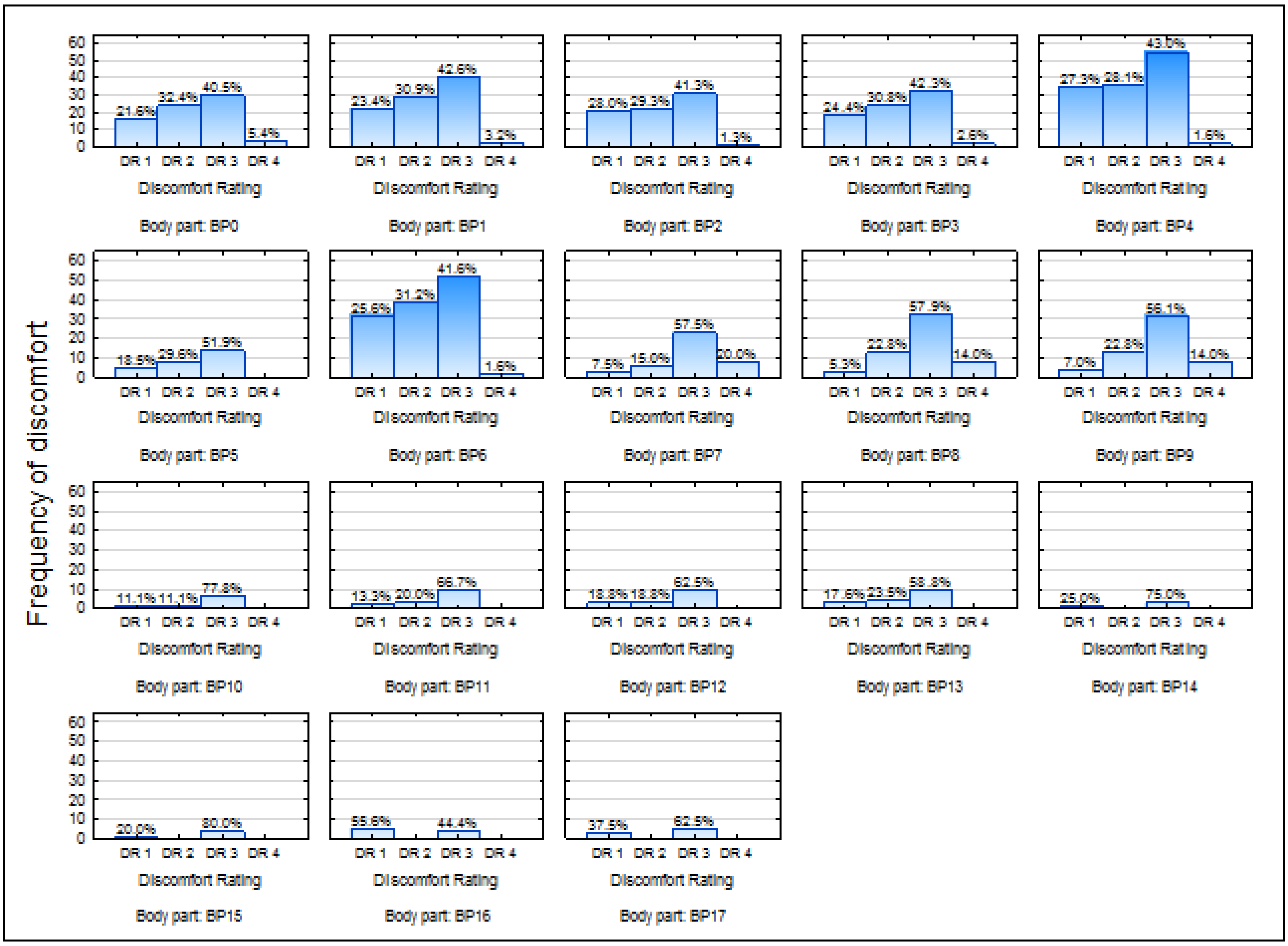


Figure 23. Body discomfort rating for each operation for body parts 1-17. Fisher's exact test $p < 0.01$).

5. Discussion

The results show that the interaction between the pruning lift, pruning method and workers is significant for productivity, productive heart rate and body discomfort responses. The results of the study summarised in Table 14 show key findings from each sub-objective assessed in the study. Identified ergonomic risk factors are adverse awkward postures, medium to heavy workload and prevalence of discomfort before the shift. This is an indication of potential prevalence of musculoskeletal disorders. The nature of the pruning operations is cyclic (repetitive activities), which is an additional risk factor. Duration of exposure is an additional risk factor, even though it was not directly measured in this study, it can arguably be equated to machine utilisation or machine efficiency. Since the operations are not fully mechanised, successful execution of the operation is highly dependent on availability of the worker. Therefore, the worker is equally exposed to the operation as the machine is utilised.

Table 14. Key summary findings from results for 2.0 m manual (2.0 M), 2.0 m motor-manual (2.0 MM), 3.5 m manual (3.5 M) and 3.5 m motor-manual (3.5 MM) pruning operations.

Pruning Operation	**2.0 m M**	**2.0 m MM**	**3.5 m M**	**3.5 m MM**
Mean HR	115	113	110	119
Workload classification	medium to heavy	medium to heavy	medium to heavy	medium to heavy
Productivity (trees.P(M)H^{-1})	34	71	66	136
Machine and operator efficiency (exposure to operation)	83%	72%	76%	71%
Overall Discomfort Rating	Severe Discomfort	Severe Discomfort	Severe Discomfort	Moderate Discomfort
Body Parts affected the most	BP2-4, BP6-17	BP0-1, BP4, BP6-14	BP0-1, BP4-6, BP14-17	BP0-3, BP5
Highest discomfort reported for recording period	MB and AS	MB and LB	MB and AS	BS and LB
Dominant awkward postures	- shoulder abduction and extension - highly flexed bending of the back -ulnar deviation	-moderate flexion of the back -shoulder abduction and extensions -moderate neck flexion -twisting of neck and waist -ulnar deviation	- shoulder abduction and extension -elbow flexion and extension -ulnar deviation -neck extension -twisting of neck and waist	-shoulder abduction and extension -neck and back extension -radial and ulnar deviation -twisting of waist -elbow extensions

5.1. Study site

The mean recorded temperature differed between compartments by 3° (Table 1). This difference is expected due to the period of the study as data collection for compartment 1 was done in late August when temperatures were warming up towards the end of winter. Temperature influences the HR variables and can lead to heat stress. Based on observations, in compartment 2, which was done between 30 July and early August, workers worked throughout the shift with no other delays, such as taking off outer clothing due to increased body heat. However, in compartment 1, workers frequently stopped with the operation to take off their outer clothes. This response to increased heat can also explain the increased productive heart rates for the 2.0 m pruning lift operations. Heart rate increases to maintain cardiac output for workload and simultaneously dissipating body heat (Dubé *et al.*, 2019). Relative humidity and wind speeds recorded during the study were generally low, with no concern of contributing to making the operations risky to execute.

5.2. Study participants

Participants' physical attributes presented in Table 8 shows each participant's profile with regards age, height, weight, body mass index (BMI), theoretical maximum heart rate and their experience with the pole pruner. They had a mean age of 31 years (range: 25-39 years). Participants fall within the normal range (18.5-24.9) BMI of South African men (STATS SA, 2017) however, participants E and G, are just within the overweight range (BMI 25-29.9), which can be highly influenced by their bone mass since they are relatively tall with heights 1.73 m and 1.74 m respectively. BMI does not distinguish between excess fat, muscle mass, bone mass or the distribution of fat among individuals. However, it is still used due to its proven high correlation with body fat and health risks (CDC, 2011). Theoretical maximum heart rate of 189 beats.min^{-1} (range: 181-195 beats.min^{-1}) helps to account for the individuality of participants' workload threshold. The mean years of experience of 24 months (range: 7 - 48 months) are only for the pole-pruner, which is the operation all participants are accustomed to. Only two of the participants had previous experience with the manual pruning saw, but since it did not require much training due to its low injury risk (Ford, 1995), participants trained for a week before the study to get comfortable with the manual saw.

5.3. Pruning quality

Pruning damage (Figure 8) caused is an example of moderate damage and poor pruning quality in terms of the expected pruning requirements. For instance, the other stem was meant to be removed; however, the operator wasted time and energy pruning it. At the end of the study, when compartment 2 was visited after three weeks, the damage to the trees was not noticeable. The motor-manual operations caused more damage to the trees compared to the manual operations, which emphasises the disadvantage of motor-manual operations. Workers worked relatively faster with motor-manual operations and moved the saw along the stem of the tree for a 'smooth' flow of operation. As the shift progressed and they get more tired, they applied more force to the trunk, which caused more damage to the tree.

5.4. Productivity of pruning operations

Time study results (Table 10) show that the 3.5 m MM is the most productive operation and the 2.0 m M the least productive operation, whether operator factor is considered or not. However, the manual (M) operations had the highest operational efficiency compared to the motor-manual (MM) for both 2.0 m and 3.5 m pruning lifts even though the total study time was the longest and the least number of pruned trees for manual operations. The M and MM 2.0 m pruning lift operations yielded the lowest productivity compared to the 3.5 m pruning lift operations (M and MM). Overall, the 2.0 m pruning lift operations had lower productivity and least total trees pruned over the shift compared to the 3.5 m pruning lift operations for both pruning methods. The 2.0 m M (439 trees) pruning operation had the least total trees pruned throughout the study compared to the 3.5 m (983 trees) M operations. Even though the 2.0 m M operation had a low output of total trees pruned, the mean study time (309 min) is longer than that of the 3.5 m M operation. These findings suggest that the 2.0 m M operation requires more time to complete compared to the 3.5 m M operation even though the work task size of the 2.0 m M (150 trees) is less than the 3.5 m M (180). The 3.5 m MM pruning (2166) had the most trees pruned and the 2.0 m MM (1667 trees) less with mean study time of 256 min and 383 min respectively. Again, the 2.0 m pruning lift operations seem to require more time to complete compared to 3.5 m pruning lift, with fewer trees required to prune.

The manual operations showed the highest operational efficiency with 83% (2.0 m pruning lift) and 76% (3.5 m pruning lift) compared to the motor-manual operations with 72% (2.0 m pruning lift) and 71% (3.5 m pruning lift). These results contradict the findings by de Oliveira, *et al.* (2012), in which the motor-manual operations showed the highest efficiency of 76, 79 and 73 % and 21, 23 and 25 % for the manual operations at first (2.5 m), second (4.0 m) and third (5.0 m) pruning. De Oliveira *et al.* (2012) suggested that the results were probably due to the greater physical effort the manual operation required; workers took more frequent resting breaks which reduced the productive time. In the motor-manual operations, workers took advantage of maintenance and refuelling time to recovery, which reduces the time for resting breaks and increased operation efficiency (de Oliveira *et al.*, 2012). In the current study, however, workers commented that the lightweight of the manual saw made the operation more bearable. Other contributing factors, such as refuelling and maintenance delays, did not impact the manual operation. Workers used the same saw throughout the study and saw heads were changed before the operation when needed. Operator influence can also be considered in the difference of these results (Martin, 2016).

