An ergonomics intervention study into the physiological, perceptual and productivity effects of three citrus harvesting bag designs in the Eastern Cape of South Africa- a combined laboratory and field approach

BY

ELIZABETH MISAN BASSEY-DUKE

THESIS

Submitted in fulfilment of the requirement for the degree of Master of Science

Department of Human Kinetics and Ergonomics

Rhodes University, 2015

Grahamstown, South Africa

ABSTRACT

Background: Agriculture plays a vital role in the economy of any industrially developing country, including South Africa. In the Eastern Cape of South Africa citrus farming is a significant contributor to the local economy (Johnson *et al.,* 2005). The harvesting phase of citrus farming is performed manually and exposes workers to physical risks, which can lead to the development of musculoskeletal disorders. In particular, the standard harvesting bag comprises of a single shoulder strap and promotes asymmetrical load carriage which results in shoulder and lower back pain complaints. The current study compared the physiological (EMG), perceptual (RPE), usability (PUEU) and productivity effects of two new harvesting bag designs (a hip belt and a backpack bag design) to the standard harvesting bag design. This was performed in a laboratory as well as a field setting.

Methods (Laboratory phase): 36 participants (12 males and 24 females) were assigned to one worker group. The “tall ladder worker” group was comprised of only males and the “step ladder worker” and “ground worker” group of females. Each participant was required to simulate a citrus harvesting task while utilizing each of the bag designs on different days. On each day/test session, participants performed three harvesting cycles. Muscle activity was measured throughout the entire testing session and RPE were recorded at the end of each cycle.

Results (Laboratory phase): The EMG and RPE results indicate that the backpack design was the most ideal design to reduce asymmetry, while the standard harvesting bag design was the worst. Although not significant, there was greater muscle asymmetry (p=0.109) and a significantly higher perceived exertion when using the standard bag (p=0.0004), in comparison to using the backpack.

Methods (Field phase): 17 Xhosa-speaking citrus harvesters (6 females and 11 males) participated in this study. Each harvester worked with one of the three bag designs on a different day. Productivity of each worker was assessed every hour by recording the number of bags filled with fruit and at the end of the shift. A Perceived Usefulness & Ease of Use questionnaire was presented to each participant to obtain feedback on worker acceptance to the new bag designs.

Results (Field phase): A general trend in support of the hip belt bag design over the other two bag designs were found, even within the different worker demographic groups (age, sex and worker experience). The workers perceived less exertion (7.98 ± 1.86) and were more productive (9.90 ± 2.11 bags/hour) when using the hip belt design; they also found this bag the most useful (1.02 ± 0.09) and easy to use (1.07 ± 0.25). In contrast, the backpack bag design had significantly poorer responses when compared to the other two bag designs and this was evident in all the dependent variables assessed (RPE, productivity and PUEU).

Conclusion: The results from the laboratory phase supported the expectation that the backpack bag design reduces asymmetry and hence, is more suitable than the standard harvesting bag. However, results from the field show that the hip belt bag design was the most preferred and the backpack was the least preferred. Bao & Shahnavaz (1989) highlight the need for ergonomics researcher to convey laboratory findings into the field context. However, as shown by the current study, there are numerous challenges associated with field work, making it difficult for laboratory findings to be successfully conveyed to the field.

Limitations and Recommendations: For the laboratory phase of the project, no biomechanical and cardiovascular responses were assessed. However, for a holistic approach, these variables should be considered in future studies. Due to high variability from one harvesting cycle to another, more than three harvesting cycles should also be performed to accurately replicate the harvesting process as done in the field over extended durations of time.

For the field phase, data should be collected from more than one citrus farm and thus a larger sample size could be obtained. This would improve the validity of the study. In addition to this, data should be collected for a full working day, especially if environmental conditions are not a hindrance, as well as for a whole season, since workloads vary, depending on the time of the harvesting season.

ACKNOWLEDGEMENTS

I would like to thank God for seeing me through this journey. It has been by His grace.

For their endless support and encouragement, a million thanks to my family, partner and friends. Thanks to my dad for the financial assistance, I couldn’t have done this without you.

I would like to also give a massive thanks to my supervisor of 3 years, Miriam Mattison, for her guidance, trust, encouragement and support. Thank you for having faith in me and giving me the courage to keep pushing forward. You have been exceptionally instrumental to my academic growth.

I am also thankful to my co-supervisor Swantje Zschernack for her immense support, to Tyrone Douglas, for building the best simulated citrus trees, to my participants, who gave up time to participate in my study and finally, to the entire HKE family (past and present) for their support, genuine interest and appreciation of this project.

TABLE OF CONTENTS

ABSTRACT i

ACKNOWLEDGEMENTS iii

LIST OF TABLES vii

LIST OF FIGURES viii

CHAPTER 1: INTRODUCTION 1

1.1 Background to the Study 1

1.2 Statement of the Problem 3

1.3 Research Question 4

1.4 Scope of the Study 4

1.5 Project Structure 5

CHAPTER 2: REVIEW OF LITERATURE 6

2.1 The State of Agriculture in Industrially Developing Countries with Specific Reference to the Eastern Cape Region of South Africa 6

2.2 Industrially Developing Countries and the Negative Spiral 8

2.3 Citrus Harvesting 9

2.4 Harvesting Bag Design and Load Carriage 10

2.5 Ergonomics Interventions 14

CHAPTER 3: PRELIMINARY INVESTIGATION AND TASK ANALYSIS 17

3.1. Introduction 17

3.2. Methodology 18

3.3. Results and Discussion 18

3.4. Bag Re-design 26

3.5. Conclusion 30

CHAPTER 4: LABORATORY STUDY 31

4.1 Introduction 31

4.2. Methodology 31

4.3. Results ... 45
4.4 Discussion ... 60
4.5 Conclusion, Limitations and Recommendations ... 63
CHAPTER 5: FIELD STUDY ... 65
5.1. Introduction ... 65
5.2 Methodology ... 65
5.3 Results ... 72
5.4 Discussion ... 82
5.5 Conclusion, Limitations and Recommendations ... 85
CHAPTER 6: INTEGRATED DISCUSSION & CONCLUSION ... 86
6.1 Integrated Discussion ... 86
6.2 Integrated Conclusion Limitations and Recommendations ... 89
CHAPTER 7: REFERENCES ... 91
APPENDICES FOR PHASE 1 ... 99
Appendix A: Product Design Specification (PDS) , Procedure and Product Alternatives. ... 100
Appendix B: Letter of Information to Participants ... 101
Appendix C: Informed Consent Form ... 106
Appendix D: Borg's RPE SCALE (English Version) ... 108
Appendix E: Randomization Order ... 109
Appendix F: Data Collection Sheet ... 110
Appendix G: Statistica Analyses ... 111
APPENDICES FOR PHASE 2 ... 129
Appendix H: Letter of Information to Participants (Xhosa Version) ... 130
Appendix I: Informed Consent Form (Xhosa version) ... 136
Appendix J: Letter of Information to Farm Owner ... 138
Appendix K: Informed Consent for Farm Owner ... 141

Appendix L: Borg's RPE SCALE (Xhosa Version) 142

Appendix M: Perceived Usefulness and Ease of Use (Xhosa & English) 143

Appendix N: Data Collection Sheet.. 144

Appendix O: Randomization Order 145

LIST OF TABLES

Table I: Subtasks performed by each worker group 25

Table II: Test conditions for the laboratory phase of the project................................ 32

Table III: Descriptive stats for participant demographics (means ± standard deviations; CV=coefficient of variation presented as a percentage)......................... 46

Table IV: Descriptive statistics (means ± standard deviation; CV=coefficient of variation presented in %) comparing left and right sides muscle groups (where LT= left trapezius, RT= right trapezius, LAD= left anterior deltoid, RAD= right anterior deltoid, LES=left erector spinae and RES= right erector spinae). 47

Table V: Descriptive statistics comparing left and right sides muscle groups (means ± standard deviation; CV=coefficient of variation (%). 49

Table VI: Descriptive statistics comparing left and right sides muscle groups (means ± standard deviation; CV=coefficient of variation (%) 51

Table VII: Descriptive statistics (means ± standard deviation; CV=coefficient of variation (%) 54

Table VIII: Descriptive statistics (means ± standard deviation; CV=coefficient of variation (%) 56

Table IX: Descriptive stats means ± standard deviation; CV=coefficient of variation (%)... 58

Table X: Summary data for worker demographic group (means with standard deviations; CV = coefficient of variation) 70

Table XI: Descriptive statistics for variable responses (means ± standard deviations; CV=coefficient of variation presented as a percentage)... 72

LIST OF FIGURES

Figure 1: The economic cycle of diseases (taken from O'Neill, 2000. pp 634) 8
Figure 2: The standard citrus harvesting bag 12
Figure 3: Ground worker harvesting fruit 20
Figure 4: Stepladder workers harvesting fruit 21
Figure 5: Tall ladder worker harvesting fruit 22
Figure 6: Standard harvesting bag design- bag with a single strap carried unilaterally 27
Figure 7: Hip belt bag design-the standard bag design with the addition of a hip belt 28
Figure 8: Anterior (a) and lateral (b) view of the backpack bag design 30
Figure 9: Schematic diagram of laboratory set up, showing three harvesting stations (representing citrus trees) and the collection bin 33
Figure 10: Electrodes placed on different muscle groups: A) left and right erector spinae, B) left and right trapezius and anterior deltoids. 38
Figure 11: Ground workers asymmetry ratio (right: left sides) for the different muscle groups and the different bag designs. 48
Figure 12: Stepladder workers asymmetry ratio for the different muscle groups and the different bag designs. 50
Figure 13: Tall ladder workers asymmetry ratio for the different muscle groups and the different bag designs. 52
Figure 14: Mean shoulder RPE responses to different bag designs for the ground workers. 54
Figure 15: Mean lower back RPE response to different bag designs. 55
Figure 16: Mean shoulder RPE response to different bag designs for the stepladder workers. 56
Figure 17: Mean lower back RPE response to different bag designs. 57
Figure 18: Mean shoulder RPE response to different bag designs for the tall ladder workers. 58
Figure 19: Mean lower back RPE response to different bag designs. 59
Figure 20: Mean shoulder RPE for all worker groups using the three different bag designs 73

Figure 21: Mean RPE score (lower back) for each individual worker group when using the different bag designs... 74
Figure 22: Worker productivity for all worker groups combined when using the three different bag designs. 75
Figure 23: Mean productivity for each individual worker group when using the different bag designs 76
Figure 24: Mean rating of perceived usefulness of the bag designs for all worker groups, (where 1=extremely useful, 2=slightly useful, 3= neutral 4=slightly un-useful and 5=extremely un-useful)... 78
Figure 25: Mean usefulness rating for each individual worker group using the different bag designs (where 1=extremely useful, 2=slightly useful, 3= neutral 4=slightly un-useful and 5=extremely un-useful) 79
Figure 26: Mean ratings for perceived ease of use for all worker groups, where 1=extremely easy to use, 2=slightly easy to use, 3= neutral, 4=slightly un-easy to use and 5=extremely un-easy to use. 80
Figure 27: Mean rating of ease of use for each individual worker group using the different bag designs (where 1=extremely useful, 2=slightly useful, 3= neutral 4=slightly un-useful and 5=extremely un-useful). 81

CHAPTER 1: INTRODUCTION

1.1 Background to the Study

Agriculture remains the foundation for economic growth in most developing economies (Myers, 1998; Davis, 2007), and thus the developing South African economy needs to ensure a healthy agricultural industry in order to boost the country's GDP, food security, social welfare, job creation and ecotourism (Department of Agriculture, Forestry and Fisheries - DAFF, 2011). Agriculture plays a vital role in the lives and well-being of citizens in any region as they depend on the varying farming sectors for food, income and employment (Eastern Cape Development Corporation - ECDC, 2012). It has been estimated by Statistics SA (2012) that about 638,000 workers are formally employed in the agricultural sector, but numbers of casual/informal employment are unknown. It was also estimated that around 8.5 million people are directly or indirectly dependent on the agricultural sector for employment and income (Statistics SA, 2012).

Food production through agriculture is essential for any developing country. South Africa's population is growing at almost 2% per year, which, according to Statistics SA (2009), is expected to result in a population increase from 49 million in 2009 to 82 million by the year 2035. For this reason, food production through agriculture or imports must more than double to feed the expanding population and production needs to increase using the same or fewer natural resources (Statistics SA, 2009).

Like in other industries, most, if not all, labour intensive agricultural activities pose a serious health risk to the workers involved (Davis, 2007). These workers are exposed to risk factors such as the physical nature of the work (which can lead to the development of musculoskeletal disorders), exposure to extreme environmental conditions, noise and vibration, poorly designed equipment or the lack of any equipment, contact with animals and/or exposure to hazardous chemicals, all of which pose threats to their health and well-being (Cowie *et al.,* 2005). Several studies have shown that labour intensive/manual agriculture has one of the worst fatal accident records of any industry and, though not usually reported in most countries, workers are also exposed to non-fatal accidents such as falls from ladders (Myers, 1998; McCurdy & Carroll, 2000; Schuman, 2008). For agricultural workers, injury caused from years of hard physical work, as well as the use of poorly designed equipment and tools remains a contributor to mortality and morbidity (Myers, 1998; McCurdy & Carroll, 2000; Cowie *et al.,* 2005). In regions such as the Eastern Cape of South Africa, where there are numerous labour intensive agricultural sectors, it is anticipated that a wide range of physical risks, and thus musculoskeletal injuries, are present, and therefore the application of ergonomics to alleviate or reduce these disorders is necessary (ECDC, 2012).

South Africa has a dual agricultural economy, with both large scale commercial farming and small scale subsistence farming, mostly in the deep rural areas of the country (Myers, 1998). In the Eastern Cape, for example, livestock farming, deciduous fruits (citrus, apples, pineapples etc.), wool/mohair, leather, crop/vegetable farming, dairy farming and chicory farming, are the most common agricultural sectors (ECDC, 2012). Although these sectors are essential for development in this region of South Africa, the methods, systems and/or practices associated with them, continue to be a major obstacle affecting the growth and prosperity of the agricultural industry in South Africa (DAFF, 2011).