5.5. Mean productivity per operator

The three-way interaction between worker, pruning method and pruning lift was significant (Figure 9). The 2.0 m M and 3.5 m M operations differ significantly, with 3.5 m M yielding higher productivity for all workers (A, B, C and D). Additionally, there is a significant difference between the 2.0 m MM pruning and the 3.5 m MM pruning operation. Only the productivity means of the 3.5 m M and the 2.0 m MM do not differ significantly among workers, which suggests that the 2.0 m MM productivity may be equated to the 3.5 m M.

There is no significant difference between workers A, E and F in the 3.5 m MM operation, only operator B differs significantly with the lowest productivity. The 3.5 m MM operation is the operation most of the workers have the most experience in (Table 8). Worker E had, the highest productivity in the 2.0 m MM operation, with worker B the lowest whose mean productivity differs significantly from worker C’s. Productivity in the 3.5 m M and 2.0 m MM do not differ significantly between the workers, except for worker A and F in the 3.5 m M. These findings suggest that some of the workers can yield similar productivities for the 3.5 m M and 2.0 m MM operations. Furthermore, the mean productivity of the 2.0 m MM (71 trees.PMH^{-1}) and the 3.5 m M (66 trees.PH^{-1}) operations differ by only five trees.P(M)H^{-1} which supports the non-significant difference between the workers' productivity for the 2.0 m MM and 3.5 m M operations. Lastly, in the 2.0 m M operations, worker A's mean productivity differs significantly from the other workers, yielding the highest productivity and worker B the lowest. Even though worker B had the lowest productivity overall, based on observation during the time study, worker B had the highest quality pruned trees (less damage on trees and did corrective pruning) and generally worked slower.

Worker attitude and experience are contributing factors to the results of the studies and should be acknowledged (Hogg, Pulkki and Ackerman, 2011; Purfürst and Erler, 2011; Martin, 2016); however, the findings above are limited to the four workers. Therefore, to achieve a clear picture of overall productivity performance between the operations, a two-way ANOVA analysis showed a significant interaction between pruning method and pruning lift (Figure 10), which indicates that the pruning method and pruning lift contribute to the differences in productivity. Furthermore, mean productivity differed between all four pruning operations with the 3.5 m MM proving to be the most productive followed by 2.0 m MM, 3.5 m M and the lowest productivity yield in the 2.0 m M operations.

In addition to worker influence factors, such as the density of branches, thickness of branches and accessibility to the lowest branches can explain the differences in the 2.0 m and 3.5 m pruning lift operations. Workers had to prune the 2.0 m pruning lift from the lowest branches (ground level) while the 3.5 m pruning lift had easier access and fewer branches (Figure 24). In the study by Shekwa, *et al.* (2017), the pruning time of the manual saw was found to be influenced by the branch thickness. Additionally, the size of the thickest branch is more influential than the number of branches and thicker branches took longer to prune than smaller branches (Skovsgaard *et al.* 2018). Shekwa *et al.* (2017) found that diameter at breast height (DBH) was not significant in influencing the productivity of the pruning operations because there was no direct contact with the tree stems. Although, it can be argued that DBH is directly proportional to branchiness in some pine species (Huuskonen, Hakala, Mäkinen, Hynynen and Varmola, 2014) it may not be true to the findings of this study. Because the mean DBH of compartment 1 was 10.71 cm and 16.47 cm in compartment 2. In the case of this study, it can be supported with the abovementioned findings that the branchiness of compartment 1's trees contributed to the low productivity in the 2.0 m pruning lift operations.

Figure 24. The 3.5 m lift compartment (left) has easier accessibility compared to the 2.0 m compartment (right) which has a higher density compared to the 3.5 m lift compartment - photo credits: Charles Swart.

Previous studies (Hartsough and Parker, 1996; Giefing and Złota, 2007; de Oliveira *et al.*, 2012; Nutto *et al.*, 2013; Shekwa *et al.*, 2017; Skovsgaard *et al.*, 2018) investigating similar objectives, comparing pruning saw types and their productivity, found manual pruning saws to be the least productive. The study conducted by Shekwa *et al.* (2017) in Mpumalanga *Pinus elliotti* stands, found that the mean pruning times were not significantly different between treatments in 2.0 m pruning lifts using a manual pruning saw and an electric shear pruner. The mean pruning time per tree of the manual saw was 1.22 ± 0.34 min tree^{-1} (Shekwa *et al.*, 2017), which is double the time of the current study (2.25 ± 1.15 min tree^{-1}) for the manual 2.0 m pruning operation. However, the results are similar to the 2.5 m M pruning lift (2.35 ± 0.81) of a *Pinus taeda* pruning operation (de Oliveira *et al.*, 2012). Time taken per tree for both the 2.0 m and 3.5 m motor-manual pruning lifts were 0.99 min.tree^{-1} (± 0.37) and 0.5 min.tree^{-1} (± 0.19) respectively. These figures deviate from findings in the study by de Oliveira *et al.* (2012). They found productivity in the *Pinus taeda* pruning study for motor-manual operations to be 1.91 min.tree^{-1} (± 0.17) for 2.5 m pruning lift and 3.05 min.tree^{-1} (± 0.35) for a 4.0 m pruning lift. These differences can potentially be marginally attributed to higher pruning lifts (0.5 m difference) and species differences, as *P. taeda* generally has fewer branches (Huuskonen *et al.*, 2014).

Therefore, manual operations are less productive compared to motor-manual operations. However, manual operations are more efficient compared to motor-manual operations. The pruning lifts, pruning method and operator influence have a significant impact on the productivity of the operations. Finally, the branchiness of the stand contributes to the productivity of the operation. It is recommended to explore a model for predicting productivity based on these findings, especially for the industry if there is a growing interest to move towards mechanisation of pruning operations.

5.6. Biophysical assessment: Heart Rate Results

5.6.1. Physiological workload: heart rate indices

Physiological strain (workload) of workers can be effectively determined using heart rate indices (Caliskan and Caglar, 2010). The results (Table 11) of the heart rate indices include all workers and HR recorded throughout study time, including delays. The one-way ANOVA of the heart rate indices found no significant difference between the means of the pruning operations (2.0 m M, 2.0 m MM, 3.5 m M and 3.5 m MM) for HR_{work}, HR_{rest}, RHR % and the HR_{work}/HR_{rest} ratio indices.

Mean HR_{work} ranged between 110-119 beats.min^{-1}for all the pruning operations. The 2.0 m M mean HR_{work} (115 beats.min^{-1}) with a maximum HR of 172 beats.min^{-1} is more strenuous compared to 3.5 m M operation with 110 beats.min^{-1} and a maximum of 160 beats.min^{-1}. The 3.5 m MM operation (119 beats.min^{-1}) had the highest HR_{work} recorded while 2.0 m MM had 113 beats.min^{-1}; however, both maximum HR_{work} reached 189 beats.min^{-1}. HR_{rest} for all workers fell within the "good resting heart rate" range for adult men between the ages of 25 and 45, which is 60-66 beats.min^{-1} (Burngardner, 2019).

The mean relative heart rate at work (RHR %) index ranged between the 30-40 % (and higher) aerobic capacity level recommended for prolonged continuous work with a maximum range of 43-63 %. Manual operations had the highest mean RHR % of 47 % for 2.0 m pruning lift and 40 % for 3.5 m pruning lift and the motor-manual operations with the 3.5 m pruning lift (38 %) being 4% higher than the 2.0 m (34 %) pruning lift operations. The HR_{work} and RHR % findings of this study place all four pruning operations in the “medium to heavy” workload category and can reach a maximum of a “very heavy” workload (Table 2). Subjective feelings of fatigue are a warning mechanism of overstraining of a body part or the person. Fatigue usually occurs at the end of an 8-hour workday when the average workload exceeds 30 % to 40 % of the individual’s maximal aerobic power and certainly when the load exceeds 50% of the maximal aerobic power (Åstrand, Rodahl, Dahl and StrØmme, 2003). Lammert (1972) suggests that the 50% level can be used as an effective way of measuring strain. If the ratio of HR_{work} to a 50% level is equal to

1.0, the workload can be classified as hard-continuous work. In both the 2.0 m MM and 3.5 m MM pruning operations had a ratio of 0.9 and the 2.0 m M and 3.5 m M had ratios of 0.7 and 0.8, respectively. The maximum ratios however are above the suggested ratio (1.0) for 2.0 m MM (1.1), 3.5 m M and 3.5 m MM (12), which indicates that the pruning operations can reach the hard-continuous work category.

All physiological measures placed the pruning operations in this study in the "medium to heavy" workload categories, with the maximum possibility of reaching "very heavy" workload and hard-continuous work. These results are equivalent to chainsaw and ladder pruning of *Pinus radiata* (Ford, 1995), manual pruning of Douglas fir (Kirk and Parker, 1996b) and chainsaw and shear pruner operations (Nutto *et al.*, 2013) all categorised within the "medium to heavy" and "very heavy" workload classification. Additionally, the pruning operations are within the same or can reach similar workload categories as cable-hauler/ chokers (Kirk and Sullman, 2001), chainsaw operations (Caliskan and Caglar, 2010), manual brick-laying (Adeodu, Daniyan and Dada, 2014), forestry harvesting production work (Yilmaz *et al.*, 2013) and motor-manual tree felling (Cheţa *et al.*, 2018).

5.6.2. Productive heart rate

Productive HR (HR_{prod}) is the heart rate recorded during the productive time of the operation and excludes all delays. Therefore, these values can be considered as the heart rate of workers during exposure to operation (human efficiency) in which they were actively engaged with the pruning activity, which is equivalent to the machine efficiency (Table 10). A three-way ANOVA and two-way ANOVA were done to investigate the difference between weighted mean HR for all the operations.

The three-way ANOVA interaction between pruning method, pruning lift and workers (A, B, E and F) was significant with p-value < 0.05 (Figure 11). Which indicates that these variables have an influence on the variability of the HR values and adding the worker factor reduced the standard error for this analysis. The 2.0 m M and 3.5 m M mean HR_{prod} differ significantly for each worker, with 2.0 m M pruning operation having a higher mean HR_{prod} compared to the 3.5 m M pruning operation. In the motor-manual pruning method, the mean HR_{prod} for 2.0 m and 3.5 m pruning lifts differ significantly, however, the 3.5 m MM mean HR_{prod} for all workers was higher than that of the 2.0 m pruning lift for each worker. These results are not necessarily expected, considering that these workers are more accustomed to the 3.5 m MM operation compared to the other pruning operations.

In Table 12, all four workers' mean HR_{prod} differ significantly for the 2.0 m MM and 2.0 m M pruning operations. In the 3.5 m M and 3.5 m MM, only workers A and E's mean HR_{prod} differ significantly, but B and F's do not differ significantly. These differences can potentially be explained by the height of the workers (Table 8), workers B (1.69 m) and F (1.56 m) are the shortest and even though the pole pruner can be extended to up to 5.0 m, the manual saw was limited to the wooden shaft length (3.0 m).

Unique physical attributes (Table 8) of each worker contribute to the differences between workers' HR_{prod} and assessing the differences between workers limits the findings of this study to just the four workers. However, comparing the productivity of each worker and their mean HR_{prod} reading will provide insight into how productivity compares to HR. In the 2.0 m pruning lift operations, for each worker, HR_{prod} for manual operations is less than the motor-manual operations and productivity is less in manual operations compared to motor-manual operation. In the 3.5 m pruning lift operations, each workers' productivity is lower for the manual operation compared to the motor-manual operations. However, only worker B and F's HR_{prod} for 3.5 m M is slightly lower than 3.5 MM, but for workers A and E, HR_{prod} for 3.5 m M operation is higher than 3.5 m MM. The study did not investigate the correlation coefficient of HR and productivity; however, with these findings, it can be said that higher productivity does not necessarily mean increased mean HR_{prod}.

Interaction between pruning method and pruning lift of the two-way ANOVA proved to be significant (Figure 12) for HR_{prod} response. These results provide a general overview of HR_{prod} for each of the pruning operations (including all six workers, A-F). Mean HR_{prod} differ significantly between all operations (2.0 m M, 2.0 m MM, 3.5 m M and 3.5 m MM). The 2.0 m M operation had a higher productive HR (128 beats.min^{-1}) compared to the 3.5 m M operation (110 beats.min^{-1}). Motor-manual 3.5 m operation had a higher productive HR (113 beats.min^{-1}) compared to the 2.0 m pruning lift operation (106 beats.min^{-1}). The 3.5 m manual pruning had a higher productive HR compared to the 2.0 m pruning lift operation. An increase in physiological strain is indicated by an increase in HR, which implies that the workload is higher (Kirk and Sullman, 2001). Therefore, the 3.5 m pruning lift operation is in overall more strenuous and the manual 2.0 m pruning operations is the most strenuous operation.

While the work activity and individual's health is a key contributor to heart rate variability in operations, other factors attributed to HR values include but not limited to; heat stress (Wästerlund, 1998; Yoopat *et al.*, 2002; Wilson and Crandall, 2011; Dubé, Imbeau, Dubeau, Lebel and Kolus, 2016; Dubé *et al.*, 2019), terrain conditions (Kirk and Parker, 1996a; Kirk and Sullman, 2001) and increasing slope increases workload. The mean recorded temperature differed between the compartments by 3°C. Temperature influences the HR variables and can lead to heat stress. Based on observations in compartment 2, which was done between July and early August, the workers worked throughout the shift with no other delays such as taking off outer clothing due to increased body heat. However, in compartment 1, workers frequently stopped work to remove outer clothes. This can also explain the increased productive heart rates for the 2.0 m pruning lift operations. Heart rate increases to maintain cardiac output for workload and simultaneously evacuating heat that is building up in the body (Dubé *et al.*, 2019).

Heart rate indices used in this study indicate that manual pruning at 2.0 m and 3.5 m pruning lifts in *P. patula* stands are "medium to heavy" workload operations, producing average HR_{work} of 115 beats.min^{-1} and 110 beats.min^{-1}respectively. Additionally, HR indices indicate that motor-manual operations at 2.0 m and 3.5 m pruning lifts in *P. patula* stands, are "medium to heavy" workload with average HR_{work} of 113 beats.min^{-1} and 119 beats.min^{-1}.

5.7. Awkward postures and prevalence of discomfort

The human body is adaptable and moves and works efficiently when joints are in the neutral range, but poorly designed work systems force individuals to adopt awkward postures (Kumar, 2001; McPhee *et al.*, 2009). Body posture is a major physical factor associated with musculoskeletal disorders (Gallagher, 2005; Phairah, 2014). In agricultural activities, the most commonly affected body parts are the neck, back, shoulders, wrists, hips and knees (Kirkhorn, Earle-Richardson and Banks, 2010). The results of this study support the findings by Kirkhorn *et al.* (2010), however, there was no discomfort reported for the knees or the lower limbs.

Considering the postures, the workers adopted during this study, instead of squatting to reach the lower branches, they bent their backs.

5.7.1. Prevalence of discomfort in pruning operations

Discomfort is a reaction of the musculoskeletal system experiencing stressors to the joints and muscles during work activities (Ford, 1995). Prevalence of discomfort and pain are health risk indicators and warning signs for future health problems in the body due to incorrect postures or repetitive work (Lopes *et al.*, 2019). Pruning operations have a significant effect on the prevalence of discomfort. Adopted postures, repetitive work (cyclic activities), weight of equipment, exposure to activity, psychological factors and individual differences may result in prevalence of discomfort and risk of musculoskeletal disorders (Sullman and Byers, 2000; Nutto *et al.*, 2013; Phairah *et al.*, 2016; Lopes *et al.*, 2019).

Prevalence of discomfort for both manual (M) and motor-manual (MM) pruning methods, with higher prevalence in the M (55 %) pruning method compared to MM (49 %), do not have a significant association (Figure 17). However, the prevalence of discomfort in the pruning lift had a significant association with a higher prevalence of discomfort reported for 2.0 m (61 %) pruning lift and only 42 % in the 3.5 m pruning lift (Figure 18).

Frequency of discomfort reported for each pruning operation based on recording period had a significant association (Figure 19). The 3.5 m MM (29 %), 2.0 m M 29 %) and 2.0 m MM (28 %) had the highest prevalence of discomfort reported before shift (BS). Workers reported the most discomfort before the morning break (MB) (37 %) for the 2.0 m M operation and after shift (AS) (39 %). Discomfort reported before the lunch break (LB) was the highest in the 2.0 m MM (45 %) followed by the 3.5 m MM (23 %) operation. Prevalence of discomfort reported before shift (BS) raises the concern of prevalence of work-related muscular diseases (WMSD), however, the discomfort may also be due to poor quality of sleep or rest from the previous evening. These results correspond with the study by Solman (2002), in which he studied truck drivers and recorded discomfort in similar recording periods/intervals (just when arrived at work, before meal, after meal, just before the end of work). In which fluctuation of prevalence of discomfort was observed throughout the operation and discomfort was reported when workers arrived at work, with highest prevalence just before the end of work (Solman, 2002). In this case, however, the 3.5 m M and MM operations often ended at lunchtime, which was considered the 'after shift' regardless of time. This raised the concern of the accuracy of the data, but it should be noted that it is the most representative of the workers' daily work. Where sometimes, workers will not take the lunch break to finish the task, which is an additional risk of increasing pace of work to finish earlier.

Frequency of discomfort rating (DR) by workers from "No discomfort" to "unbearable discomfort" for each operation had a statistically significant association with each pruning operation (Figure 20). The 2.0 m M (51 %), 2.0 m MM (57 %) and 3.5 m M (43%) pruning operations were reported as causing severe discomfort (DR 3), while the 3.5 m MM (35 %) caused moderate discomfort. However, there is only a 3 % difference between the moderate (35 %) and severe (32 %) discomfort ratings for the 3.5 m MM pruning operations. The 2.0 m M pruning operation showed the highest frequency for unbearable discomfort (DR 4), which can be explained by the prolonged exposure to the operation in the 2.0 m M operations.

5.7.2. Awkward postures and discomfort per body part

Awkward postures identified during operations for 2.0 m M (Figure 13), 2.0 m MM (Figure 14), 3.5 m M (Figure 15) and 3.5 m MM (Figure 16) were identified as contributors to ergonomic risks and contribute to body discomfort. Table 14 summarises the results of figures 15-18 of the frequency of discomfort reported per body part. The association between body part discomfort and pruning operation (Figure 21), recording period (Figure 22) and discomfort rating (Figure 23) was statistically significant.

Upper and lower neck: Neck twisting and extension greater than 20° were found to result in increased occurrences of neck and shoulder symptoms of discomfort (Keyserling *et al.*, 1992). Frequent occurrences of neck extensions were observed in 3.5 m M and MM operations due to work requiring workers to extend their necks to look up to the branches when pruning, (Figures 16 and 17) and tilting neck to the side (Figure 16P). In the 2.0 m M and MM operations, however, workers did not deviate from the neutral plane of the neck, in some instances in the MM operations, workers flexed their neck while keeping their body static (Figure 14F). Recommendations by ErgoWood and EX (2006) suggest that the head should not be turned more than 30° to the side or tilted more than 5° degrees up or 25° degrees down. Even though it was not measured in this study, Figure 14H is an example of a deviation of the neck at an angle greater than 30°. These results explain the high prevalence of severe to unbearable discomfort reported for the upper and lower neck (BP 0 and 1) in the 3.5 m MM, 3.5 m M and 2.0 m MM pruning operations. The hard hats and visors worn by workers also contribute to the need to tilt or extend their heads to see the higher branches. Additionally, discomfort of upper neck was frequently reported BS (28 %) and AS (28 %). However, discomfort in lower neck most frequently reported AS (31 %).

Shoulders, arms and elbows: Shoulder abduction and extensions were observed in all the pruning operations and showed to be the most common posture adopted by the workers followed by the elbow flexion and extension, mostly flexion of the dominant hand (right elbow). Due to the nature of the operation, the manual operations, require of operator to pull and push the saw. Depending on the pruning lift and workers' height, workers may have to extend their reach as in Figure 13A in the 2.0 m M pruning operation or 3.5 m M (Figure 15I), which may go above shoulder level. The worker in Figure 13A is using the shortest saw, even though he is relatively tall, he still requires extending his shoulders to reach the branches. In Figure 15I, the worker is using a longer manual saw, however, still requires extending and reach the higher branches leading to shoulder abduction and extension and elbow flexion of dominant arm. These motions are repeated in the motor-manual operations; however, there is no push and pull motion which engages additional force, although, a slight up and down motion was observed. Due to the load carried in the dominant hand (the heavier side of the pole-pruner) workers frequently adopt shoulder abduction and elbow flexion of the dominant arm (Figures 15 and 17). Furthermore, in the 22.0 m MM operations, workers extended their non-dominant arms (left) to reach to the lower branches leading to shoulder and elbow flexion (Figures 14E and 14G), while in the 3.5 m MM a series of shoulder abduction and extension (Figures 16M and 16O) and elbow flexion and extension (Figures 16O and 16P) are adopted.