South Africa is the third largest world trader in citrus farming, exporting over one million tonnes internationally, with Europe being its main export market (Philips, 2006). For this reason, citrus farming in South Africa remains essential for development and growth of the country. However, in the Eastern Cape region of South Africa, one of the poorest provinces in South Africa, there are several obstacles that are said to restrict the growth and development of this farming sector. These include a piece-rate pay scale that allows for a fast and potentially risky work pace, a working system that does not motivate sound relationships between the employer and worker, language and literacy issues which lead to a downfall in communication and for safety training, and varying cultural backgrounds/barriers that make it difficult for workers to accept new interventions (Philips, 2006 & Monaghan *et al.,* 2011). Like with other crops, citrus farming generally includes four phases: land preparation, planting, maintenance and harvesting (Jutras & Coppock, 1958). Due to the almost non-existent mechanization involved in the citrus industry in developing countries like South Africa, these phases of farming are performed manually, leading to an increased worker exposure to certain risk factors. Although all phases are equally important for ergonomics consideration, only the harvesting phase was investigated in this study. The harvesting season for citrus fruits in the Eastern Cape of South Africa occurs between April and August yearly. Citrus harvesters are required to detach the citrus fruits from the trees using a pair of harvesting clippers (secateurs) and placing the fruit into a harvesting bag. The design of these harvesting bags is similar to the bags used in other types of fruit farming such as apples and pears (Earle-Richardson *et al.,* 2004.The main problem with the design of these harvesting bags is the asymmetrical means of load carriage that the workers are forced to adopt while harvesting the fruit. This load carriage method not only impacts on the workers' balance and stability (Pascoe, 2010), it also negatively impacts on the musculoskeletal system (Earle-Richardson *et al*. 2005; Monaghan *et al.,* 2011). Earle-Richardson *et al*. (2004 & 2006) also suggest that worker productivity rate/ job performance is affected as a result of the fatiguing effects these asymmetrical harvesting bags have on the body. For these reasons, the current study was an intervention project during which the standard harvesting bag was redesigned to reduce the impact of asymmetrical load carriage on the musculoskeletal system, and improve worker productivity.

1.2 Statement of the Problem

The design of the standard harvesting bag used in the citrus industry poses serious risk for the development of musculoskeletal disorders as a result of the asymmetrical load carriage method utilized. Research by numerous researchers including Uyttendaele & Dangerfield (2006), Earle-Richardson *et al*. (2004) and Corrigan & Xian Liu (2012) indicate that asymmetrical load carriage has a significant negative impact on the musculoskeletal system. Increased muscular activity, contact stress (Pascoe, 2010), energy expenditure (Earle-Richardson, 2004 & 2006) and static loading (Corrigan & Xian Liu, 2012) are all factors associated with asymmetrical load carriage and could potentially lead to injury. Monaghan *et al.* (2011) suggested that the harvesting bags used, especially in countries where fruit harvesting is not automated, may be the biggest problem in citrus harvesting as they promote asymmetrical load carriage and potentially reduce productivity/performance rate.

1.3 Research Question

Due to the risks imposed on workers by the current citrus harvesting bag design and the workers' high reliance on the citrus industry for an income, these bags need to be modified to ensure the load is evenly distributed around the body (Earle-Richardson, 2004; Monaghan *et al.,* 2011) and the asymmetrical load carriage component is significantly reduced to decrease the risk of injury (Uyttendaele & Dangerfield, 2006), while ideally improving worker productivity (Fathallah, 2010; Monaghan, 2011).

The purpose of this project was to redesign the current citrus harvesting bag and then investigate the effects of the new bags on a variety of variables by comparing them to the responses elicited by the harvesting bag currently used in the industry. The first phase of the study tested the effects of the new bag designs on physiological and perceptual responses within each worker groups in the laboratory, while the second phase of the project took place in the field and tested the new bag designs on worker productivity, as well as the workers' acceptance (perceived usefulness and ease of use) to the new designs.

1.4 Scope of the Study

This study focused on the harvesting process in citrus farming, the methods, equipment and procedures used. In the first phase of this study (laboratory phase) the effects of bag designs were investigated on the musculoskeletal system only. Further studies must be conducted to investigate the impact of these bag designs on cardiovascular exertion. For the field phase only one citrus farm in the Eastern Cape of South Africa was selected. Farm workers from multiple farms should be considered for future research.

1.5 Project Structure

This project is divided into three parts: a) *a* task analysis¸ b) a laboratory study (phase 1) and c) a field study (phase 2). The task analysis phase was necessary for familiarization with physical and organizational set-up, as well as the physical problems/risks that citrus farm workers are exposed to as a result of the work they perform. This task analysis phase was performed through a site visit by the researcher to a citrus farm in the Eastern Cape region, where discussions and interviews with the farm workers and the farm manager were held. After the problem had been identified from the task analysis phase, it was investigated in the laboratory in order to obtain in-depth results. Since Bao & Shahnavaz (1989) highlight the importance of "conveying findings obtained in the laboratory into the field setting so as to improve the working conditions of real workers", a field phase was also performed to assess the intervention in its real setting.

CHAPTER 2: REVIEW OF LITERATURE

2.1 The State of Agriculture in Industrially Developing Countries with Specific Reference to the Eastern Cape Region of South Africa

Agriculture is regarded as one of the oldest and most essential practices (McCurdy & Carroll, 2000), since human beings have depended, and continue to depend, on it for food, income, job creation and general wellbeing (O'Neill, 2000 & Shahnavaz, 2000). Agriculture remains essential in contributing vastly to the growing economy of an industrially developing country (IDC), such as South Africa (DAFF, 2011). South Africa's political change in the 1990's built a foundation for significant changes in the nation's socioeconomic status and the agricultural sector is one of the many areas in which this socioeconomic difference is seen (Nel & Davies, 1999). Agricultural production in South Africa constitutes just over 15% of the country's gross domestic product (GDP), down from the 20% seen in the 1930s (DAFF, 2011). Hence, it is essential that productivity in the agricultural sector must be enhanced to cater for the growing South African population. To boost agricultural activity for farmers in different socioeconomic groups, Nel & Davies (1999) suggested that 3 areas must be addressed; *1)* farmers' access to land, *2)* the provision of adequate infrastructure and *3)* financial support. However, in addition to these O'Neill (2005) and Fathallah (2010) highlighted that if the general aim is to boost agricultural activity, ergonomics interventions/awareness would also have to be implemented and be given more attention by all farmers, regardless of their socioeconomic background.

The dynamics of agriculture in South Africa are associated with more negative than positive results. This is as a result of environmental conditions (such as shifts in rainfall patterns, droughts etc.) leading to infertile soils for planting, governmental policies influencing agricultural workers' pay, poor ergonomics awareness resulting in increased rates of injury and disability amongst agricultural workers, but to mention a few (O'Neill, 2000 & 2005). The government, farmers, farmworkers, agricultural organizations, researchers and even the entire South African population can all play a vital role in shaping the agricultural sector of the country by providing management systems for the harsh and unpredictable South African weather, by including more labour laws that protect agricultural workers and by educating these workers as well as farm owners on the importance of ergonomics and its relevance in their field of work (Spedding, 1996; O’Neill, 2005).

Three types of agriculture exist in South Africa and in other IDCs, namely plantations, commercial agriculture and small holder crop/livestock farming (O’Neill, 2000). In the Eastern Cape of South Africa, small scale farming is the most dominant of these three types of agriculture, with an abundance of small scale livestock farming and crop farming (including fruits and vegetables) occurring. Crop farming and production generally includes operations such as land preparation, planting of crop, maintenance, and harvesting (Rogan and O'Neill, 1993). In IDC’s there is little or no existence of mechanization, hence these operations must be performed manually (O’Neill, 2000). Accidents, injuries and/or the risk of developing musculoskeletal disorders are serious considerations in the different types of labour-intensive agriculture.

For the above reasons, the implementation of the science of ergonomics to these crop farming and production operations/practices is thus significant. Ergonomics has been applied in few industrially developing countries to design better methods and tools to improve work conditions and productivity (Bao *et al.*, 2013). The application of ergonomics in countries such as South Africa, Brazil and Thailand has introduced benefits such as improved productivity, occupational health standards/knowledge, and a general increase in the quality of life to the workers that reside in these countries (Jeyeratnam, 1992; Spedding, 1996; Scott, 2008). There is a wide range of opportunities for ergonomics to play a vital role in improving wellbeing and reducing injuries/accidents amongst workers in IDCs, especially through the use of participatory ergonomics. However, the assistance of ergonomists in IACs as well as the International Labour Organization (ILO) is needed to actively contribute to the awareness, implementation and application of participatory ergonomics in IDCs (Wisner, 1985; Shahnavaz, 1996; O’Neill, 2005).

2.2 Industrially Developing Countries and the Negative Spiral

The “economic cycle of disease” put forward by O’Neill (2000 & 2005) in Figure 1 is another reason for the negative results such as poor productivity/performance rate, high rates of injury/accidents/musculoskeletal disorders, poor worker capacity high rate of absenteeism etc. in the agricultural sector of most IDCs. This cycle of disease applies to the agricultural sector of South Africa and refers to workers receiving low income and therefore living impoverished lives with inadequate food, little or no education and poor housing conditions. This in turn, negatively impacts on worker capacity, performance and productivity, which in turn reinforces the negative spiral of low productivity, low income etc. O’Neill (2000 & 2005) stated that governmental interventions to improve health, housing, feeding and educational conditions may not be sufficient for a national change but a combination of the above, with interventions to improve worker capacity and productivity through higher incomes or incentives, improved equipment, etc. will be most effective to address the economic cycle of diseases evident in IDCs.

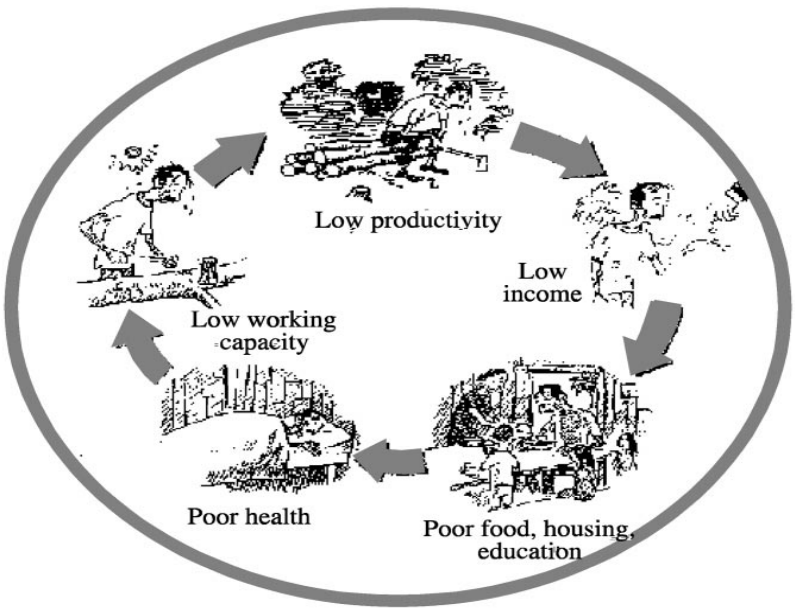


Figure 1: The economic cycle of diseases (taken from O'Neill, 2000. pp 634)

2.3 Citrus Harvesting

South Africa is the 3rd largest world trader in citrus products, exporting over 1 million tonnes to the international market (Philips, 2006). Citrus farming in the Eastern Cape region of South Africa appears to be very common and prosperous due to the climatic conditions and vast spaces. In citrus farming maintenance and harvesting are the only operations that occur after the trees have grown to maturity. The maintenance phase involves irrigation and pesticide control which, according to Monaghan *et al. (*2011), is not as tedious as the harvesting phase, due to mechanization in this phase. The harvesting phase, an integral part of citrus farming, involves separation/detachment of the fruit from the tree with secateurs / clippers and placing it into a suitable container, such as a bag, bucket, or apron (Jutras and Coppock, 1958. This manual harvesting process is a strenuous, expensive and time-consuming task (Jutras & Coppock, 1958. Harvesting citrus remains mostly a manual task, particularly in IDCs, even though the mechanization of fruit harvesting, especially those destined for fresh markets, is highly desirable in order to increase productivity, and reduce rate of injury from labour intensive work (Sarig, 1993). Mechanized farming however also has its weaknesses. Previous attempts to harvest citrus fruits, as well as other soft fruits like apples, pears and peaches by mechanical means have not been very successful (Monaghan *et al.,* 2011). These attempts have included tree shaking and separation of one fruit at a time by snapping the supporting twig or by pulling the fruit with a suction force (Coppock, 1999). Regardless of these interventions, none of them came close to emulating a human picker as there was often damage to the fruit, as well as unripe fruits being picked (Sarig, 1993). Additionally, mechanization of fruit harvesting in South Africa and other IDC's is not viable as a result of high unemployment rates and the high costs of mechanized equipment or machinery, compared to costs of minimum wages earned by citrus workers (Citrus Academy, 2006), especially since a large percentage of the population in the Eastern Cape depends on this task for income and jobs. Therefore, while some researchers are of the opinion that mechanized agriculture is the essential, others believe that until an intervention is developed and proven to be as economically efficient as the human picker, agricultural workers such as citrus farm workers will continue to be exposed to physical risk factors associated with harvesting the fruits manually with harvesting equipment (Sarig, 1993; Coppock, 1999; Monaghan, 2011).

As long as fruit harvesting is labour intensive, there is a role for ergonomics researchers to ensure that the harvesting methods/practices and tools used are safe, appropriate and do not pose a risk of accidents and/or workplace injuries. For this reason, this study investigated an intervention relating to the harvesting bags used amongst citrus farm workers in the harvesting phase. It must be noted that there are other containers, such as aprons and buckets that the citrus fruits may be harvested into. However, based on enquiries made from several citrus farms and agricultural product companies, and also based on the literature available (Sarig, 1993; Jutras & Coppock, 1958; Monaghan, 2011), it is evident that the harvesting bags are the most preferred and most commonly used container in comparison to harvesting aprons and buckets.