These postures explain the discomfort workers experienced in the shoulders (BP 2 and 3), left and right upper and lower arms and elbows (BP 4, 6 and 10-13), upper back or between shoulder blades (BP 5). High prevalence of shoulder discomfort was reported for the 3.5 m MM and 2.0 m M operations mostly AS, followed by MB and BS. Workers rated discomfort in the shoulders as severe discomfort. The 2.0 m M and MM operations, however, had the highest prevalence of discomfort reported in the upper arms, elbows and lower arms, with severe to unbearable discomfort ratings.

Wrists and hands: Ulnar deviation of the wrist was observed in all four pruning operations and mostly in the motor-manual operations. This motion could be avoided, especially in the 2.0 m M operation (Figure 13A) which allows operator to rely on shoulder and elbow extension and holding the saw in a somewhat neutral position. Deviation of the wrist from its neutral position may lead to manual pruners, eventually suffering from tennis elbow (Kirk and Parker, 1996b). Kirk and Parker (1996b) suggested that motor-manual pruning operations may alleviate the repetitive strain-type injury that is caused in manual operations. This study, however, shows otherwise, where the dominant hand (right hand) stays in the same position since its where the throttle of the machine is located and the wrist stays in this deviated posture in the motor-manual operations (Figures 15 and 17), workers are exposed to repetitive ulnar deviation.

Discomfort of the hands and wrists (BP 14-17) was only reported for the 2.0 m M and 3.5 m M pruning operations. The manual operations require workers to exert a firm grip onto the tool while applying force to push and pull. The pull and push motions are held static and adjusted after the branch is pruned off. This motion leads to abduction and extension of the shoulder, flexion of the elbows, and additionally ulnar deviation of the wrists due to the nature, in which workers hold the equipment. The intensity and duration of this gripping action, combined with pull and push force lead to muscular fatigue in the forearms and discomfort in the palms and hands due to vaso-constriction (Ford, 1995). Kirk and Parker (1996b) concluded that manual repetitive and strenuous motions of pruning lead to development of cumulative effect trauma, which can cause progressive damage to the tendons, tendon sheaths, and related bones, nerves of the hand, wrist, elbow and arms.

Motor-manual operations do not require additional force on the palms and wrists, but merely holding the extension pole and pressing on the throttle. Discomfort in the hands was reported for the 2.0 m MM operation by two workers (C and D), just before the lunch break and only on the one day both times. These workers are both right-handed and use their right hand to control the throttle. The discomfort may be due to workers holding the pruning tool in an “unnatural” manner for some unexplained reason. There were no close images taken of these workers; therefore, we cannot further analyse the contributing reason on how they held the tool as an influential factor.

Waist, lower back and hips: Awkward postures relating to non-neutral trunk postures to low back (mild or severe flexion) are found to have a strong association with low back disorders (Punnett, Fine, Keyserling, Herrin and Chaffin, 1991). Mild to severe flexion of the back was mostly observed in the 2.0 m M and MM operations (Figures 16 and 17). Due to the low branches, workers had to bend (flexion) to reach the branches. In the 2.0 m MM operation, workers were able sometimes to avoid bending because the pole-pruner allows workers to rely on extension of shoulders and elbow (Figures 14F and 14G). However, this leads to workers flexing their heads and extending their arms and elbows. Severe flexion of the back was observed in the 2.0 m M operations (Figure 13C). Workers shortened the lengths of the wooden shafts for the 2.0 m M operations, which limited their reach and led to the adoption of highly flexed postures. Flexion of the back was barely observed in the 3.5 m M and MM operations; however, slight (Figure 16N) to severe (Figure 16O) back extensions are adopted and twisting

(Figure 16P) of the waist as they move around the tree. These postures explained high prevalence of discomfort in the waist, lower back and hips (BP 7-9) which was dominantly reported for the 2.0 m M and MM pruning operations with discomfort rating of severe to unbearable discomfort. Discomfort was mostly reported AS, however, discomfort in the waist was also reported BS (De Oliveira *et al.* 2012).

Primary risk factors that affect or can lead to MSDs identified are repetitive work, awkward postures and duration of exposure to operation. The manual pruning operations required an active repetitive push and pull motion of the saw which engages shoulder abduction and extension at the 3.5 m and downward reaching at the 2.0 m pruning lift. The 3.5 m manual task is above 75% of repetitive work (productive work). The motor-manual task requires a slight range of motion of repetitive work of lifting the pole pruner up and down the stem of the tree. The per cent time spent on the motor-manual operations is just above 70% of the total study time. Both operations involved cyclic awkward postures based on pruning lifts. Both the 2.0 m M and MM pruning operations had frequent bending and reaching down to the lowest branch. Workers spend most of their time-bending, putting them at risk for lower back injuries and disorders.

The duration of exposure to an awkward posture increases the prevalence and frequency of discomfort or pain experienced during an operation (Gallagher, 2005). Duration of exposure to adopted postures was not recorded in the study, however, the duration of exposure to the operation is considered the same as the machine utilisation of the operation (Table 4). Workers were exposed to the operation for a duration of 83%, 72 %, 76 % and 73 % of the total study time for 2.0 M, 2.0 MM, 3.5 M and 3.5 MM respectively. Even though workers took rest breaks in between, they are still at risk of WMSDs as their exposed to "medium to heavy" workload for five to six hours per workday.

6. Conclusion

The main objective of the study was to assess if there are ergonomic risks associated with manual and motor-manual pruning operations of *Pinus patula* stands in KZN Midlands for 2.0 m and 3.5 m pruning lifts. The sub-objectives were assessed for the productivity of the pruning operations, heart rate as a measure of workload and awkward postures as a contributor to body discomfort experienced during operations to answer the research question. This study showed that pruning operations do have associated ergonomic risks. The study objectives were valuable tools to answer the research question.

The results of the study showed that manual operations yield the lowest productivity and motor-manual operations the highest. The 3.5 m motor-manual (3.5 m MM) pruning operation was the most productive operation and the 2.0 m manual (2.0 m M) the least productive operation. However, workers can yield similar productivity for both 3.5 m M and 2.0 m MM operations. Even though the manual operations are the most efficient, the motor-manual operations still produce the highest yield. Machine utilisation of operations is influenced by the duration of exposure to operation, which contributes to how long workers are exposed to workload.

Heart rate indices showed that the pruning operations fall within the "medium to heavy" and can reach up to "very heavy" workload category. The 2.0 m M, 3.5 m M and 3.5 m MM can reach the hard-continuous workload category of work executed over nine scheduled work hours. Productive heart rate ($HR_{prod)}$ of workers can be equated to the duration of exposure to operation where the worker is actively engaged with the operation. The individuality of workers has a significant influence in the variability of the heart rate responses, in which the results of heart rate changes must be interpreted per individual, rather than considered as the result of the overall outcome of the specific operation. However, these results can also be analysed in correlation with productivity per worker and operation to see the influence if there is a correlation between productivity and heart rate. When the operator factor was excluded, the productive heart rate showed to differ significantly with 2.0 m M reaching the highest mean HR_{prod} value, which makes it the most strenuous operation. On the contrary, the 2.0 m MM operation showed to be the least strenuous operation with the lowest mean HR_{prod}. The 3.5 m M operation was more strenuous than the 3.5 m MM.

Awkward postures adopted by workers contributed to the prevalence of discomfort experienced by operations for each operation. Most common postures adopted by workers deviate from the neutral plane of the body quite often resulting in postures, such as shoulder abduction and extensions, elbow extension and flexion, twisting and extension of neck, lower back flexion and ulnar deviation of the wrist. These postures contributed to prevalence of body discomfort whereby high prevalence of discomfort was mostly reported in manual operations compared to motor-manual operations and the most in 2.0 m pruning lifts compared to 3.5 m pruning lift operations. Discomfort was mostly reported before the morning break and after the shift, for the 2.0 m M and 3.5 m M operations. In the 2.0 m MM discomfort was mostly reported before the morning break and before the lunch break and mostly before shift and lunch break for the 3.5 m MM pruning operation.

Workers rated all operations as 'severe discomfort' except 3.5 m MM as 'moderate discomfort'. Prevalence of discomfort was mostly reported in the 2.0 m MM, 3.5 m M and 3.5 m MM for upper and lower neck and shoulders in 2.0 m M and 3.5 m MM operations. Discomfort in upper arms was mostly reported in 2.0 m M, 2.0 m MM and 3.5 m Mand for elbows and lower arms in

2.0 m M and MM operations. Discomfort in the back was mostly reported for the 2.0m M and MM operations. Finally, only the 2.0 m, 2.0 m MM and 3.5 m M had the most prevalence of discomfort reported for the wrist and hands. Workers did not report prevalence of discomfort in the lower body parts.

Pruning operations are repetitive operations, which increases the ergonomic risks; however, based on these findings, motor-manual operations have the least ergonomic risks compared to the manual operations. The shorter duration of exposure to the operation contributes to decreasing ergonomic risk for workers while still yielding high productivity, even though the workload is “medium to heavy”, it is within the safe limits of hard-continuous work. However, workers are still at higher risks of injuries due to the high risk of the operations and should be continuously be encouraged to practice safe forestry work.

7. Recommendations for future research

The need for ergonomic studies in industrially developing countries should not be taken lightly, because human capital is the highest value forestry industries have and should ensure the activities are of optimal health. For future research, this study can be repeated with a larger sample size of operators which can include gender as a factor because that is a thorough representation of the current pruning operation teams. Towards the end of this study, more women were being trained for the motor-manual operations and it will be of great benefit to not only the industry but the workers to practice safe forestry. Furthermore, an analysis of the relationship between productivity and heart rate values will be helpful to indicate if heart rate decreases with increased productivity or vice versa. Lastly, a thorough ergonomics assessment on awkward postures and musculoskeletal disorders for pruning operations with the proposed assessment methods can give a deeper understanding of the workers’ physical wellbeing.

8. Bibliography

Ackerman, P., Gleasure, E., Ackerman, S. and Shuttleworth, B. 2014. *Standards for Time Studies for the South African Forest Industry*. [Online], Available: http://www.icfr.ukzn.ac.za/sites/default/files/pubs/Time Study Standards 2015.pdf.

Ackerman, P., Williams, C., Ackerman, S. and Nati, C. 2016. Diesel Consumption and Carbon Balance in South African Pine Clear-Felling CTL Operations: A Preliminary Case Study. *Croatian Journal of Forest Engineering*. 38(1):65–72.

Ackerman, S., Ackerman, P., Spong, B. and Terblanche, M. 2019. *Forest Operations Productivity Initiative*. [Online], Available: https://www.forestproductivity.co.za/ [2019, September 30].

Adeodu, A.O., Daniyan, I.A. and Dada, O.M. 2014. An assessment of physical strain experienced by manual workers in brick laying operation - A case study in Nigeria. *Journal of Computation in Biosciences and Engineering*. 1–6. [Online], Available: http://scienceq.org/Journals/JCLS.php%0AOpen Access%0AAn assessment of physical strain experienced by manual workers in brick laying operation - A case study in Nigeria%0AAdeodu A. O*, Daniyan I. A and Dada O. M Department of Mechanical and Mechatronics E.

American College of Cardiology. 2014. Your Health: How to Measure Your Pulse. 2. [Online], Available: https://www.cardiosmart.org/~/media/Documents/Fact Sheets/en/zu1592.ashx.

Åstrand, P.-O., Rodahl, K., Dahl, H.A. and StrØmme, S.B. 2003. *Textbook of work physiology*. Fourth ed. McGraw-Hill.

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

Bačić, M., Šušnjar, M., Pandur, Z., Šporčić, M. and Landekić, M. 2018. Physical workload while working with hedging bill and battery cutter in tending of pedunculate oak. In Zadar, Croatia *7th International Ergonomics Conference, Ergonomics 2018- Emphasis on wellbeing*. 59–64.

Bates, G.P. and Schneider, J. 2008. Hydration status and physiological workload of UAE construction workers: A prospective longitudinal observational study. *Journal of Occupational Medicine and Toxicology*. 3(1):1–10.

Van Der Beek, A.J. and Frings-Dresen, M.H.W. 1998. Assessment of mechanical exposure in ergonomic epidemiology. *Occupational and Environmental Medicine*. 55(5):291–299.

Błuszkowska, U. and Nurek, T. 2014. Effect of mechanization level on manpower needs in forestry. *Folia Forestalia Polonica, Series A*. 56(4):194–201.

Burngardner, W. 2019. *Resting Heart Rate and Fitness*. [Online], Available: https://www.verywellfit.com/resting-heart-rate-3432632?prin [2019, July 29].

Caliskan, E. and Caglar, S. 2010. An assessment of physiological workload of forest workers in felling operations. *African Journal of Biotechnology*. 9(35):5651–5658. [Online], Available: http://www.academicjournals.org/AJB/PDF/pdf2010/30Aug/Çaliskan and Çaglar.pdf%5Cnhttp://ovidsp.ovid.com/ovidweb.cgi?T=JSandPAGE=referenceandD=emed9andNEWS=NandAN=2010549998.

CDC, Center for disease control and prevention. 2011. *Body mass index: Considerations for practitioners*. [Online], Available: http://scholar.google.com/scholar?hl=enandbtnG=Searchandq=intitle:Body+Mass+Index+:+Considerations+for+Practitioners#3%5Cnhttp://scholar.google.com/scholar?hl=enandbtnG=Searchandq=intitle:Body+mass+index:+Considerations+for+practitioners%233.

Cheţa, M., Marcu, M.V. and Borz, S.A. 2018. Workload, exposure to noise and risk of musculoskeletal disorders: A case study of motor-manual tree feeling and processing in poplar clear cuts. *Forests*. 9(6):1–20.

Christie, C. 2001. Consideration of the effect of nutritional status and disease patterns on work output amongst black South African workers involved in manual materials handling

(MMH) tasks. *Ergonomics SA*. 1(September).
Christie, C.J.A. 2012. Straightforward yet effective ergonomics collaborations in South Africa. *Ergonomics in Design*. 20(4):39–42.
Cohen, M.A., Clark, R.E., Silverstein, B., Sjostrom, T. and Spielholz, P. 2006. Work-related deaths in Washington State, 1998-2002. *Journal of Safety Research*. 37(3):307–319.
da Costa, D. 2013. Modernisation and The Effect On Silviculture. (November).
Cremasco, M.M., Giustetto, A., Caffaro, F., Colantoni, A., Cavallo, E. and Grigolato, S. 2019. Risk assessment for musculoskeletal disorders in forestry: A comparison between RULA and REBA in the manual feeding of a wood-chipper. *International Journal of Environmental Research and Public Health*. 16(5):1–13.
David, G.C. 2005. Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. *Occupational Medicine*. 55(3):190–199.
Dempsey, P.G., Wogalter, M.S. and Hancock, P.A. 2000. What's in a name? Using terms from de® nitions to examine the fundamental foundation of human factors and ergonomics science. *Theoretical Issues in Ergonomics Science*. 1(1):3–10.
Diamante-Camacho, L. 2012. Meeting of the minds: Contextualizing the role of traditional knowledge in forest management and governance. *Forest Policy and Economics*. 22:1–2.
Dickerson, C.R., Martin, B.J. and Chaffin, D.B. 2006. The relationship between shoulder torques and the perception of muscular effort in loaded reaches. *Ergonomics*. 49(11):1036–1051.
Dubé, P.-A., Imbeau, D., Dubeau, D., Auger, I. and Leone, M. 2015. Prediction of work metabolism from heart rate measurements in forest work: some practical methodological issues. *Ergonomics*. 58(12):2040–2056.
Dubé, P.-A., Imbeau, D., Dubeau, D., Lebel, L. and Kolus, A. 2016. Removing the thermal component from heart rate provides an accurate V ˙O2 estimation in forest work. *Applied Ergonomics*. 54:148–157.
Dubé, P.-A., Imbeau, D., Dubeau, D. and Auger, I. 2019. Worker heat stress prevention and work metabolism estimation: comparing two assessment methods of the heart rate thermal component. *Ergonomics*. 62(8):1066–1085.
Etikan, I., Musa, S.A. and Alkassim, R.S. 2016. Comparison of Convenience Sampling and Purposive Sampling Comparison of Convenience Sampling and Purposive Sampling. *American Journal of Theoretical and Applied Statistics*. 5(January 2016):1–5.
Fenety, A. and Walker, J.M. 2002. Short-term effects of workstation exercises on musculoskeletal discomfort and postural changes in seated video display unit workers. *Physical therapy*. 82(6):578–89.
Fischer, S.L. and Dickerson, C.R. 2014. Applying psychophysics to prevent overexposure: On the relationships between acceptable manual force, joint loading and perception. *International Journal of Industrial Ergonomics*. 44 (2):266–274.
Ford, D. 1995. An Ergonomics Analysis of Manual versus Chainsaw High Ladder Pruning of Pinus radiata in New Zealand. Massey University.
Fox, R.R. 1993. A psychophysical study of high-frequency lifting. Texas Tech University.
Fox, R.R. and Smith, J.L. 2014. A psychophysical study of high-frequency arm lifting. *International Journal of Industrial Ergonomics*. 44 (2):238–245.
Gallagher, S. 2005. Physical limitations and musculoskeletal complaints associated with work in unusual or restricted postures: A literature review. *Journal of Safety Research*. 36(1):51–61.
Gallo, R. and Mazzetto, F. 2013. Ergonomic analysis for the assessment of the risk of work-related musculoskeletal disorder in forestry operations. *Journal of Agricultural Engineering*. 44 (2s):730–735.
Garet, M., Boudet, G., Coudert, J., Montaurier, C., Vermorel, M. and Chamoux, A. 2005. Estimating relative physical workload using heart rate monitoring: A validation by whole-body indirect calorimetry. *European Journal of Applied Physiology*. 94 (1–2):46–53.
Gellish, R.L., Goslin, B.R., Olson, R.E., McDonald, A., Russi, G.D. and Moudgil, V.K. 2007. Longitudinal modeling of the relationship between age and maximal heart rate. *Medicine*

and Science in Sports and Exercise. 39 (5):822–829.

Giefing, D.F. and Złota, M. 2007. Efficiency of pruning scots pine (*Pinus sylvestris* l.) Using different types of saws. *Acta Sci. Pol. Silv. Colendar. Rat. Ind. Lignar.* 6 (4):81–88.

Hartsough, B. and Parker, R. 1996. Manual pruning of Douglas-fir. *New Zealand Journal of Forestry Science*. 26 (3):449–459.

Hogg, G., Pulkki, R. and Ackerman, P. 2011. Excavator-based processor operator productivity and cost analysis in Zululand, South Africa. *Southern Forests*. 73 (2):109–115.

Husqvarna. 2019.

Huuskonen, S., Hakala, S., Mäkinen, H., Hynynen, J. and Varmola, M. 2014. Factors influencing the branchiness of young Scots pine trees. *Forestry*. 87 (2):257–265.

ILO, I.L.O. 1992. *Fitting the job to the forest worker: An illustrated training manual on ergonomics*. Geneva.

ILO, I.L.O. 1998. *Safety and health in forestry work*. First ed. Vol. 16. Geneva: International Labour Organization.

James, G. 2006. *An erognomic assessment of manual timber extraction*. [Online], Available: https://www.icfr.ukzn.ac.za/publications/ergonomic-assessment-manual-timber-extraction [2019, June 20].

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

Kew, G. 2002. The Medical Surveillance Programme. Procedure Guidelines.

Keyserling, W., Brouwer, M. and Silverstein, B. 1992. A checklist for evaluating ergonomic risk factors resulting from awkward postures of the legs, trunk and neck. *International Journal of Industrial Ergonomics*. 9:283–301.

Kirk, P.M. and Parker, R.J. 1996a. Heart rate strain in New Zealand manual tree pruners. *International Journal of Industrial Ergonomics*. 18:317–324.

Kirk, P.M. and Parker, R.J. 1996b. An ergonomic evaluation of Douglas fir manual pruning in New Zealand. *Journal of Forest Engineering*. 7 (2):51–58.

Kirk, P.M. and Sullman, M.J.M. 2001. Heart rate strain in cable hauler choker setters in New Zealand logging operations. *Applied Ergonomics*. 32:389–398.

Kirk, P.M., Sullman, M.J. and Parker, R.J. 1998. The physical demands of New Zealand Forest Work. In First ed. P. Scott, R. Bridger, and J. Charteris (eds.). Elsevier Science Ltd *Global Ergonomics: Proceedings of the Ergonomics Conference, Cape Town, South Africa, 9-11 September 1998*. 315–318.

Kirkhorn, S.R., Earle-Richardson, G. and Banks, R.J. 2010. Ergonomic risks and musculoskeletal disorders in production agriculture: Recommendations for effective research to practice. *Journal of Agromedicine*. 15 (3):281–299.

Klamerus-Iwan, A., Błońska, E., Lasota, J., Kalandyk, A. and Waligórski, P. 2015. Influence of Oil Contamination on Physical and Biological Properties of Forest Soil after Chainsaw Use. Water, Air and Soil Pollution. 226 (11).

Kolus, A., Dubé, P.-A., Imbeau, D., Labib, R. and Dubeau, D. 2014. Estimating oxygen consumption from heart rate using adaptive neuro-fuzzy inference system and analytical approaches. *Applied Ergonomics*. 45 (6):1475–1483.

Kotze, H. and du Toit, B. 2012. Silviculture of industrial pine plantations in Southern Africa. In 5th ed. B. V Bredenkamp and S.J. Upfold (eds.). Pinetown: Southern African Institute for Forestry South African Forestry Handbook. 123–140.