2.4 Harvesting Bag Design and Load Carriage

Literature by Meyers *et al*. (1997, 2000 & 2001) and Fathallah (2010) suggest three main risk factors of utmost priority in the agricultural sector; 1) lifting and carrying heavy loads, 2) awkward postures, e.g. sustained or repeated full body bending (stooping) and 3) highly repetitive hand work, e.g. cutting or clipping. Load carriage is an integral/inevitable task performed in labour-intensive agricultural activities, but it has often been associated with spinal injury, although it is not ethically possible to experiment the causal relationship between these two parameters (Grimmer & Williams, 2000). Hence, the method in which a load is carried is important to consider. Loads can be carried unilaterally, as seen amongst post mail workers, and citrus farm workers, or bilaterally, as seen in the standard school bag designs (Devita *et al.,* 1991). The varying types of load carriage strategies (back packs, front packs and side packs) all impact on muscle activity, gait cycle, posture and energy expenditure (Grimmer & Williams, 2000; Earle-Richardson *et al.*, 2004; Motmans *et al.*, 2007). However, Smith & Ashton (2006) state that the severity of these variables depends on the load carriage strategy adopted, i.e. the location of the load. Many studies have indicated that the most injury prone method of load carriage is the unilateral carrying method, which is mainly used during citrus harvesting (Devita *et* *al.,* 1991; Grimmer & Williams, 2000; Earle- Richardson *et al*., 2004; Motmans *et al.*, 2007; Pascoe *et al.,* 2010; Corrigan & Xian Liu, 2012; Quereshi & Shamus, 2012; Bao *et al.,* 2013). Research has shown that asymmetrical/unilateral load carriage for long periods of time has negative effects on the body, including musculoskeletal misalignment, musculoskeletal compensation, muscle spasms, and postural asymmetry, which in turn gives rise to asymmetric muscular activity leading to the development of MSDs, specifically lower back pain (LBP) (Grimmer & Williams, 2000; Motmans *et al.*, 2007; Pascoe *et al.,* 2010; Quereshi & Shamus, 2012). While the use of shoulder bags is not the primary cause of lower back pain, the use of these shoulder bags with additional load has been established as a significant risk factor for the development of LBP (Grimmer *et al.,* 2002). Another factor that may lead to MSD risk due to unilateral load carriage is the uneven weight distribution throughout the lower extremities (Goh *et al.,* 1998; Quereshi & Shamus, 2012). When carrying a shoulder bag, the disproportionate forces imposed on the lumbar spine are transferred disproportionately to the lower extremities (Goh *et al.,* 1998). Mechanical pressure from these bags on the shoulder, and aggravated by working in an overhead posture, are also a serious problem associated with this asymmetrical bag design and will eventually lead to anterolateral shoulder pain and, in some cases, impingement syndrome (Goh *et al.,* 1998; Corrigan & Xian Liu, 2012). However, despite the warnings of the harmful effects of this type of load carriage method, citrus harvesters are required to make use of these shoulder bags because of cost, convenience and to have a good range of motion (Qureshi & Shamus, 2012; Bao *et al*., 2013).

The standard citrus harvesting bag currently used in most citrus industries in the Eastern Cape, is designed to have a single strap that can be slung over the shoulder of the harvester as shown in Figure 2.

Figure 2: The standard citrus harvesting bag

These bags are usually made from a heavy canvas material or polyvinyl for durability purposes; however, the structure/design of the bag remains the same worldwide, in both developing and developed countries (that do not use mechanized harvesting methods), as is evident from fruit farming literature (Whitney & Coppock, 1984; Whitney & Harrell, 1989). The asymmetrical means of load carriage utilized as a result of the fruit harvesting bag design refers to unequal load being distributed across the body (Motmans *et al*., 2007). This has negative implications for the human body and possibly worker productivity and output (Spedding, 1996; O'Neill, 2000 & 2005; Scott, 2008). These authors, and others, clearly indicate in their work, the link between muscle strain, which eventually leads to the early onset of fatigue and a poor productivity rate/job performance. Hence it is essential, in the absence of mechanical means of fruit harvesting, to intervene and reduce the biomechanical and muscular stresses that fruit harvesters who make use of these harvesting bags are exposed to.

Early investigations by Murray and Miller (1985) showed that 77% of letter carriers that utilized the conventional mail bags (which were also single strap bags, similar to the standard citrus harvesting bags and carried unilaterally) in the UK, experienced discomfort, pain, temporary and/or permanent injury. A biomechanical analysis was performed on these same single strap bags and baskets used in harvesting coffee beans in Nicaragua (Bao *et al.,* 2013). This study showed high contact stress on the abdominal and back areas of the workers, static loading of the low back region and increased low back load during the harvesting task (Bao *et al.,* 2013). Evidence from research by Murray & Miller (1985 & 1989) and Bao *et al.* (2013) indicate that these single strap bags are indeed a problem. Yet, this bag design is continually used for fruit harvesting and even school bag designs (Murray & Miller, 1985 &1989; Earle-Richardson *et al.*, 2004; Motmans *et al.,* 2007). Previous intervention studies have all shown the physical impact and the muscular imbalance these asymmetrical bags have on the human body during load carriage. Corrigan & Xian Liu (2012), for example, showed that in carrying a single strap hockey bag across the shoulder (loaded or unloaded), peak muscle activity in the rectus abdominis significantly increased. Earle-Richardson *et al*., in 2004, modified the current unilateral strap picking bag by adding an adjustable hip belt. Results from this study showed that the addition of the hip belt to the unilateral strap bag, displaced/redistributed load more evenly across the body, specifically between the shoulder and the hip, as 71.4% of apple harvesters noted a reduction in back, neck and shoulder pain (Earle-Richardson *et al.*, 2004). Motmans *et al.* (2007) found in their study, using a reference of 100% MVC (maximum voluntary contraction) that 1) EMG activity levels in the erector spinae (ES) were highest (206% right ES and 203% left ES) while carrying a shoulder bag and a front bag respectively, among college students, 2) asymmetrical EMG activity between the right and the left back muscles was clearly observed while carrying a shoulder bag, and 3) the abdominal muscles revealed a significant asymmetry from the EMG results (199% right abdominals and 154%- left abdominis) for the shoulder bag. They then concluded from their findings that asymmetry in muscle activity may indicate a failure of trunk stabilization and contribute to the development back pain and that shoulder bags should be avoided for this reason (Motmans *et al.*, 2007). Similarly, the effect of shoulder bags on gait cycle, posture and energy expenditure was investigated by Pascoe *et al.* (2010), and they found that the physical/biomechanical stress of carrying load on one shoulder significantly altered posture and the gait cycle. Similar to Motmans *et al., (*2007) this study investigated asymmetry of muscle activity of the left and right sides of selected muscles but while walking. Effects of these single strap bags while walking were then linked to subjective fatigue responses, which increased with increase use. Another study by Mackie *et al.* (2005) further suggested that the length of the strap is the most important factor for consideration to reduce physical stresses associated with shoulder bags, as these authors found that manipulating the strap length of these bags altered shoulder tension and shoulder pressure. Murray & Miller (1989) suggested an adjustable pelvic/hip harness should accompany the "diagonal shoulder strap" bags to redistribute load and enhance stability of the user's centre of gravity and also to keep the bag stable while the user performs mobile duties. These authors also suggested a shoulder pad to reduce pressure on the shoulder and an underarm strap to keep the shoulder pad in place, i.e. to prevent the shoulder strap/pad from moving up to the lower region of the neck. The main problem with these shoulder bags, according to Murray & Miler (1989), is that direct compression of the straps on the shoulder and trapezius (lower neck), leads to excessive and intense muscular contractions which may eventually lead to the development of musculoskeletal disorders.

2.5 Ergonomics Interventions

Once an ergonomic problem has been identified through a task analysis in a workplace, the development of an intervention, implementation and evaluation of that intervention follows (Norman & Wells, 1998). "The term 'ergonomic intervention' refers to the reduction or even the total elimination of ergonomic risk factors. It implies that the MSDs that develop as a result of these risks such as high forces, awkward postures and high repetition rates can be reduced/eliminated or completely prevented through one or a combination of ergonomic intervention strategies including administrative/organizational, engineering and/or personal intervention (Dempsey, 2007). Musculoskeletal disorders in the workplace may be the result of multiple risk factors; hence a multidisciplinary intervention approach may be used in this instance (Norman & Wells, 1998). It has been suggested by Anderson (1992), Norman & Wells (1998) & Dempsey (2007) that, depending on the circumstance, engineering interventions should be the first option over the administrative and personal intervention strategies. This intervention method has proven to be more permanent than the other two intervention methods, as engineering interventions tend to affect all the workers involved and are most unlikely to be bypassed / overlooked by the workers (Anderson, 1992; Norman & Wells, 1998; Dempsey, 2007). This intervention strategy can be referred to as any engineered or physical manipulations to a worker's tools or equipment to promote worker productivity and reduce the risk of injury (Dempsey, 2007). They could range from a slight alteration/adjustment of an already existing office chair to the redesign and production of a brand new office chair.

Laboratory Versus Field debate

Lofland & Lofland (1984, pp.77) defined field research as "the process in which an investigator establishes multiple and relatively long-term relationships between individuals and their association with the natural setting in which they live/work for the purpose of developing a scientific understanding of that association". Field research consists of studies that are conducted in their natural setting in which one or more of the independent variables are manipulated and very little can be controlled for (Parasuraman *et al*., 2004). According to Nel & Davies (1999) and Fathallah (2010), assessing the type of work that manual (farm) workers perform, a field study would be most appropriate to assess the physical strains that the farm workers are exposed to and in the natural setting in which they occur.

Research in the field involves a range of well-defined, although variable, methods including: informal interviews, direct observation, participation in the life of the group, collective discussions, analyses of personal documents produced within the group, self-analysis, results from activities undertaken off- or on-line, and life-histories (Nell & Errouaki, 2008). Although the method generally is characterized as qualitative research, it may (and often does) include quantitative dimensions. Research in the field should allow for the discovery or generation of a theory, which requires understanding of behaviour, and is usually performed by a group of people (Lofland & Lofland, 1984). The ethical implications when conducting field research are as important to consider as when conducting laboratory research (Burgess & Robert, 1984). However, in field research, the experimenter must be cautious in the means used for data collection as there are also certain inevitable challenges that may occur, such as; interrupting worker productivity, uncontrollable conditions that may always make findings from previous similar field research impossible to obtain, changing environmental conditions, language barriers, literacy and education, political issues etc. (Nell & Errouaki, 2008). These are all problems that make it difficult to conduct field research particularly in an IDC such as South Africa. To conduct field research most efficiently, a researcher will require prior knowledge of the characteristics listed above of field studies. However, even the more experienced field researchers will face difficulties and this may be attributed to the fact that no two field studies can be the same or produce the exact same outcomes (Parasuraman *et al.*, 2004). Different contexts, countries, uncontrollable situations, varying environmental and/or economical climates will ensure that the results/findings of a field study are virtually impossible to replicate (Nell & Errouaki, 2008). This often may create room for doubt on the validity and reliability of field research.

Performing field research has its strengths, as well as weaknesses. Lofland & Lofland (1984) suggest that field research allows for flexibility as the researcher, due to the unpredictability of field research, can modify their research design at any time where necessary. This may be a considered a strength or a weakness; a strength in that some components not accounted for in the start of the research can be added, or a weakness in that the viability/credibility of the entire project is questioned with constant changes. Field research creates a social component to testing as opposed to research conducted in the laboratory and allows for the collection of non-verbal data (Burgess & Robert, 1984; Parasuraman *et al.,* 2004). The researcher is also able to develop relationships with the participants and this could provide the researcher with further insight on the topic.

In terms of negatives, field research tends to be time and effort-consuming. This is mostly due to the great amount of detailed information that needs to be obtained (Fathallah, 2010). Numerous factors are to be considered in the field, for example, nothing is controlled for, hence large amounts of time, manpower and resources must be utilized to collect data accurately (Parasuraman *et al.,* 2004).

However, most ergonomic scientific research is based solely in the laboratory (Bao & Shahnavaz, 1989). It is very rare that ergonomic researchers take their findings from a laboratory based study (which is highly controlled) into the field (not controlled) to assess what impact (if any), their findings may have on the real workers in the real context. Bao & Shahnavaz (1989) suggested that interrupting worker productivity may be the major concern for most researchers. However, if worker productivity is not assessed, the effectiveness/efficacy of an intervention or of a lab finding cannot be investigated. Therefore to ensure efficacy and effectiveness, an intervention study in a laboratory setting must be taken out into the field setting.

CHAPTER 3: PRELIMINARY INVESTIGATION AND TASK ANALYSIS

3.1. Introduction

The interest in the current citrus harvesting bags arose from an initial farm site walk-through and informal chats with the citrus farm workers. Based on these, it was noted that these workers experienced shoulder and back pains, most likely as a result of the design of the standard harvesting bag, since they did not experience such discomfort outside the harvesting season. Hence, redesigning the current harvesting bag to reduce and/or eliminate the workers pain was of interest to the researcher. Furthermore, to investigate the effectiveness of a redesigned citrus harvesting bag, this project was divided into two phases. The purpose of the first phase was to perform extensive measurements in the laboratory comparing the biomechanical, physiological and perceptual responses of the standard citrus harvesting bag to the responses of two newly redesigned citrus harvesting bags. Having observed, from the site walk-through that not all aspects of the harvesting process could be tested in the laboratory and vice versa, a second phase (field phase) was introduced. The purpose of this second phase of this study was to introduce the new bag designs from the first phase into the field, and again compare this design to the standard bag design. Of interest in this second phase were worker productivity as well as workers' acceptance to the new bag designs.

Due to the labour-intensive nature of citrus harvesting, citrus farm workers are exposed to a variety of physical risk factors which pose a threat to their health, well-being and productivity. Through a task analysis phase, the current citrus harvesting bag was identified as a serious physical risk factor. A task analysis provides a detailed description of task characteristics, durations, frequencies, complexity, environmental conditions, necessary clothing and equipment, and any other factors associated with performing that task; which allows for the researcher to explore the implications for the design/interventions of tasks (Johnson *et al.*, 1985). Kirwan & Ainsworth (1992), suggest that a task analysis should be performed during the early stages of any research project, to gain any relevant information that will be useful for the future/later phases of that research project. This chapter explains the task analysis methods and all information obtained to identify this physical risk.

3.2. Methodology

A task analysis was performed in the early stages of this study, at a citrus farm close to Grahamstown, in the Eastern Cape region of South Africa. This task analysis was performed during the late harvesting season (June 2013), with the purpose of obtaining information on the worker groups, subtasks performed, tools and equipment used, postures assumed, methods employed, systems and practices in the citrus industry (Drury, 1983). Informal interviews with questions relating to worker fatigue and discomfort were also conducted. Three different workers groups were observed during this phase, namely; the ground workers, stepladder workers and tall ladder workers. A description of their job including the subtasks they performed, the tools they used and the postures they assumed while performing these subtasks were also noted and are summarized in the results section below.

3.3. Results and Discussion

The following section describes and discusses 1) the work system, 2) the worker population groups, 3) the subtasks performed, and 4) worker perceptions, all observed during the task analysis.