Krueger, G.P. 2012. Book Review: Ergonomics in Developing Regions: Needs and Applications. *Ergonomics in Design: The Quarterly of Human Factors Applications*. 20 (4):43–43.

Kumar, S. 2001. Theories of musculoskeletal injury causation. *Ergonomics*. 44 (1):17–47.

Kumaraveloo, K., Sakthiaseelan and Kolstrup, C.L. 2018. Agriculture and musculoskeletal disorders in low- and middle-income countries. *Journal of Agromedicine*. 23 (3):227–248.

Lammert, O. 1972. Maximal aerobic power and energy expenditure of eskimo hunters in

Greenland. *Journal of Applied Physiology*. 33 (2):184–8.
Längin, D., Ackerman, P. and Olsen, G. 2010. Introduction to Ground Based Harvesting Systems and Methods. In First ed. D. Längin, P.A. Ackerman, B. Krieg, A. Immelmann, C. Potgieter, J. Van Rooyen, and S. Upfold (eds.). Forest Engineering Southern Africa and Institute for Commercial Forestry Research *South African Ground Based Harvesting Handbook*. 36–40. [Online], Available: www.icfr.ukzn.ac.za.
Lopes, E. da S., Oliveira, F.M., Malinovski, J.R. and da Silva, R.H. 2013. Avaliação biomecânica de Trabalhadores nas atividades de poda manual e semimecanizada de Pinus taeda. *Floresta*. 43 (1):9–18.
Lopes, E. da S., Britto, P.C. and Rodrigues, C.K. 2019. Postural discomfort in manual operations of forest planting. *Floresta e Ambiente*. 26 (1).
Martin, C.J. 2016. Slope effect on costs and productivity of single-grip purpose-built and excavator-based harvesters. (December):1–60.
McAtamney, L. and Nigel Corlett, E. 1993. RULA: a survey method for the investigation of work-related upper limb disorders. *Applied Ergonomics*. 24 (2):91–9.
McEwan, A. and Steenkamp, J. 2014. Silvicultural modernization in the South African Forestry Industry. In Florence *Proceedings of the Second International Congress of Silviculture*. [Online], Available: http://dx.doi.org/10.4129/2cis-ame-sil 1.
McPhee, B., Scott, P. and Kogi, K. 2009. *Ergonomics Guidelines for occupational health practice in industrially developing countries*.
Miller, S. 2001. *Workload measures.* Iowa. [Online], Available: http://www.nads-sc.uiowa.edu/publicationstorage/200501251347060.n01-006.pdf.
Moore, S.M., Torma-Krajewski, J. and Steiner, L.J. 2011. *Practical demonstrations.* Pittsburg. [Online], Available: www.cdc.gov/niosh/eNews.
Nakagawa, M., Hamatsu, J., Saitou, T. and Ishida, H. 2007. Effect of Tree Size on Productivity and Time Required for Work Elements in Selective Thinning by a Harvester. *International Journal of Forest Engineering*. 18 (2):24–28.
Nolimo Solman, K. 2002. Analysis of interaction quality in human-machine systems: Applications for forklifts. *Applied Ergonomics*. 33 (2):155–166.
Nutto, L., Malinovski, R.A., Brunsmeier, M. and Schumacher, S.F. 2013. Ergonomic aspects and productivity of different pruning tools for a first pruning lift of Eucalyptus grandis Hill ex Maiden. *Silva Fennica*. 47 (4):1–14. [Online], Available: http://dx.doi.org/10.14214/sf.1026.
de Oliveira, F.M., Lopes, E. da S., Malinovski, J.R., da Silva, R.H. and Rodrigues, C.K. 2012. Avaliação técnica e de custos de poda manual e semimecanizada em plantios de pinus taeda. *Floresta*. 42 (4):691–700.
Parker, R. and Kirk, P. 1994. Physiological workload of forest work. 19 (4):1–8.
Payne, G. and Payne, J. 2004. The Hawthorne Effect. In the SAGE Key Concept series: Key concepts in social research. *London, England: SAGE Publications, Ltd*. 108–112.
Phairah, K. 2014. Operator work-related musculoskeletal discomfort during forwarding operations in South Africa: An ergonomic assessment.
Phairah, K., Brink, M., Chirwa, P. and Todd, A. 2016. Operator work-related musculoskeletal disorders during forwarding operations in South Africa: an ergonomic assessment. *Southern Forests*. 78(1):1–9.
Polar Electro Oy. 2008. [Online], Available: www.polar.fi.
Potočnik, I. and Poje, A. 2017. Forestry ergonomics and occupational safety in high ranking scientific journals from 2005-2016. *Croatian Journal of Forest Engineering*. 38 (2):291–310.
Purfürst, F.T. and Erler, J. 2011. The Human Influence on Productivity in Harvester Operations. *International Journal of Forest Engineering*. 22 (2):15–22.
Rabie, H.F. 2015. By submitting this thesis electronically, I declare that the entirety of the work.
Rodrick, D. and Karwowski, W. 2006. Manual Materials Handling. In Third ed. G. Salvendy

(ed.). John and Wiley Sons. Inc *Handbook of Human Factors and Ergonomics*. 818–854.

Schnepf, C.C. and Schwandt, J.W. 2006. Pruning Western White Pine, A Vital Tool for Species Restoration.

Scott, P.A. 2009. The Development of and the Need for, Ergonomics in Industrially Developing Countries. In First ed. P.A. Scott (ed.). CRC Press Taylor and Francis Group *Ergonomics in Developing Regions Needs and Application*. 1–3. [Online], Available: http://www.taylorandfrancis.com.

Senate Research Ethics Committee. 2013. *POLICY FOR RESPONSIBLE RESEARCH CONDUCT AT STELLENBOSCH UNIVERSITY*. [Online], Available: https://www.google.com/url?sa=tandrct=jandq=andesrc=sandsource=webandcd=2andved=2ahUKEwj41Imc2sPlAhUktHEKHWi_DtUQFjABegQICxAEandurl=https%3A%2F%2Fwww.sun.ac.za%2Fenglish%2Fpolicy%2FDocuments%2FResearch%2520Ethics%2520Policy.pdfandusg=AOvVaw1zvdvR5tW3lelcF68njduX.

Shakouri, M., Ikuma, L.H., Aghazadeh, F. and Nahmens, I. 2018. Analysis of the sensitivity of heart rate variability and subjective workload measures in a driving simulator: The case of highway work zones. *International Journal of Industrial Ergonomics*. 66:136–145.

Shekwa, A., Chirwa, P., Ngulube, E. and Ghebremariam, T. 2017. Productivity, efficiency and costs of manual saw and electric shear pruning operations in Pinus elliottii stands of Mpumalanga, South Africa. *International Journal of Forest Engineering*. 28 (3):169–175.

Skovsgaard, J.P., Markmann, J.J.M., Attocchi, G. and Talbot, B. 2018. High pruning of European beech (Fagus sylvatica L.) and pedunculate oak (Quercus robur L.): work efficiency for target pruning as a function of tree species, pruning height, branch characteristics, pole saw type and operator. *Scandinavian Journal of Forest Research*. 33 (5):511–517.

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

Smith, L.A., Wilson, D.G. and Sirois, D.L. 1983. Work physiology evaluation of southern forest harvesting tasks. *Forest products journal*. 33 (9):38–43.

Stanton, N.A. 2005. Human Factors and Ergonomics Methods. In 1st ed. N. Stanton, A. Hedge, K. Brookhuis, E. Salas, and H. Hendrick (eds.). CRC Press LLC *Handbook of Human Factors and Ergonomics*. 1–8.

STATS SA, S.S.A. 2017. *South Africa Demographic and Health Survey 2016.*

Steenkamp, J.C. 2007. The Effect of HIV and Aids on the Viability and Management of Forestry Contracting Businesses in South Africa. Nelson Mandela Metropolitan University.

Sullman, J.M. and Byers, and J. 2000. An Ergonomic Assessment of Manual Planting Pinus Radiata Seedlings. *Journal of Forest Engineering*. 11 (1):53–62.

Thompson, R. 2013. Mechanization and Modernisation in the Forestry Value Chain Reaction. In Pietermaritzburg *Southern African Institute of Forestry: Mechanisatio an*.

Todd, A.I. 2011. Opinion section: Shaping the future ergonomics landscape of South Africa: A co-operative co-responsibility. 23 (1):5–8.

Toupin, D., LeBel, L., Dubeau, D., Imbeau, D. and Bouthillier, L. 2007. Measuring the productivity and physical workload of brush cutters within the context of a production-based pay system. *Forest Policy and Economics*. 9 (8):1046–1055.

Vasseljen, O., Holte, K.A. and Westgaard, R.H. 2001. Shoulder and neck complaints in customer relations: Individual risk factors and perceived exposures at work. *Ergonomics*. 44 (4):355–372.

Vitalis, A., Gaskin, J. and Jeffrey, G. 1984. *A physiological cost of work-An ergonomics approach.*

Vos, T., Flaxman, A., Naghavi, M., Lozano, R., Michaud, C. and Ezzati, M. 2012. Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*. 380 (9859):2163–2196.

Wanave, S.B. and Bhadke, M.K. 2013. An Ergonomic Evaluation and Assessment Of The Workstation To Improve The Productivity For An Enterprise: -A Review. *International Journal of engineering research and applications*. 3 (6):1598–1602.

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

Williams, C. and Ackerman, P. 2016. Cost-productivity analysis of South African pine sawtimber mechanised cut-to-length harvesting. *Southern Forests*. 78 (4):267–274.

Wilson, T.E. and Crandall, C.G. 2011. Effect of thermal stress on cardiac function. *Exercise and Sport Sciences Reviews*. 39 (1):12–17.

Wu, H. and Wang, M.J. 2010. Relationship between maximum acceptable work time and physical workload. 0139.

Yilmaz, R., Eroğlu, H., Cihan, H. and Kayacan, Y. 2013. Determination of Physiological Workloads of the Harvesting Workers: A Case Study from Artvin. In Atvin, Turkey *International Caucasian Forestry Symposium*. 152–159.

Yoopat, P., Toicharoen, P., Glinsukon, T., Vanwonterghem, K. and Louhevaara, V. 2002. Ergonomics in practice: Physical workload and heat stress in Thailand. *International Journal of Occupational Safety and Ergonomics*. 8 (1):83–93.

9. Addenda

9.1. Addendum A: Ethical application confirmation letter

Approved with

Stipulations

New

Application

04/07/2018
Project ID: 7329

HREC Reference #: S18/05/109

Title: Ergonomic Assessment of manual and motor-manual pruning of Pinus patula stands in KZN midlands

Dear Miss Zimbili Sibiya,
The **Response to Deferral** received on 02/07/2018 14:45 was reviewed by members of the **Health Research Ethics Committee 2 (HREC2)** via Minimal Risk Review procedures on 04/07/2018 and was approved with stipulations.
Please note the following information about your approved research protocol**:**
Protocol Approval Period: **04-July-2018 – 03-July-2019**.

<u>The stipulations of your ethics approval</u> are as follows:

Thank you for making the requested changes to your HREC submission. The study can now be approved, provided that you address the following minor administrative issues and requested or suggested changes.

1. Please submit an investigator's declaration form for Ms James.

2. Informed consent:

   - Purpose of the study- Reference to "the operation" is somewhat ambiguous. It is suggested to substitute "manual pruning vs. motor-manual pruning" instead of "the operation", in keeping with the stated aim of the study.

   - Possible risks and discomforts- It is suggested to paraphrase the Hawthorne effect rather than using this scientific term (with which Worker are unlikely to be familiar).

3. Body Discomfort Questionnaire:

   - Please revise the grammar of the first sentence and correct the typo at the start of the second sentence "Thereof"

   - Consider addressing Worker directly in the first paragraphs (i.e. you/your) instead of "the worker".

- It is highly recommended to re-format the questionnaire such that the body map and ratings table are on the same page (i.e. the participant is not having to refer back and forth between pages).

Please remember to use your **Project ID [7329]** and ethics reference number on any documents or correspondence with the HREC/UREC concerning your research protocol.
Please note that this decision will be ratified at the next HREC full committee meeting. HREC reserves the right to suspend approval and to request changes or clarifications from applicants. The coordinator will notify the applicant (and if applicable, the supervisor) of the changes or suspension within 1 day of receiving the notice of suspension from HREC. HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

After Ethical Review:

Please note you can submit your progress report through the online ethics application process, available at: https://apply.ethics.sun.ac.za and the application should be submitted to the Committee before the year has expired. Please see Forms and Instructions on our HREC website for guidance on how to submit a progress report.
The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility, permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Please consult the Western Cape Government website for access to the online Health Research Approval Process, see: https://www.westerncape.gov.za/general-publication/health-researchapproval-process. Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.
We wish you the best as you conduct your research.

Page 1 of 2

For standard HREC forms and instructions, please visit: Forms and Instructions on our HREC website (www.sun.ac.za/healthresearchethics) If you have any questions or need further assistance, please contact the HREC office at 021 938 9677.

Yours sincerely,
Francis Masiye,
HREC Coordinator,
Health Research Ethics Committee 2 (HREC2).

National Health Research Ethics Council (NHREC) Registration Number:

REC-130408-012 (HREC1) ·REC-230208-010 (HREC2)

Federal Wide Assurance Number: 00001372
Office of Human Research Protections (OHRP) Institutional
Review Board (IRB) Number: IRB0005240
(HREC1)·IRB0005239 (HREC2)

The Health Research Ethics Committee (HREC) complies with the SA National Health Act No. 61 of 2003 as it pertains to health research. The HREC abides by the ethical norms and principles for research, established by the World Medical Association (2013). Declaration of Helsinki:

Ethical Principles for Medical Research Involving Human Subjects; the South African Department of Health (2006). Guidelines for Good Practice in the Conduct of Clinical Trials with Human Worker in South Africa (2nd edition); as well as the Department of Health (2015). Ethics in Health Research: Principles, Processes and Structures (2nd edition).

The Health Research Ethics Committee reviews research involving human subjects conducted or supported by the Department of Health and
Human Services, or other federal departments or agencies that apply the Federal Policy for the Protection of Human Subjects to such research
(United States Code of Federal Regulations Title 45 Part 46); and/or clinical investigations regulated by the Food and Drug Administration (FDA) of the Department of Health and Human.

9.2. Addendum B: Consent Form in English and IsiZulu

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

STELLENBOSCH UNIVERSITY

CONSENT TO PARTICIPATE IN RESEARCH

Dear Worker

You are invited to take part in a study conducted by Zimbili Sibiya from the Department of Forest and Wood Science at Stellenbosch University. You were approached as a possible participant because you meet the requirements for the Worker needed for this study; you are declared fit to work by the company's Occupational Health Officer and are experienced in both motor-manual and manual pruning operations.

1. PURPOSE OF THE STUDY

To assess and compare the potential risks that the manual and motor-manual pruning may have on your body. To further, mitigate the potential risks to ensure a safe and healthy work environment for the worker.

2. WHAT WILL BE ASKED OF ME?

As you are here, it means that you have been declared fit to work by the company's Occupational Health Officer. If you agree to take part in this study, you will be asked to wear a heart rate monitor so we can examine the workload based on your heart rate readings throughout the study as you do your work. Before the study starts, you will be asked to complete a survey in which you rate which parts of your body feel certain discomforts using the Body Discomfort Map which will be handed out to you. This will be repeated four times per shift; i.e., before the shift, before the mid-morning break, after the mid-morning break and at the end of the shift. You will also be requested to get on a scale so we can record you mass, will measure your height and ask for your age.

While working you will be exposed to a time study. We will remain at a certain distance as required by the company risk policy (20 m away from the operator). The purpose of the time study is to record the duration of specific elements within the pruning activity cycle the outcome of which will be used to determine productivity of the operation. . This will not affect your work profile and you will be referred to as worker A, B, C and D only. Therefore, you should not be concerned about your work profile being negatively affected.

The participation period will be approximately eight days. The period may change depending on weather conditions and your availability. You will be required to wear a heart rate monitor for the entire shift; in this case about eight hours in duration. In order to adhere to the statistical design of the research you will be required to execute both manual and motor-manual pruning to 2 m and 3.5 m using the two different types of equipment. The heart rate data and monitors will be collected every day after the shift and will be handed out to you every morning before the start of shift. The study will be done at the two compartments scheduled for pruning according to the company (Mondi) silviculture APO.

3. POSSIBLE RISKS AND DISCOMFORTS

Risks that may come with this study would be discomfort and insecurities and you may be tempted to exceed your potential capacity **because you will know that you are watched and may want to impress**. This may include not declaring some or all of the discomfort being experienced. Therefore, please be advised that the success of the study depends on your honesty. If there are reasons to feel uncomfortable about the study, you may withdraw from it without being required to explain yourself.

Work-related injuries may also happen and therefore, as usual, the supervisors will brief you through a safety talk at commencement of the study in the morning of each day of the study. If injuries occur these will be treated appropriately.

4. POSSIBLE BENEFITS TO WORKER AND/OR TO THE SOCIETY

This study will benefit future workers as ways to improve the use and operation of equipment and by limiting potential ergonomic risks the different equipment and tasks may have on the person. It will further provide suitable information to machine/equipment designers to ensure that the equipment has minimal risks to the worker.

5. PAYMENT FOR PARTICIPATION

The participant will not receive any extra payment for their participation. The study will take place during normal working hours and days and no additional time will be expected of the Worker.

6. PROTECTION OF YOUR INFORMATION, CONFIDENTIALITY AND IDENTITY

Any information you share with me during this study and that could possibly identify you, as a participant will be protected. This will be done by not identifying you by name or the company/ contractor you work for. You will be randomly assigned an ID as worker A, B, C and D. The data collected will not be personalised, but rather referred to for e.g. as “worker A’s height”.
The data will be stored on my personal computer and a memory stick for back-up. The Mondi Operations Manager will have access to the data that will be collected for the purpose of improving the work space and experience for you as an individual. It will further assist in the planning of future manual and **motor-manual pruning operations**. The company’s name will not be mentioned in the final research report and therefore, there will not be any traces of the data that can be linked to you.

The activities will be video recorded during the study for purposes of validating time study data collection. The videotape will not be distributed or shared with the company to ensure that the confidentiality of your identity is maintained. It will be solely used by me as the principle researcher to double-check the quality of the time study. As soon as the research has been published, the videotape will be erased. This may take up to 18 months.

7. PARTICIPATION AND WITHDRAWAL

You may choose whether to participate in this study. If you agree to participate in this studyand you may withdraw at any time without any consequence. You may also refuse to answer any questions posed to you and still remain part of the study. The researcher may withdraw you from this study if you are injured and are unable to positively contribute to the study. If, according to the company's policies and practices, you are deemed unfit to continue working for ethical reasons, you may be withdrawn from the study.

8. RESEARCHERS' CONTACT INFORMATION

If you have any questions or concerns about this study, please feel free to contact Zimbili Sibiya at 072 430 7087 and/or my supervisor Pierre Ackerman at packer@sun.ac.za.

9. RIGHTS OF RESEARCH WORKER

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

DECLARATION OF CONSENT BY THE PARTICIPANT

As the participant I confirm that:

- I have read the above information and it is written in a language that I am comfortable with.
- I have had a chance to ask questions and all my questions have been answered.
- All issues related to privacy and the confidentiality and use of the information I provide, have been explained.

By signing below, I ________________________________ *(name of participant)* agree to take part in this research study, as conducted by Zimbili Sibiya.

____ _______________________

Signature of Participant **Date**

DECLARATION BY THE PRINCIPAL INVESTIGATOR

As the **principal investigator,** I hereby declare that the information contained in this document has been thoroughly explained to the participant. I also declare that the participant has been encouraged (and has been given ample time) to ask any questions. In addition, I would like to select the following option:

	The conversation with the participant was conducted in a language in which the participant is fluent.
	The conversation with the participant was conducted with the assistance of a translator (who has signed a non-disclosure agreement) and this "Consent Form" is available to the participant in a language in which the participant is fluent.

____________________________________ _____________________

Signature of Principal Investigator **Date**

ISIVUMELWANO SOKUZIBANDA KANYE NOCWANINGO OLWENZIWA YINYUVESI YASE STELLENBOSCH

Msebenzi

Uyamenywa ukuba usebenzisane noZimbili Sibiya owase nyuvesi yase Stellenbosch phansi komnyango wezemfundo zamahlathi kulocwaningo azobe alenza. Umenywa ngoba uzifezile zonke izidingo zokumelana nalocwaningo njengoku qhashwa ngokusemthethweni wale nkampani nolwazi olwanele nolu phusile lwalomsebenzi wokuhlelembiswa kwezihlahla ngezandla nangemishini.

1. INHLOSO YALOCWANINGO

Inhloso yalocwaningo ukuhlola nokuqathanisa ubungozi obungenzwa yilohlelo lokusebenza ngokomzimba yomsebenzi. Ukubheka noku sungula ezinye izindlela zokuqinisekisa ukuphepha komsebenzi, kulohlelo lomsebenzi.

2. IMIBUZO ENGALINDELWA UMSEBENZI KULOCWANINGO:

Njengoba usebenzela kule kampani kusho ukuthi unamandla anele futhi anele ngokwempilo ngakhoke uzocelwa ukuba ugqoke lomshini ozosho ukuthi umzimba wakho uthwele kanzima kangakanani yilomsebenzi obhekene nawo kulesikhathi esibekiwe socwaningo.