3.3.1. Work System

At least 15 workers were observed in each worker group during the task analysis phase, but it must be pointed out that from day to day there was “movement” between worker groups in order to balance out the required number of workers per group.

The citrus orchards consisted of citrus trees planted in rows, the distance between rows being 7.0m. In each row, there were about 20-35 trees, depending on the size of the orchard, with 4.5m spacing between trees. All workers (ground, stepladder and tall ladder workers) were required to move from tree to tree along the same row, performing a variety of subtasks (explained below) until the harvesting bags were filled with fruit (weighing an average of 13-14kg), after which they would carry the full bag to the tractor (which was usually parked at the end of a row) to empty the content of the harvesting bag into the collection bin. Once all trees in one row had been harvested, the workers moved to the next row of citrus trees.

A full working shift consisted of 9 hours, including a 30-minute tea break and a one hour lunch break, although the start of the harvesting process would vary, depending on the amount of dew that had settled overnight. Fruit had to be dry when harvested; hence the start of the shift was delayed at times. Task characteristics would vary, depending on the point of time during the harvesting season. These variations were as a result of the type of citrus harvested (lemons, oranges, soft citrus), the size of the fruit (which in turn is affected by the type of citrus, the timing of the harvest and rainfall throughout the growing season), the frequency of walking from tree to tree and the number of bags collected. During the peak of the harvesting season each worker would harvest between 60 to 100 bags per day, each bag containing about 60 oranges, although this varied considerably depending on the type of citrus harvested. The harvesting task was self-paced, although there is pressure to keep up with the rest of the members of the harvesting team. Worker wages are calculated per bag harvested; hence individual productivity varied depending on effort and experience.

3.3.2. Worker Groups

a) **Ground workers:** These workers, as seen in Figure 3 below, were mostly females and they were required to harvest fruits at the bottom levels of the tree (about 1.5 m high off the ground). To achieve this, they mainly worked in an overhead posture. The subtasks they performed throughout the day included: a) carrying the harvesting bag from tree to tree, b) picking/clipping the fruits with harvesting secateurs from the tree and placing them into the harvesting bag, and c) once the harvesting bag was full, emptying the harvested fruit into an collection bin (a large container on a trailer pulled by a tractor).

Figure 3: Ground worker harvesting fruit

b. **Stepladder workers:** These workers were also predominantly females. They made use of a stepladder to harvest fruit from the mid-level branches (approximately 3 m above ground level) of the citrus tree (as seen in Figure 4). They assumed a relatively upright posture with the picking levels at or just below shoulder height. The subtasks these workers performed included: a) carrying the harvesting bag and stepladder from tree to tree, b) climbing up and down the stepladder, c) clipping the citrus fruit and placing them in the harvesting bag, and d) emptying harvested fruit into the collection bin once the bag had been filled.

Figure 4: Stepladder workers harvesting fruit

c. **Tall Ladder workers:** These workers were entirely males, who would harvest citrus fruits at the top most levels of the tree (around 4.5-5 m above the ground), using tall A-frame ladders to reach the highest levels of the tree. As seen in Figure 5, they were required to assume a forward reaching and stooped posture in order to harvest the fruit. The subtasks they performed included a) carrying the bag and the tall ladder from tree to tree, b) climbing up and down the tall ladder, c) clipping the citrus fruit and placing it into the bags, and d) emptying harvested fruit into the collection bin.

Figure 5: Tall ladder worker harvesting fruit

3.3.3. Sub-Tasks

The following descriptions provide further details of each of the observed subtasks. Table I below shows each subtask performed according to each worker group.

Task A: Carrying bag only or carrying bag with ladder:

Once the workers had harvested all ripe fruit from one tree, they had to move on to the next tree. This meant having to carry either only the harvesting bag, or carrying the harvesting bag together with either the stepladder or the tall ladder from one tree to the next. Once they had arrived at the next tree, the ladder (stepladder and tall ladder) workers had to first set up the ladders before commencing with the harvesting task. Both types of ladders had to be placed on the ground and as close to the tree as possible, while also ensuring that the ladders were stable. Once the worker had finished collecting the citrus, they picked up the ladders and the process was repeated. Three concerns arose with this subtask. Firstly, the main problem with carrying the standard citrus harvesting bag was the asymmetrical component it promotes. Literature has shown, and continues to show, that asymmetrical loads have negative effects on the body, including musculoskeletal misalignment, musculoskeletal compensation, muscle spasms, and postural asymmetry, which in turn, gives rise to asymmetric muscular activity and leads to the development of MSDs, specifically lower back pain (LBP) (Devita *et al*., 1991; Grimmer & Williams, 2000; Earle-Richardson *et al.*, 2004; Motmans *et al.*, 2007; Pascoe *et al.*, 2010; Corrigan & Xian Liu, 2012; Quereshi & Shamus, 2012). The second concern was the mechanical pressure placed on the shoulder from wearing these single shoulder-strap bags, as this increased pressure on the shoulder could result in increased discomfort or pain on the shoulders (Earle-Richardson *et al.,* 2004 & 2006). The third concern was the load carriage of the ladders which are bulky, awkward to manipulate and add to the loading already imposed by the harvesting bag and its content (Armstrong *et al.,* 2009).

Task B: Climbing ladder:

This sub-task required only the stepladder and tall ladder citrus workers to climb up the ladders in order to reach the fruit to be harvested in the middle and higher levels of the citrus trees respectively, and, once completed, climb down the ladders again. The main concern with this task was the increased whole body muscle activity or muscle compensation to maintain balance while climbing up and down the ladder, especially with additional load from already harvested fruit in the bags (Earle-Richardson *et al*., 2004 & 2006). These could lead to an increased risk of falls off the ladders and hence were a concern.

Task C: Clipping fruit:

The clipping task refers to detaching the citrus fruit from the stem using a pair of harvesting secateurs. To perform this task effectively, i.e. cutting the citrus stem at the correct length and without damaging the fruit, workers had to assume a variety of postures, some of which were considered awkward. The ground citrus workers, for example, were required to clip the fruits with the harvesting secateurs in an overhead posture while, at the same time, carrying the bag and its content. The literature states that this increases contact pressure on the shoulders, as well as muscle stabilization of the trunk muscles from a fine manipulative task such as using secateurs to cut fruit (Pascoe *et al.*, 2010). The stepladder workers mostly worked at what would be considered optimal height (no higher than shoulder level), but again of concern were the trunk muscles that are needed to be recruited to stabilize the body while performing the fine manipulative tasks while balancing on the stepladder, as well as the mechanical pressure placed on shoulders by the shoulder strap while carrying the load and working overhead (Corrigan & Xian Liu, 2012; Quereshi & Shamus, 2012), in addition to the lateral spinal tilting from carrying load (Motmans *et al.,* 2007; Pascoe *et al.*, 2010). The tall ladder workers assumed a forward leaning / stooping posture of approximately 45 degree flexion) to reach and clip/harvest the fruit at the uppermost parts of the tree. This can lead to high compression forces acting on the lower back due to increasing internal muscle activity (Motmans *et al.*, 2007), as well as increased trunk muscle activation to stabilize the body on top of the tall ladder while also carrying an asymmetric load.

Task D: Emptying Fruit:

Once a harvesting bag had been filled, the workers were required to carry the bags and their contents to a collection bin on a trailer, pulled by a tractor. This subtask comprised of workers climbing onto the tractor (1.2m high from the floor). This tractor held a collection bin (1.45m high and 1.07m wide) and workers leaned over the edge of this bin while tipping over the harvesting bag for the fruit to fall into the collection bin. Since workers were paid according to the number of bags they harvested, the use of a control sheet was the system the farm owner used to keep track of how many bags each worker has collected. Every time a worker emptied a full bag of fruit into the collection bin, the supervisor marked a box on the control sheet. The problem associated with the sub-task of emptying the fruit into the collection bin was the potentially excessive muscle activity from heavy lifting, lateral spinal tilting, velocity and acceleration of tilt that is required to perform the task, as also pointed out by Pascoe *et al*. (2010) and Quereshi & Shamus (2012), and which could result in increased muscular injury.

Table I: Subtasks performed by each worker group

	Subtask			
	Carrying bag only/ bag + ladder	**Climbing up/down ladder**	**Clipping fruits**	**Emptying fruits**
Ground worker (females)	These workers carried the bag only throughout the entire harvesting task	N/A	These workers were required to work in an overhead posture to clip fruits.	All workers emptied the harvested fruit into an emptying bin 1.45m high and 1070mm wide by climbing up one step and tilting the bag to release harvested fruit.
Stepladder worker (females)	These workers carried both the harvesting bag and a stepladder while walking from one tree to another	These workers climbed up and down a stepladder in order to clip fruits at each	These workers were required to work around shoulder height	
Tall ladder worker (males)	These workers carried both the harvesting bag and a tall ladder while walking from one tree to another	These workers climbed up a tall ladder in order to harvest the fruits at each tree	These workers harvested fruit in a 45 degree forward stooped posture	

3.3.4. Worker perceptions

Informal individual and group discussions were conducted with the workers to determine the workers' perceptions of their job and it requirements. It was established through these conversations that the current design of the citrus bag was problematic as the workers commented on pain and discomfort experienced in the lower back and also the shoulders, most likely as a result of the asymmetrical load carriage method they adopted while using these bags. Consequent and more in depth interviews/discussions with the workers were impossible to perform as the citrus harvesting season was over and the workers moved to other jobs. Citrus harvesters are migrant workers and they would only return the following citrus harvesting season.

3.4. Bag Re-design

Once the standard harvesting bag had been identified as a problem, new bags were designed. Since the harvesting bag design currently used in the citrus industry promotes asymmetrical load carriage, bag design was chosen as an independent variable to assess whether changing the bag design would reduce the strain on the musculoskeletal system and therefore the risk of musculoskeletal disorders development.

In developing the new bag designs, a product design specification (PDS) was set up (see Appendix A). The PDS is a statement of intention to design a certain product that has not yet been developed, to ensure that the new design meets the needs of the user of that product (Cross, 2006). The PDS phase is usually performed after finding the need for a new design as a result of worker feedback or complaints. Researchers therefore attempt to understand a problem on a deeper level which enables them to develop sound requirements for the new design. Limits for these requirements are also determined in this phase. Cross (2006) suggests that this phase is a specification of “what is required” and not of the actual product itself.

A PDS checklist was developed for redesigning the standard citrus harvesting bag design, based on existing literature on the requirements for bag designs and load carriage, and results obtained from the task analysis. It would have been preferable to obtain more detailed worker input in this phase, however the citrus farm harvesters in this region were migrant workers and were unavailable for further interviews between harvesting seasons. The PDS checklist comprised of practical but principal issues that needed to be addressed in order to develop the most suitable bag designs for the citrus harvesters (see Appendix A). Considerations on the PDS checklist developed for this study included: increased worker performance, reduction of asymmetry from load carriage (Earle-Richardson *et al.,* 2006; Motmans *et al.,* 2007), reduced muscle activity (Earle-Richardson *et al.,* 2006; Corrigan & Xian Liu, 2012), low production costs, high range of motion, decreased shoulder pressure (Earle-Richardson *et al.,* 2006; Bao *et al.,* 2013), easy emptying, durability, adjustability, worker acceptance to new design (Earle Richardson *et al.,* 2004; 2006). Three bag designs were selected to be tested in the current study; a) the standard bag design, b) a hip belt bag design and c) a back pack bag design:

A. ***Standard bag (SB) design*****:** From previous research by Grimmer & Williams (2000), Earle-Richardson *et al*. (2004), Motmans *et al.* (2007), Kudryk (2008), Pascoe *et al.* (2010), Corrigan & Xian Liu (2012) and Quereshi & Shamus (2012) and by questioning agricultural equipment manufacturers and distributors, this bag design appeared to be the most commonly used one world-wide for citrus harvesting, as well as other fruits (e.g. pears and peaches). It comprises of a single strap, worn across the shoulder (refer to Figure 6), a loop in the front to keep the bag open and a pin down system at the bottom, which, when released, allows emptying of the fruit from the bottom of the bag. It is usually made of a canvas or polyvinyl material for durability purposes. This bag design forces the worker to adopt a unilateral/asymmetrical load carriage method which leads to asymmetrical postures, increased muscle activity, poor balance, and increase in contact pressure while performing the different tasks; since the load is unequally distributed around the body (Earle-Richardson *et al.,* 2006; Corrigan & Xian Liu, 2012). This load carriage method has negative implications for the musculoskeletal system of the worker and possibly, the workers' productivity (Fathallah, 2010).

Figure 6: Standard harvesting bag design- bag with a single strap carried unilaterally

B. ***Hip belt (HB) bag design:*** The addition of a hip belt to a front pocket bag design was implemented for apple harvesters in New York (Earle-Richardson *et al.,* 2006). Although citrus harvesting bags have a side pocket instead of a front pocket, the idea of adding an adjustable hip belt was similar. The study amongst apple harvesters found that the addition of a hip belt to a front-pocket bag design redistributed weight from the upper back, neck and shoulders to the hips, much in the same way a mountaineering backpack redirects the weight to the hips (Murray & Miller, 1989; Murray *et al.,* 2001). A similar intervention for mail carriers in a study by Murray & Miller in 1989 showed that loading on the lower back was reduced with the addition of an adjustable hip belt. The bag designed and shown in Figure 7 had a soft and well-padded neoprene hip belt with an adjustable clip buckle for workers of different sizes to be able to make use of the same bag. The hip belt was designed to sit on the iliac crests, being the uppermost part of the largest bone in the pelvis (the ilium) (Tortora & Derrickson, 2005) and, as such, useful to ensure that the bag sits and balances well around the pelvis (Tortora & Derrickson, 2005).

Figure 7: Hip belt bag design-the standard bag design with the addition of a hip belt

C. ***Backpack (BP) design:*** As shown in Figure 8 below, this bag design comprised of 1) wide and adjustable shoulder straps, which sat across the full width of the workers' shoulders (to ensure weight distribution across upper back, neck area and shoulders), 2) a loop to keep the bag open at the back of the bag for harvested fruits to be placed easily, 3) an additional strap across the upper chest area to keep the shoulder straps from slipping off the workers' shoulders, and 4) an adjustable hip belt similar to one used in the hip belt bag design. The shoulder strap was selected instead of a "cross-your-heart" design to cater for female workers who may experience high discomfort from having straps across their breasts. However, another feature of this bag design included a strap with a clip situated across the workers upper chest. This feature did not cause discomfort amongst the female workers/participants since it was located across their upper chest and not across their breasts and was essential to prevent the shoulder straps from slipping out of place while the workers/ study participants performed the harvesting subtasks. Based on previous bag design research studies performed by Murray & Miller (1989), Goh *et al. (*1998), Qureshi & Shamus (2012) and Bao *et al*. (2013), there is a general consensus suggesting that a backpack design may be the most beneficial to redistribute the load evenly across the body and hence reduce the risk associated with asymmetrical load carriage. The backpack design was also suitable as it allowed freedom of movement at the front, both for the arms when picking the fruit, but also for the legs when climbing up ladders (Corrigan *et al.,* 2010). The hip belt was essential to re-distribute the load and also to keep the bag fixed against the worker's body (Grimmer & Williams, 2000; Earle-Richardson *et al.*, 2004; Motmans *et al.*, 2007).

(a) (b)

Figure 8: Anterior (a) and lateral (b) view of the backpack bag design

3.5. Conclusion

Findings from this task analysis phase showed that citrus farm workers perform a variety of tasks, and use certain tools for long durations that expose them to physical risk. In this study specific attention was paid to the standard harvesting bag they use as the major cause of musculoskeletal pain (in shoulders and lower back). Hence redesigning this bag is the focus of this study.

CHAPTER 4: LABORATORY STUDY

4.1 Introduction

There is evidence to suggest that the current citrus harvesting bags being used in the citrus industry promote asymmetrical load carriage, which in turn negatively impacts on the musculoskeletal system and the workers' well-being (Pascoe *et al.,* 2010; Qureshi & Shamus 2012). This phase of the project was a laboratory based intervention study in which the standard citrus harvesting bag was compared to the two new designs to determine whether the physical risk factors had been reduced.

4.2. Methodology

4.2.1 Experimental design

The purpose of this laboratory study was to compare the EMG and RPE responses while using the standard citrus harvesting bag for the different worker groups in citrus farming, to the two newly designed citrus harvesting bags. A holistic approach involving biomechanical response in addition to the physiological and perceptual response would have been most ideal for the current study. However, during exploratory studies, it was found that the readily available biomechanical means of assessing asymmetry (i.e. use of lumbar motion monitor, inclinometer and accelerometer) would be affected with the use of the backpack design. For this reason, biomechanical responses were not assessed in this study.

The two new harvesting bags designed were the "hip belt design" and the "backpack design", both which are described in detail in Chapter 3 under the "Bag Re-design" section. To determine the effects of the standard harvesting bag design over the new bag designs for the three different worker groups (refer to Chapter 3, "Worker groups"), a partial repeated design was developed for this first phase of the project. The impact of bag design was tested using a repeated one-factorial experimental design, on each of the three different worker groups. Differences in responses of each bag design and within each group was of interest in this phase of the study, hence no comparisons were made across the different worker groups since the tasks each worker group performed varied.

Participants were allocated to one of the three worker group (all male participants were allocated to the "tall ladder worker" group and females to either "ground" or "stepladder worker" group), and were required to perform a simulated citrus harvesting protocol with each bag design. This participant allocation corresponded to the worker allocation on the citrus farm observed during the task analysis. One bag was tested during one testing session/day; hence participants attended a total of three test sessions. The participants allocated to the ground worker group performed only conditions 1-3, the step ladder workers conditions 4-6 and the tall ladder workers conditions 7-9- These conditions are outlined in Table II.

Table II: Test conditions for the laboratory phase of the project

		Harvesting bag design		
		Standard bag design	**Hip belt bag design**	**Backpack bag design**
Worker population	**Ground worker**	C_1: SB-GW	C_2: HB-GW	C_3: BP-GW
	Stepladder worker	C_4: SB-SL	C_5: HB-SL	C_6: BP-SL
	Tall ladder worker	C_7: SB-TL	C_8: HB-TL	C_9: BP-TL

Where;

SB: Standard bag

HB: Hip belt design

BP: Backpack design

GW: Ground worker

SL: step ladder worker

TL: tall ladder worker

4.2.2 Statistical Hypotheses

The null hypothesis stated that the EMG and RPE effects of the standard bag would be no different to those produced by the new bag designs. The alternative hypothesis stated that there would be a difference between the muscular and perceived exertion responses.

Ho: $\mu_{SBD} = \mu_{HBD} = \mu_{BPD}$

Ha: $\mu_{SBD} \neq \mu_{HBD} \neq \mu_{BPD}$

Where:

μ= mean EMG and RPE responses,

SBD= standard bag design,

HBD= hip belt bag design,

BPD= back pack design

4.2.3 Laboratory set up

The laboratory set-up for the simulation of citrus harvesting comprised of three harvesting stations - these were metal structures each constructed to represent a citrus tree using dimensions obtained in the field during the task analysis. The harvesting stations were each 3m high and stood 4.5m apart from each other with “fruit” to be harvested and a collection bin (refer to Figure 9).

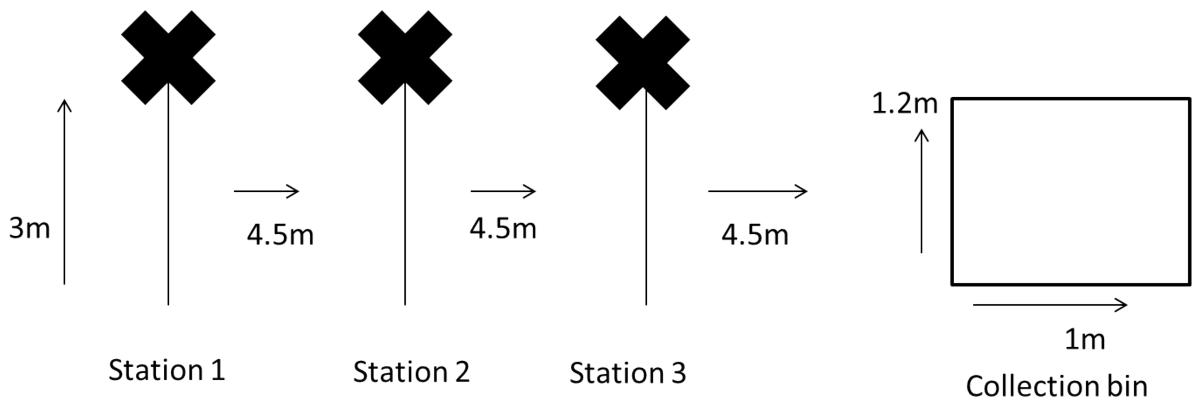


Figure 9: Schematic diagram of laboratory set up, showing three harvesting stations (representing citrus trees) and the collection bin

Sand-filled socks/stockings hanging from pieces of string simulated citrus fruits on the trees. This option was found the most suitable to prevent waste of citrus fruits that were only just coming in season at the time of the laboratory phase and also as the more resourceful option. In addition to this, the sand-filled socks corresponded best in weight and size to real citrus fruits, compared to other options that were explored. Each harvesting station also comprised of a carpeted area (to improve ladder stability) and two safety mats on either side of the "trees" (in case of a participant falling off the ladder).

To execute one harvesting cycle, participants had to perform the following activities: carry the harvesting bag to the first harvesting station (with or without a ladder, depending on the worker group allocated to) and climb up the ladder (stepladder and tall ladder workers only). To pick the fruit participants were required to cut a string using a pair of children's art scissors (to minimize risk of injury) and place the "fruit" into the harvesting bag. In this manner the participants harvested 20 "fruits" from each "tree" / harvesting station. Once 20 "fruits" had been harvested from the first tree, they had to climb down the ladder (stepladder and tall ladder workers only) and move to the second harvesting stations, repeating the subtasks as at the first station, and, after another 20 "fruits", they moved to the third harvesting station. Once participants had completed picking the fruit at the third station and the harvesting bag had been filled with 60 socks, weighing between 13 and 14kg, participants carried the fruits to the collection bin and emptied them into it. Having performed explorative studies prior to the actual data collection, it was decided to have participants perform three harvesting cycles of each condition to reduce the influence of variability between cycles.

It must be noted that the working postures (overhead posture for ground workers, shoulder height for stepladder workers and forward stoop for tall ladder workers), were made relative to each participant's stature to accommodate the different anthropometries, and reduce the effects of the varying working postures on workload and physical strain, as well as to also standardize this posture, thus eliminating the participants' statures or arm lengths as extraneous variables. To achieve this, selected participant demographic data, including stature (using a stadiometer), mass (using an electronic scale), age, sex, and shoulder height (distance between the acromion process and floor, using a tape measure) were collected during the habituation/introductory phase. Having performed explorative studies a 40 degree angle between the arm and the trunk (i.e. 75% of arm length) was used for the ground and stepladder workers and approximately a 45^0 forward lean for the tall ladder workers. This angle for the tall ladder workers was made possible by the researcher marking, on the carpeted area, spots where the tall ladder would be placed for each participant according to their height.

Participants performed all three harvesting cycles in total with a one minute rest break in between cycles. This break was not for recovery purposes but necessary for the researcher to collect local RPE data and check equipment set-up. Participants were required to have at least four days between each test session to ensure there was no DOMS (delayed onset muscle soreness).

4.2.4 Independent Variables

4.2.4.1 Bag Designs

The standard harvesting bag currently used in the citrus industry was compared to the redesigned bags, namely the "hip belt bag design" and the "backpack bag design". See chapter 3 for a detailed description of the bag designs.

4.2.4.2 Worker Groups

From the task analysis phase, three different worker groups were observed. Although all worker groups harvested the citrus fruit, the subtasks they performed differed slightly from one group to another (Chapter 3 provides a detailed task description of each worker group's activities). In this phase of the study, the recruited participants were required to perform subtasks according to the worker group.

4.2.5. Dependent Variables

4.2.5.1 Muscle Activity

An increase in asymmetrical muscular activity is a component for the detection for asymmetrical load carriage and eventually the development of MSD's (Devita *et al.,* 1991; Grimmer & Williams, 2000; Earle-Richardson *et al*., 2004; Motmans *et al.*, 2007; Kudryk, 2008; Pascoe *et al.,* 2010; Corrigan & Xian Liu, 2012; Quereshi & Shamus, 2012; Bao *et al.,* 2013). Therefore, surface EMG, which is a non-invasive but still an accurate measure of muscle activity, was selected as a variable of interest in this study. It is known that an increase in EMG amplitude correlates with increased muscular force/activity as a result of greater motor units firing rates, as well as more and larger motor units being recruited (Alkner *et al.*, 2000; Kudryk, 2008). This has been observed in previous load carriage research, indicating asymmetry and fatigue (Earle-Richardson *et al.,* 2006; Motmans *et al.,* 2007; Kudryk, 2008; Corrigan & Xian Liu, 2012).

Earle Richardson *et al.* (2006) assessed muscle activity during an intervention study conducted amongst apple harvesters. The findings from this study, as well as other similar studies by Motmans *et al.* (2007), Kudryk (2008), Corrigan & Xian Liu (2012) and Bao *et al.* (2013), suggested that muscle activity is a valid and reliable measure to assess asymmetrical component in load carriage. For this reason, muscle activity was chosen in this study to infer asymmetrical loading of the trunk as a result of the different bag designs by giving information on which side (left or right muscle) was compensating most to maintain balance. Three muscle groups as suggested by Earle-Richardson *et al.* (2006), Motmans *et al.* (2007), Kudryk (2008), Corrigan & Xian Liu (2012) and Bao *et al.* (2013) were selected to detect asymmetrical load carriage from the different bag designs. These included the trapezius, erector spinae and anterior deltoid muscle. The trapezius is the main elevator muscle in the shoulder girdle, and aids in stabilizing the scapula during arm movements. Hence, for the clipping, emptying and even climbing subtasks, this muscle group was essential to assess. The erector spinae muscles allow for stabilization of the trunk and were thus important in performing all the subtasks in citrus harvesting. The anterior deltoid was chosen over the middle and posterior deltoid after the researcher conducted pilot studies. The anterior deltoid allows for shoulder abduction when the arm is internally rotated and for shoulder flexion in the sagittal plane. This muscle assists with subtasks such as climbing up ladders, emptying and clipping fruits; tasks performed by all three worker groups (Moynes *et al.,* 1986; Sherman, 2003; Corrigan & Xian Liu, 2012; Quereshi & Shamus, 2012; Bao *et al.,* 2013). Hence, these muscle groups would be a good indicator of any muscular activity experienced during the asymmetrical carriage of the bag designs (Earle-Richardson *et al.,* 2004; 2006).

4.2.5.2 Perceptual Responses

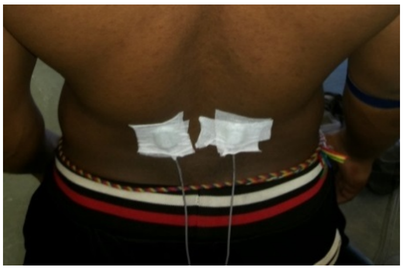
Ratings of Perceived Exertion (RPE) are a common method of determining exercise intensity levels and subjective responses to musculoskeletal strain (Borg, 1970). It was essential to obtain these perceptual responses from the participants in order to obtain subjective feedback on how hard they felt they were working while performing the test protocol. Additionally, since a holistic approach was adopted to broaden the scope of the study, perceptual responses alongside physiological (EMG) responses were measured.

The RPE scale is easy and straight forward to use and requires participants to call out, or point out on the scale, the level of exertion they are experiencing. This perception of effort or exertion is a subjective evaluation of how hard a participant feels his/her body is working (Borg, 1998). A local RPE scale (which gives subjective information on muscular effort) of the lower back and shoulders was used in this study to determine the impact of the bag designs on musculoskeletal strain. RPE was used for this laboratory protocol to give subjective/perceptual indications of how much participants in each of the different worker groups felt they were exerting themselves while performing the harvesting subtasks, using the different bag designs. RPE was recorded, at the end of each harvesting cycle.

4.2.6. Equipment and materials

4.2.6.1 Electromyography

Electromyography (EMG) is a technique for evaluating and recording electrical activity produced in the muscles (Kudryk, 2008; Pascoe *et al.,* 2010). It was essential in this study to assess muscle activity to investigate which method of load carriage required the most muscular activity and inferring asymmetry from it. The DataLOG surface EMG system (Biometrics Ltd. Newport, UK) was utilized to measure muscular activity as it is a non-invasive and objective measure of muscle function (Oddson & De Luca, 2002. The Biometrics DataLOG system has eight analogue channels and two digital channels, which allow for the simultaneous collection of a variety of data. Electrodes with conduction gel were placed on the left and right sides of the trapezius, erector spinae and anterior deltoid muscles as shown in Figure 10 below.