Ngaphambi kokuba siqale ngocwaningo uzogcwalisa elinye ifomu lapho kuzosho wena ukuthi ngokusebenzisa umshini ukuthi yikuphi la ozizwa khona ungasemnandi khona emzimbeni. Lokhu kuzokwenziwa izikhathi ezine nge-shift yakho; ngaphambi kokuqala umsebenzi, ngaphambi kwekhefu nasemuva kwekhefi nangaphambi kokuba ushayise. Uzophinde ungene esikalini sibone isisindo sakho nobude bakho sizocela neminyaka yobudala bakho.

Ngalesikhathi usebenza uzozisebenzela nje wedwa sibe kudenyana nawe. Sizobe sithatha isikathi ukuze sibone ukuthi ukwenza eminye imisebenzi kuthatha isikhathi esingakanani ukukhipha umqhizo odingekayo kulohlelo lokuhlelembisa izihlahla. Lokhu kungakwethusi ungashintshi indlela osebenza ngayo; akuzukuba nomthelela emsebenzini wakho.

Locwaningo lungathatha izinsuku ezingu-8 uma kungaphazamisanga isimo sezulu nokungatholakali kwakho emsebenzini kuzomele ugqoke lezinsiza kucwaningo kuwowonke lamahora okusebenza awu-8. Ukuze kuhambelane nezimfundo zocwaningo kuzomele umsebenzi asebenzise zozimbili lezindlela zokuhlelembisa izihlahla okuyimshini nezandla uku hlelemba ubude besihlahla esingaba u-2m no-3.5m.

Lensizwa kucwaninga zizothathwa makushayiswa emsebenzini ntambama ziphendwe zinikezwe uma kuqalwa umsebenzi ekuseni.

Lokhu kuzokwenza ezigcemeni ezimbili ezimiselwe ukuhlehlembiswa ngokwe Mondi Silviculture APO.

3. UBUNGOZI OBUNGALINDELWA KULOLU CWANINGO

Kungaba yikungakhululeki nokuzosiola okungabanga ukuthi usebenza kakhudlwana ngaphansi kwesimo socwaningo. Kungenzeka futhi ukuthi ungakusho bonke ubunzima nobuhlungu obuzwayo emzimbeni. Uyacelwa ukuba wethembeke ngokuthi unikeze iqiniso ukuze locwaningo lube impumelelo.
Uma kungakuphathi kahle lokhu ungadedelwa kulo cwaningo, nokulimala kungenzeka njengoba kuhlala kwenzeka makusetshenzwa, kodwa nizokhunjuzwa njalo ekuseni ngezokuphepha emsebenzini. Uma kwenzeka ulimala kuzolandelwa inqubo nomgomo ofanele.

4. UNGASIZAKALA NGANI WENA NOMPHAKATHI NGOKUBA YINXENYE YALOCWANINGO?

Locwaningo lungenza ncono izimo zokusebenza, njengokukhuphula izinga lwezokuphepha imishini engasebenzi kancono kunalena ukukhiqiza imikhiqizo encono ngokuphephile.

5. INKOKHELO YALOCWANINGO

Akuzukuba nankokhelo kuzokwenziwa ngesikhathi somsebenzi

6. UKUVIKELEKA KOLWAZI NGAWE

Konke ozongitshela kona kuzoba yimfihlo.Lokho kuzoqinisekiswa ngokuthi awuzukulisho igama lakho, inkampani oyisebenzelayo noma iNkontraki oyisebenzelayo, nizobiza ngo A,B,C no – D lonke ulwazi olutholakalayo kuzothiwa ngoluka A noma u – B noma u – C njalonjalo. Lolwazi luzogcinwa ku computer yami ngedwa imenenja yeMondi inemvumo yokuthola lolwazi ukuze ithuthukise izimo zokusebenza enkamoanini nolwazi lwakho njengomsebenzi nezinto angazilungisa ngokuzayo emsebenzini. Igama lekampani alizukuvela uma sekuthulwa umbiko ophelele wocwaningo ngakho negama lomuntu aluzukevla.

Izithombe ze video zizothathwa ngenxa yesikhathi esizoba sincane ukubhala okjwenzakalayo kodwa zona aziyi ngisho kune menenja ngezokusiza mina okumele ngibhale nje konke okwenzakalayo uma sengiqedile zizocishwa lezo zithombe loko kungathatha unyaka nezinyangana eziwu – 6 ukuqeda ucwaningo.

7. UKUBAYINGXENYE YOCWANINGO WOKUPHUMA KULO.

Uyazikhethela ukungena kulocwaningo awuphoqiwe. Uma sewungenile awuboshiwe ungaphuma futhi awunakujeziswa. Nokuphendula imibuzo futhi obuzwa yona unyala nje ukunikeza izimpendulo kodwa uphinde uqhubeke nje nokuba inxenye yocwaningo. Ungakhishwa kulocwaningo ngenxa yokulimala nomake kungekho ukusebenzisa kahle noma ke ngokwemigomo nezimiso zenkampani utholakala songekho esimeni sokusebenza

8. NGITHOLAKALA KUPHI

Uma kukhona ofuna ukukwazi kabanzi ngalocwaningo ungaxhumana no Zimbili Sibiya Ku 072 430 7087 kanye nomphathi wami Pierre Ackerman ku packer@sun.ac.za

9. AMALUNGELO AKHO

Ungaphuma kulocwaningo noma yinini awuna kujeziswa aluxhumene nanoma yimuphi umthetho, uma ufuna ukuqinisekisa ngamalungelo ungaxhumana no Ms Malene Fouche [mfouche@sun.sc.za; 021 808 4622] Research Development.

UKUSAYINWA KWESIVUMELWANO SOMSEBENZI OYINXENYE YOCWANINGO

Njengomunye ozoba yinxenye yalo cwaningo ngiyaqinisekisa ukuthi:

- Ngifundela konke okushiwo ngenhwli kubhalwe ngolwimi engiliqondayo.
- Nginikeziwe futhi nethuba lokubuza imibuzo langingezwa khona ngaphenduleka kahle.
- Konke okumayelana nokugcinwa kwemininingwane yami ibe yimfihlo kuchaziwe kahle.

Ngokusayina kwami langaphansi ________________________________ *(igama)* ngiyavuma ukuba yinxenye yalocwaningo olwenziwa uZumbili Sibiya.

____ ______________________

Isiginesha yomsebenzi **Usuku**

UKUSAYINWA KWESIVUMELWANO SOCWANINGO YILO OLWENGAMELE

Njengongamele lokucwaningo ngiyaqinisekisa ukuthi konke okubhalwe ngenhla kuchazwe ngokuphelele kubasebenzi abazoba yinxenye yalocwaningo.
Ngiyaqinisekisa futhi ukuthi banikeziwe isikhathi nethuba lokubuza imibuzo ukwengeza kulokwe ngize ngakhetha ukusebenzaisa lendlela elandelayo:

	Ingxoxo yenziwe ngolimi umsebenzi alu qondayo kahle-hle nokuyilwimi lwakhe.
	Ingxoxo nomsebenzi umhumushi ozibophezele ngokuthi ngeke adalule ulwazi nemininingwane yabasebenzi nokuthi lesivumelwano senziwe ngolimi umsebenzi alunqondayo nalukhulumayo.

____ ______________________

Isiginesha yonyamelo ucwaningo **Usuku**

9.3. Addendum C: Body Discomfort Rating Sheet

Research Questionnaire:
Ergonomic Assessment for manual and motor-manual pruning

Dear Worker

The purpose of the study is to understand the effects of the use of the two different equipment has on you. Therefore, to understand or have an idea on this, it is required that each of you rate the body parts according to the rating scale.

Please refer to the figure on the next page (Body Discomfort Map). The map shows the representation of a male body. Each of the body part is numbered from 1 to 27.
It is a representation of the different body parts of the body that is most likely to be affected by the activities the worker is doing. The questionnaire will be filled in on 4 occasions (before shift, before tea break, after break and at end of shift) every day during the study.

Instruction:
Please rate each body part according to the rating scale of 0-4 indicating the discomfort you may be feeling at the time you are taking the questionnaire. It is kindly requested that you be as honest as possible for the purpose of the study.

Body Part number	Rating Score				
	0	1	2	3	4
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					

Score	Discomfort Intensity
0	No Discomfort
1	Mild
2	Moderate
3	Severe
4	Unbearable Discomfort

Imibuzo yocwaningo:

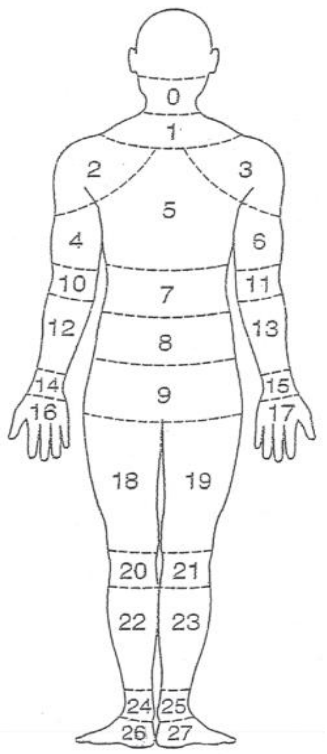
Msebenzi

Isizathu salolu cwaningo ukuthola ukuthi lemishini ehlukile oyisebenzisayo ukwenza lomsebenzi ikuphatha kanjani emzimbeni. Ngakho ke, ukuze sikwazi lokho, kuzodingeka ukuthi usebenzise isikali sokusho ukuthi ngabe ukungakhululeki kahle emzimbeni ukuzwa kuphi.
Ngcela ubheke lesthombe esinezinombolo kulekhasi elilandelayo. Lesthombe sikhombisa umzimba womuntu, zonke lezinombolo ziveza ilunga elithile lomzimba elingathinteka uma wenza lomsebenzi.
Lemibuzo kuzomele uyigcwalise kane (ngaphambi kokuqala kweshifti, ngaphambi kokuphumula kwetiye, nasekupheleni kweshift).
Uyacelwa ukuthi usebenzise lesikali esiqala ku 0-4 ukuveza ubungakhululeki nobuhlungu obuzwayo uma ngesikhathi ozobe uphendula ngaso. Kubaluleke kakhulu ukuba ukhulume iqiniso ukuze locwaningo lube impumelelo ethembekayo.

Isikali	**Ubungakhululeki**
0	Ngikjululekile angizwa lutho
1	Kancane
2	Kakhudlwana
3	Kakhulu
4	Akubekezeleki

Inombolo yelunga lomzimba	Isikali				
	0	1	2	3	4
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					

Isikali	Ukungakhululeki
0	Ngikjululekile angizwa lutho
1	Kancane
2	Kakhudlwana
3	Kakhulu
4	Akubekezeleki



Siyabonga ukugcwalisa lelifomu. Siyakuthokozela ukusebenzisana nawe.