(A) (B)

Figure 10: Electrodes placed on different muscle groups: A) left and right erector spinae, B) left and right trapezius and anterior deltoids

As normalization reference, EMG data were collected during maximal voluntary contractions (MVCs) for each muscle. The peak 3s average EMG value was selected as a normalization value (100%). The raw data obtained was sampled at 1000 Hz.

MVCs were performed on the selected muscles for reference/baseline EMG readings. The use of MVCs has received criticism as a measurement of maximal effort, as eccentric muscle exertions can exceed the force produced during an isometric exertion (Moynes *et al.,* 1986; Mirka, 1991; Sherman, 2003). It was recommended in research by Mirka (1991) and Sheppard (2012) that for dynamic tasks maximum dynamic (usually isokinetic) contractions should be used to obtain reference EMG levels. However, it must be noted from the research above that the researchers established dynamic tasks as tasks in which the participants are required to sprint (like during cricket) or exert an “all-out effort” (Mirka, 1991; Sheppard, 2012). The harvesters in the citrus industry however performed their tasks at a considerably slower and self-selected pace. Therefore, MVCs were considered to be suitable as reference/baseline readings.

Described below are the procedures for locating the selected muscle groups and determining the electrodes placements, which correspond to methods by Gross *et al.* (2009). Procedures of how MVCs were performed corresponded to those proposed by Mirka (1991).

- *Trapezius:* this is a large superficial muscle at the back of the neck and the upper part of the thorax, originating from the base of the skull and inserting on the posterior part of the clavicle and on the spine of the scapula (Gross *et al.,* 2009). It acts to support the shoulders and limbs and allows for rotation of the scapula (Mirka, 1991), which occurs during harvesting subtasks such as clipping, carrying, climbing and even emptying. The muscle was located by asking the participants to abduct the shoulders to 90 degrees so that the muscle fibres that allow for shoulder elevation would become visible at the top of the shoulder girdle (Mirka, 1991). Both the left and right sides were assessed as there would be discrepancies between both sides since different hands perform different tasks at the same point in time. The skin surface was cleaned using an alcohol swab on the left and right sides to enhance the EMG signal transmission due to cream or dirt on skin surface. The EMG electrodes were then placed parallel to the direction in which the upper trapezius muscle fibres run to obtain the strongest electrical signals (Gross *et al.,* 2009). After electrodes had been placed and connected to the DataLogger unit, the MVC for the trapezius was performed by applying a downward force on the participant's shoulders while the participant counteracted the force by attempting to elevate the shoulders (Gross *et al.,* 2009). This was performed three times and the contraction was held for five seconds every time (Gross *et al.,* 2009).
- *Erector Spinae:* this is a superficial muscle of the back, essential for trunk stabilization (Gross *et al.,* 2009) and useful during any gross or fine motor activity, such as ladder climbing, clipping citrus fruits and emptying citrus fruits into the collection container. This muscle group was located by palpating lateral to the spinous process at the L4 level of the spine, on both left and right sides of the back to account for any discrepancies. Again, this area was cleaned with alcohol swabs to improve the electrical signal. EMG electrodes were then placed on both sides of the

spinous processes as seen in Figure 10. An MVC for this muscle was obtained, as according to Gross *et al.* (2009), by requesting the participant to lie prone on a mat with both arms placed on either side, as she/he attempted to raise the sternum off the mat, while the researcher applied a downward force at the level of the shoulders and an assistant stabilized the participant's pelvis and legs to reduce the effect of the hamstrings in this motion (Gross *et al.,* 2009). Again, this was repeated three times and each exertion was maintained for five seconds.

- Anterior deltoid: the deltoid muscle surrounds the rounded contour of the shoulder and is divided into an anterior, middle and posterior section. These muscles originate from the anterior border of the clavicle, acromion process and scapula respectively and all insert on the deltoid tuberosity which is located on the lateral aspect of the humerus (Gross *et al*., 2009). This muscle assists with movements such as: abduction of the shoulder, internal rotation of shoulder and flexion of shoulder in the sagittal plane. These motions are essential when performing the citrus harvesting subtasks such as climbing up the ladder, emptying fruit and reaching for and clipping fruit. This muscle was located by asking the participant to abduct their dominant arm along the frontal plane and at 90^{o} abduction perform horizontal adduction against a slight resistance (Gross *et al*., 2009). Once the anterior deltoid was located, the skin on the surrounding area was cleaned to reduce any interference in EMG signal, and electrodes where placed halfway between the origin and insertion, and parallel to the direction of the muscle to obtain the strongest signals. MVCs were then performed three times. Participants were required to abduct their elbows to 90 degrees and then resist horizontal abduction at the level of the shoulder. Participants held this contraction for five seconds on all three attempts.

4.2.6.2 RPE Scale

The RPE scale ranges from 6-20 with verbal anchor attached to the numerical values; a rating of 6 being "*nothing at all*", i.e. no exertion and 20 being "*very very hard (maximal)"* effort. An RPE scale (Appendix D) was presented to the participants three times during a testing session, i.e. once at the end of every harvesting cycle. The participants were required to rate their perceived level of musculoskeletal strain of the lower back and left and right shoulders. The information obtained was then manually recorded for each participant on a data sheet (Appendix F).

4.2.7 Participant Sample

The sample population for this phase of the project included 36 moderately trained male and female participants, aged between 19-30 years. Rhodes University students were selected instead of work-hardened citrus harvesters as participants from this group were readily available for testing. The citrus workers are migrant workers and as thus would not have been available for the entire duration of laboratory data collection phase. In addition, the students were English-speaking and better educated than the citrus workers and would have coped better with the detailed instructions, the personally invasive EMG set-up, as well as the conditions of the laboratory environment in which the first phase of the project was tested. 12 participants each were allocated to each of the three worker population groups. None had a record of any musculoskeletal disorders to ensure they were healthy and physically capable to perform the laboratory simulation protocol. It was essential that participants were moderately trained, i.e. they engaged in any form of strength or resistance training 2-4 times per week (Alkner *et al.,* 2000) to ensure that the participants were strong enough, capable of carrying the specified amount of load, and had little or no risk of injury while performing the subtasks (Boutcher, 2011). The chances of this happening were less with well-trained participants than with sedentary participants. Participants were also free of any recent (within one year) musculoskeletal injuries to make sure they were able to perform the prescribed subtasks. There were no restrictions on participants' statures or body masses as these were not of particular interest in citrus harvesting. However, these demographics were collected for each participant to inform the methodology protocol. Since citrus harvesting in general is performed by both male and female workers in the field, the laboratory study also included both sexes as opposed to isolating one sex. However, it was observed during the task analysis that only males harvested fruit using the tall ladders and only females harvested fruit as ground workers and step ladder workers. The same was performed in this study and all male participants were automatically assigned to the tall ladder workers while the females were randomly assigned to either the ground or the step ladder worker group. Worker ages in the field ranged from 18 years to late 50's. However, the age of participants in this phase of the study was restricted to 19-25 years in order to ensure that any differences in responses were due to the effects of the different bag designs, rather than of age. Any participants with a fear of heights (for tall ladder and stepladder workers simulation) were excluded from this study as this fear/anxiety would interfere with performance and eventually the results obtained, even with proper habituation to the task requirements.

4.2.8 Experimental procedure

4.2.8.1 Introductory session

After ethical consent was obtained from the Department of Human Kinetics and Ergonomics Ethics Committee at Rhodes University, participants were recruited verbally, and, at a later stage, required to come to the laboratory in the above-mentioned department for an introductory session. Volunteers were assigned to one of the different worker groups, namely ground worker group (females only), stepladder worker group (females only) and tall ladder worker group (males only). During this introductory session, 1) participants were welcomed, informed of the proper clothing to wear while performing the conditions (this included closed training shoes and preferably gym wear), and given an information letter (Appendix B), 2) the researchers' expectations of the participants were outlined, as well as any risks, benefits and issues pertaining to privacy, anonymity and confidentiality, 3) the task requirements and procedures were explained verbally (as in the information letter), as well as the 4) maximum voluntary contractions (MVCs) for the three different muscle groups. Thereafter, 5) a consent form was signed by each participant (Appendix C) and 6) basic demographic data were collected. These data included; age, sex, mass, stature and arm length. Finally, 7) participants underwent the habituation process.

4.2.8.2. Habituation process

Habituation to the different subtasks, depending on the worker group allocated to, to the three different bag designs and to all materials and equipment used, were performed during the introductory phase/session. This habituation process was essential to ensure that the differences in responses obtained would be solely as a result of the bag design and no other interfering variables. This was done by allowing all participants to wear the different harvesting bag designs with added load, while performing the various subtasks according to the worker group they had been assigned to. EMG electrode use was demonstrated and MVC protocols were rehearsed. The researcher ensured that all participants were fully habituated, and was content with level of habituation when participants showed full understanding of the testing protocol as well as the overall aim of the study, and were comfortable executing the harvesting task at a smooth and continuous pace, i.e. no “stop-start-motions”. More habituation sessions on consecutive days were held to ensure that any residual anxiety experienced with using the equipment, especially climbing the tall ladder, was almost completely eliminated. These habituation sessions were essential to ensure that the responses obtained were as a result of the independent variable and not the results of learning effects.

Following these habituation sessions, participants were further required to come into the laboratory on three separate days. On each day, one condition was performed; hence each participant performed a total of three conditions over the three testing sessions. The ground worker group performed conditions 1-3, while the stepladder worker group performed conditions 4-6, and the tall ladder worker group conditions 7-9, the order of which depended on the randomization order.

4.2.8.3 Testing protocol for each worker group

The following procedures were performed on each testing day for all participants, regardless of the worker group they had been assigned to:

On arrival at the laboratory, trapezius, anterior deltoid and erector spinae muscles were located, cleaned and surface electrodes were placed on these muscles, following the standard electrode placement protocol developed by Gross *et al.* (2009). MVCs for each muscle were performed as explained previously and rehearsed during the habituation phase. The participant was then required to perform either conditions 1-3, if allocated to the ground worker group, or 4-6 (stepladder worker group), or 7-9 (tall ladder worker group) and according to the randomization order (see randomization order per participant in Appendix E). Participants performed three cycles of each condition. Muscle activity was measured throughout all three harvesting cycles and local RPE of the lower back and shoulders were assessed at the end of each cycle. For shoulder RPE, it must be noted that while using the hip belt and standard bag designs, all participants reported the highest RPE data which was for the right shoulder (this was the shoulder in which the strap was placed on). The researcher also performed a time study during the testing protocol to assist later on during the data reduction and analysis. One harvesting cycle lasted for 13-17 minutes depending on the condition, and each condition took approximately 45 minutes, The full test session, including set up and MVCs, lasted approximately one hour.

The participant's performance speed throughout the entire procedure was self-paced. Since fatigue was not being assessed in this study, controlling the pace was of no interest to the researcher. However, to prevent rushing which may have led to uncontrolled actions and potentially injury (although such interference should not be necessary with proper habituation), the researcher guided the participants to perform subtasks in a smooth and continuous manner. Also, a detailed time study was performed to assess how long each participant took per subtask, per cycle and per session, in case pacing issues arose later on in the study. Once a condition had been completed, the researcher and research assistants removed all equipment from the participant. Participants took 2-4 days for rest (muscle recovery) before their next testing session.

4.2.9 Data reduction and statistical analyses

All experimental EMG data from the Biometrics DataLOG, as well as the perceptual data from the RPE scale were obtained and first reduced using the HKE Data Reduction Tool, an in-house developed software program which assists with the reduction of raw data. These data were then entered into the Statistica Statsoft Inc. software 2014. Descriptive statistics including means and standard deviations for all dependent variables were obtained. One-factorial Analyses of Variance (ANOVA) with repeated measures were then used for each worker group to identify statistically significant changes in muscle activity, and ratings of perceived exertion between all three bag design). Significant differences were considered at a 0.05 level (p-value<0.05) with confidence intervals of 95% and Tukey post-hoc analyses were conducted where necessary to identify between which conditions the significant differences lay.

It must be pointed out that during the data collection, although all participants were right handed and found it most natural to have the strap of the standard and the hip belt bag design sitting on the right shoulder and hence, the bag itself, resting on the left side of the body (non-dominant side), two of the participants found it most natural for the strap to hang on the left shoulder and the bag itself on the right side of the body. To normalize the data during the data analysis, EMG data for these were adjusted accordingly to fit the rest of the group by switching EMG results of the left for the right and vice versa).

4.3. Results

This results section shows basic demographic data, EMG and RPE results using descriptive statistics in tables and parametric statistics in graphical format for the different worker groups. All p-values not mentioned in this section can be found in statistical tables in Appendix G.

4.3.1 Demographic data

Table III: Descriptive stats for participant demographics (means ± standard deviations; CV=coefficient of variation presented as a percentage).

	Ground Workers (n=12)	**Stepladder Workers (n=12)**	**Tall Ladder Workers (n=12)**	**All Workers (n=36)**
Sex	Females	Females	Males	12 Males; 24 Females
Age (years)	21.58 ± 2.15 CV= 9.96%	20.97 ± 1.17 CV= 5.61%	25.17 ± 3.11 CV= 12.30%	23.88 ± 4.73 CV= 19.00%
Mass (kg)	60.50 ± 1.57 CV= 2.51%	65 ± 1.97 CV= 3.43%	72.11 ± 2.85 CV= 4.00%	69.47 ± 4.11 CV= 5.93%
Stature(mm)	1528.3± 31.11 CV= 2.03%	1670 ± 34.42 CV= 2.06%	1757.8± 42.71 CV= 2.43%	1693.0 ± 47.35 CV= 2.80%

4.3.2 Electromyography (EMG)

The EMG results for the different muscles are presented according to each individual worker group. This structure was selected as the study focuses on comparing muscle activity for the different bag designs and not a comparison of the different worker groups, since the tasks each worker group performed differed. In addition to this, muscle activity for the overall harvesting task (i.e. all three cycles together) is presented below. Although not presented in this section, analyses of each individual cycle, as well as each individual subtask were considered, as the focus of this study was to compare which bag design is best for the overall harvesting task and not for each individual cycle or subtask.

The tables below show descriptive EMG statistics for the different worker groups and different muscle groups.

4.3.2.1 Ground workers

Table IV: Descriptive statistics (means ± standard deviation; CV=coefficient of variation presented in %) comparing left and right sides muscle groups (where LT= left trapezius, RT= right trapezius, LAD= left anterior deltoid, RAD= right anterior deltoid, LES=left erector spinae and RES= right erector spinae).

	LT	RT	LAD	RAD	LES	RES
Standard bag	32.67±9.07 CV=27.76%	32.85±17.37 CV=52.87%	28.61±10.94 CV=38.23%	32.42±7.70 CV=23.75%	15.06±6.84 CV=45.41%	26.11±5.63 CV=21.56%
Hip belt bag	28.11±8.91 CV=33.90%	26.29±8.91 CV=33.90%	20.03±8.81 CV=43.99%	36.36±17.75 CV=48.81%	4.83±4.37 CV=90.12%	24.20±5.09 CV=21.00%
Backpack bag	22.84±10.77 CV=47.15%	21.14±8.99 CV=42.52	25.21±17.07 CV=67.71%	31.82±9.59 CV=30.01%	2.41±11.87 CV=492.53%	21.30±7.48 CV=35.11%

** Shaded cells indicate bag designs that differ significantly from one another (p<0.05).*

The table above shows that the backpack design required the least muscle activity (with exception of the left anterior deltoid) and the standard bag required the most (except for the right anterior deltoid). When using the backpack design, for both sides of each muscle group there was less muscle activity compared to when using the standard bag and the hip belt bag. The left trapezius showed a significant differences in muscle activity between the standard bag and the backpack design (p=0.010) and the left anterior deltoid also showed significant difference between the standard bag and the hip belt bag designs (p=0.017)

<u>Asymmetry ratio</u>

Even though no biomechanical variables were measured per se, the ratio of left to right muscle activation was used to make inferences about postural symmetry/asymmetry. It was hypothesized that asymmetry would be reduced when using the hip belt and backpack bag designs. Figure 11 shows the asymmetry ratio (right side: left side) for the different muscles amongst the ground workers. A ratio of > 1, indicates that there was more muscle activity on the right side of the body than the left, a ratio of < 1, indicates more muscle activity on the left than right, while a ratio of =1 indicates symmetry/equal muscle activity on both sides of the body.

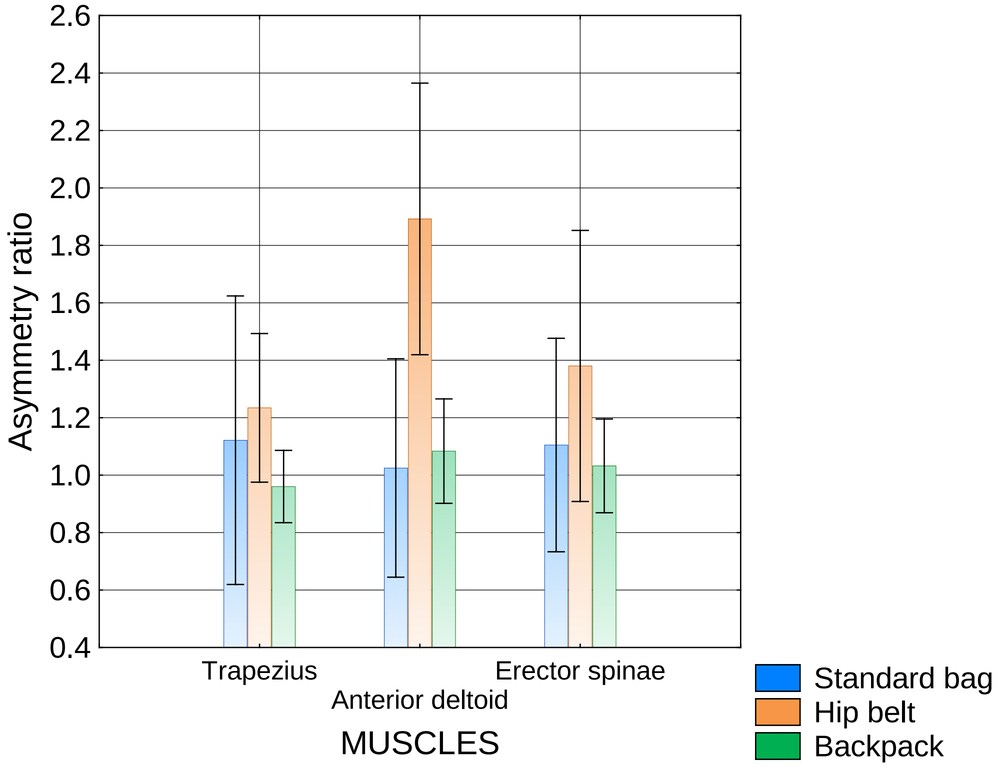


Figure 11: Ground workers asymmetry ratio (right: left sides) for the different muscle groups and the different bag designs.

Figure 11 shows that when using the standard and backpack bag designs, there was greater symmetry in activation between right and left sides of all three muscles (i.e. the asymmetry ratio was closer to 1), compared to when using the hip belt design, which showed the greatest degree of asymmetry. There was a significant difference between the hip belt and backpack for the anterior deltoid (p=0.01316). Also evident is that the variability of the backpack design was considerably less than that of the standard bag and the hip belt designs. For the trapezius asymmetry was similar when participant used all three bags. However, there was a significant difference for the anterior deltoid when using the hip belt bag compared to the other two bag designs.

4.3.2.2 Stepladder workers

Table V: Descriptive statistics comparing left and right sides muscle groups (means ± standard deviation; CV=coefficient of variation (%).

	LT	RT	LAD	RAD	LES	RES
Standard bag	27.34±8.24 CV=30.1%	31.50±14.56 CV=46.22%	29.46±11.16 CV=37.89%	37.70±10.65 CV=28.25%	19.90±8.08 CV=40.60%	26.11±14.19 CV=54.35%
Hip belt bag	18.79±5.74 CV=30.54%	24.94±7.63 CV=30.60%	30.87±7.99 CV=25.88%	39.68±10,34 CV=26.05%	16.16±6.75 CV=41.76%	18.10±10.87 CV=60.06%
Backpack bag	20.38±9.52 CV=46.17%	21.75±11.62 CV=53.43%	33.59±8.63 CV=25.70%	25.14±14.83 CV=58.99%	11.19±5.73 CV=51.02%	4.30±4.42 CV=102.80%

** Shaded cells indicate significant differences between conditions (p<0.05).*

In the table above, the general trend observed, according to the means is that there was more muscle activity required to utilize the standard bag (with exception of the LAD and RAD). Except for the left trapezius and the left anterior deltoid, the backpack design required the least muscle activity. This was expected as this bag design has been proven to redistribute load more evenly across the body, and hence, reduce muscular activity (Motmans *et al.,* 2007*).* Significant differences in muscle activity were observed in the left trapezius between standard and hip belt (p=0.0083) and standard and backpack (p=0.0332) bag designs. For the right trapezius, a significant difference existed for the standard and backpack bags (p=0.016) for the right anterior deltoid, a significant difference between hip belt and backpack (p=0.0218), and for the left and right erector spinae, significant differences existed between the standard and backpack designs (p=0.0068 and 0.0559 respectively).

Asymmetry ratio

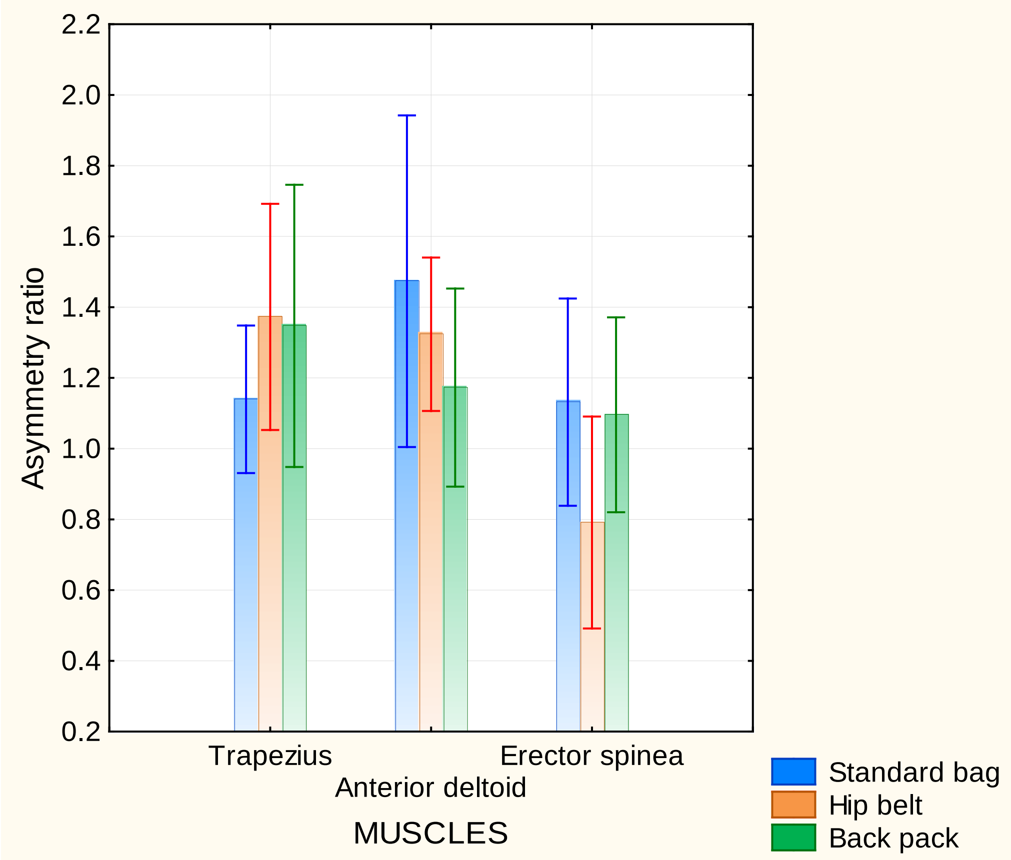


Figure 12: Stepladder workers asymmetry ratio for the different muscle groups and the different bag designs.

Figure 12 shows that, irrespective of the bag designs, there was more activity in the right muscles, as all (except for erector spinae for the hip belt) asymmetry ratios are greater than 1. However, for the different muscles, there was no significant difference between the bag designs.

4.3.2.3 Tall ladder worker

Table VI: Descriptive statistics comparing left and right sides muscle groups (means ± standard deviation; CV=coefficient of variation (%)

	LT	RT	LAD	RAD	LES	RES
Standard bag	24.60±18.45 CV=75%	27.03±18.37 CV=67.96%	28.52±8.01 CV=28.08%	32.77±13.45 CV=41.04%	17.94±4.77 CV=26.60%	20.12±15.02 CV=74.65%
Hip belt bag	21.93±8.15 CV=37.16%	24.30±10.81 CV=44.48%	39.95±15.39 CV=38.52%	42.76±24.17 CV=56.52%	17.46±4.26 CV=24.39%	20.42±5.75 CV=28.16%
Backpack bag	20.60±12.27 CV=59.56%	25.72±11.24 CV=45.47%	30.98±10.71 CV=34.57%	22.91±9.63 CV=42.03%	12.96±5.35 CV=41.28%	13.36±5.02 CV=37.57%

** Shaded cells indicate significant differences between conditions (p<0.05).*

The general trend observed from the participants in the tall ladder group was, with exception of the left anterior deltoid and right trapezius, that the backpack design required the least muscle activity. For the left anterior deltoid and right trapezius, the standard bag and the hip belt designs respectively, required the least muscle activation. The following significant differences were observed: 1) left anterior deltoid, significant difference between the standard and hip belt bags (p=0.0292), 2) right anterior deltoid, between hip belt and backpack designs (p=0.0155), and 3) left erector spinae, significance between standard bag and backpack (p=0.02207) and between hip belt and backpack (p=0.0401).

Asymmetry ratio

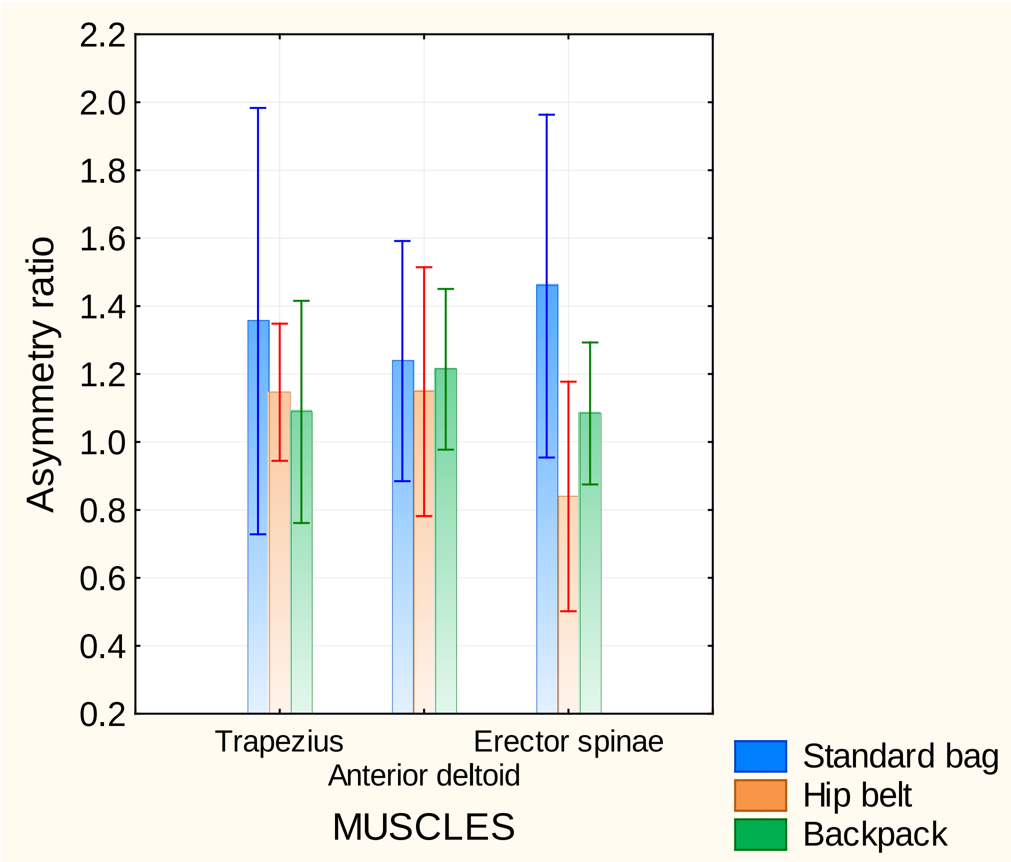


Figure 13: Tall ladder workers asymmetry ratio for the different muscle groups and the different bag designs.

Regardless of the bag used, the muscles on the right side of the body were more activated than those on the left, the one exception being the hip belt bag design, which resulted in the left erector spinae being more activated than the right (with a ratio of< 1). In comparing the bag designs, no significant difference was found. The graph above shows that the standard bag, for all muscle groups, had the highest asymmetry ratios compared to the hip belt and backpack designs.

4.3.3 Ratings of Perceived Exertion (RPE)

The RPE results are presented below for each worker group in form of descriptive stats in tables and Statistica graphs. The focus here was to compare RPE responses for the different bag designs within each worker group.

The general trend observed here was that for all worker groups, the overall harvesting session and for both shoulder and lower back RPE, when using the standard bag design, the highest levels of perceived exertion were obtained compared to the other two bag design. These results were significant. This is expected as it is hypothesized in the current study that the backpack and hip belt bag design are better than the standard harvesting bag design to reduce asymmetry and therefore, musculoskeletal strain measured through RPE responses.

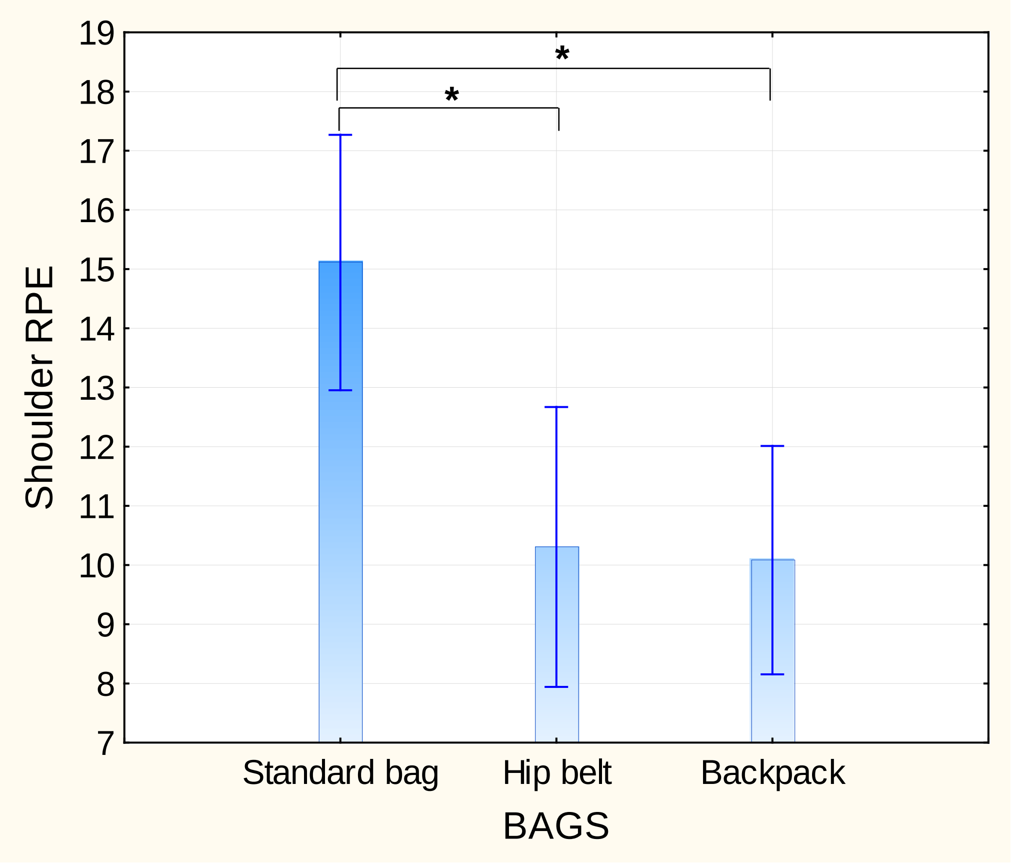
Although not presented in this section due to the researcher's intention to only compare RPE for the overall harvesting/test session (comprising of 3 cycles), RPE results for each individual cycle and for the different bag designs were considered for analysis. The general trend observed here was that RPE was highest in cycle one and decreased through to cycle 3. These findings are later discussed in section 4.4.

4.3.3.1 RPE

4.3.3.1.1 Ground worker

Table VII: Descriptive statistics (means ± standard deviation; CV=coefficient of variation (%)

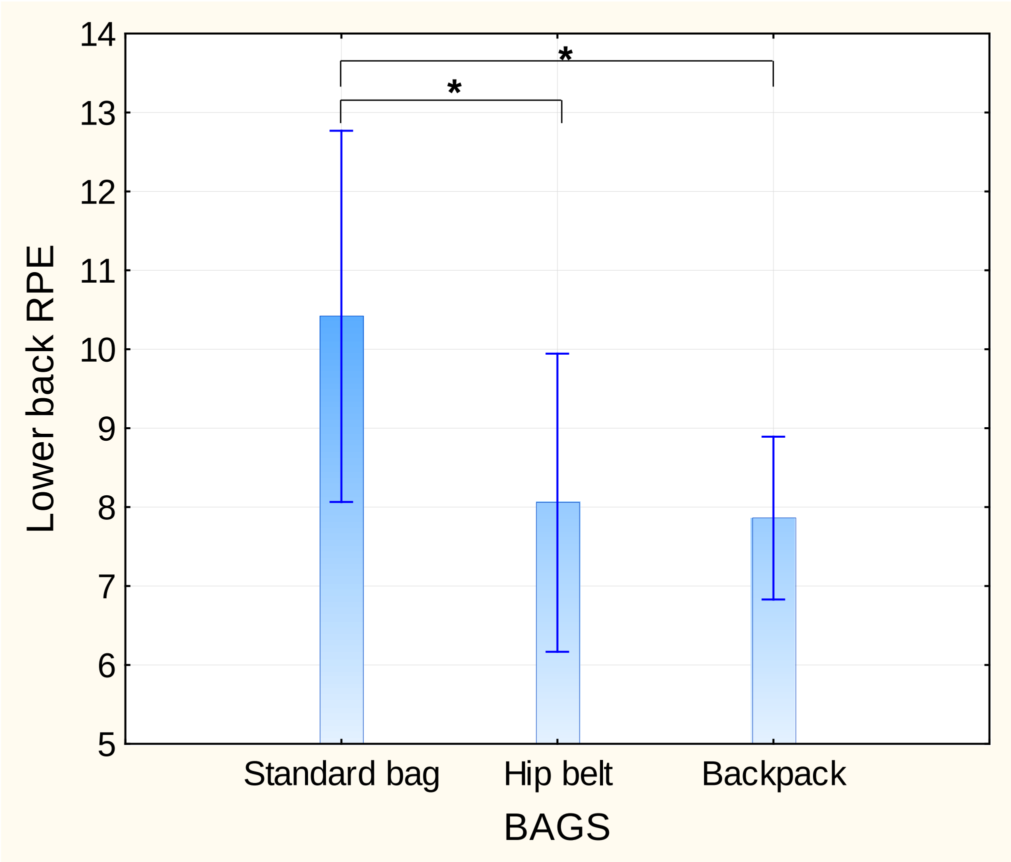
	Standard bag	**Hip belt bag**	**Backpack bag**
Shoulder RPE	15.11 ± 2.08 CV=13%	10.3 ± 2.22 CV=22%	9.97 ± 1.91 CV= 19%
Lower Back RPE	10.72 ± 2.25 CV=20.99%	8.06 ± 1.78 CV=22.08%	7.94 ± 1.02 CV= 12.85%



(Brackets with asterisk (*) indicate significant difference at p< 0.05).

Figure 14: Mean shoulder RPE responses to different bag designs for the ground workers.

The above figure and table represent shoulder RPE response when using the different bag designs. Collectively, all ground workers perceived the highest exertion when utilizing the standard bag and the least exertion when using the hip belt and backpack bags. Significant differences exist between the standard bag and the hip belt bag and standard bag and the backpack bag (p= 0.000136 for both).



Brackets with asterisk (*) indicate significant difference at p< 0.05).

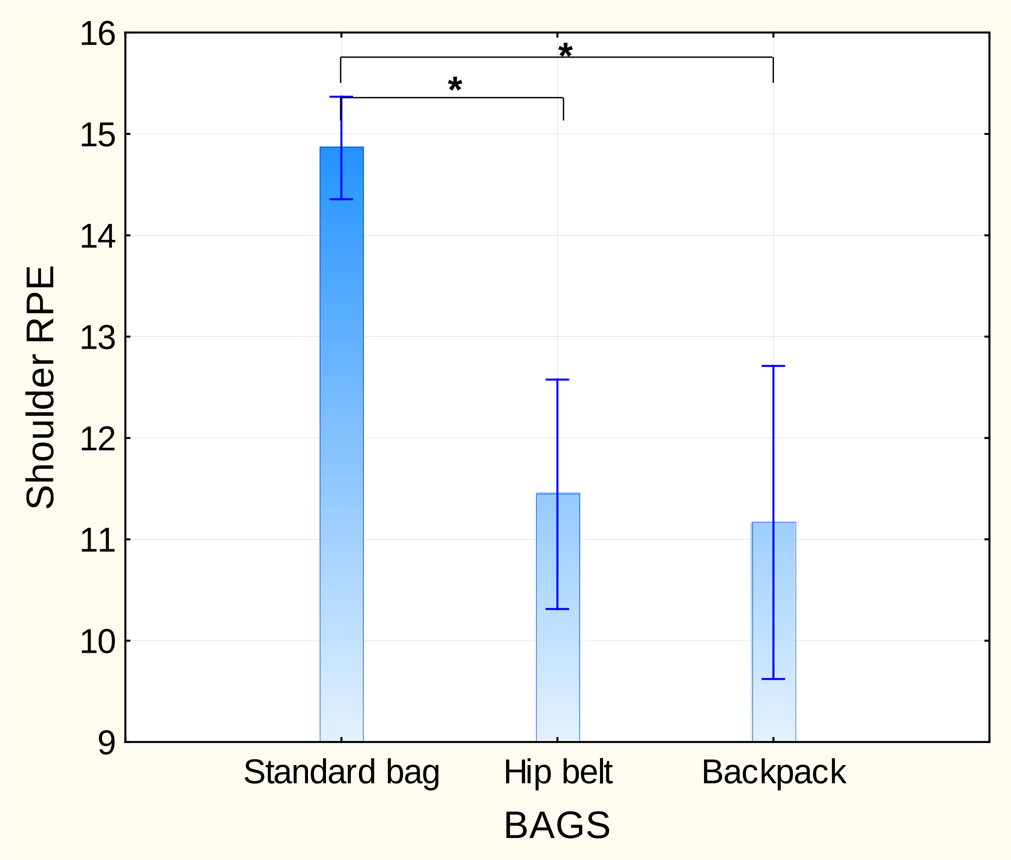
Figure 15: Mean lower back RPE response to different bag designs.

When workers in this worker group made use of the standard bag design, they experienced the highest effort in the lower back compared to when they used the other two bag designs. Significant differences exists between the standard bag and hip belt bag (p=0.001382) and also between the standard bag and the backpack bag (p=0.00670).

4.3.3.1.2 Step ladder worker

Table VIII: Descriptive statistics (means ± standard deviation; CV=coefficient of variation (%)

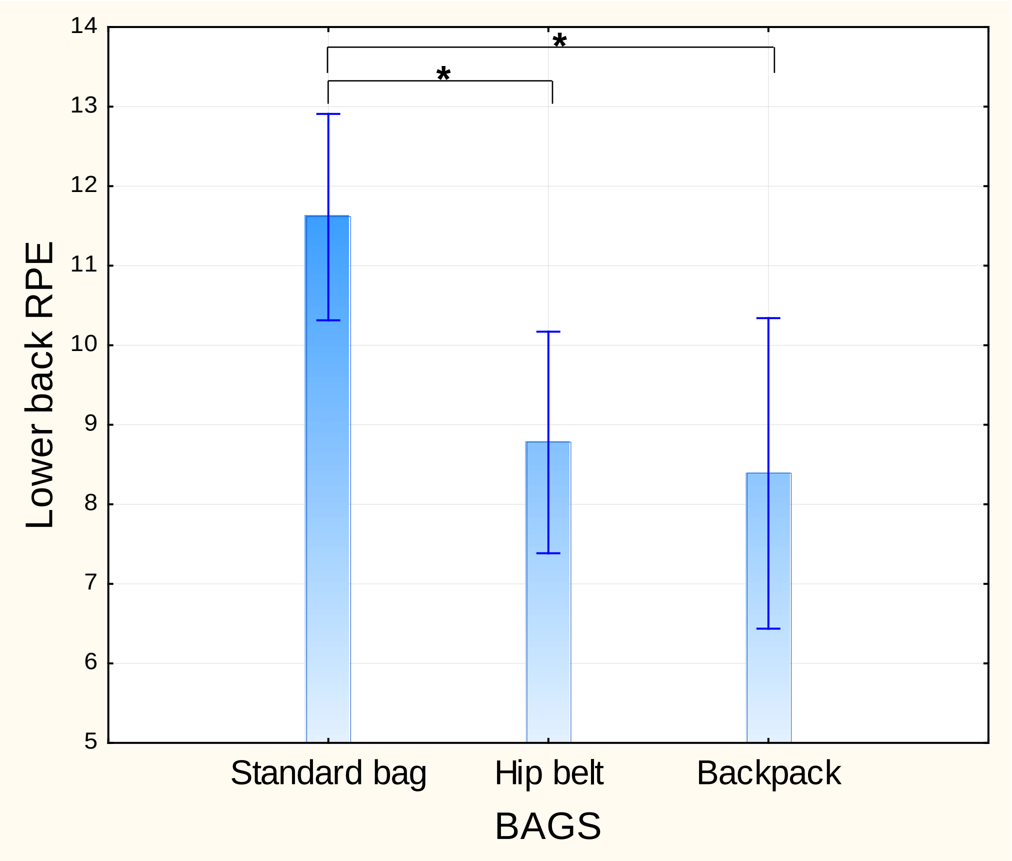
	Standard bag	**Hip belt bag**	**Backpack bag**
Shoulder RPE	14.86 ± 0.64 CV=4.30%	11.44 ± 1.27 CV=11.10%	11.19 ± 1.56 CV=13.94%
Lower back RPE	11.61 ± 1.35 CV=11.62%	8.78 ± 1.42 CV=16.17%	8.28 ± 1.78 CV= 21.49%



(Brackets with asterisk (*) indicate significant difference at p< 0.05).

Figure 16: Mean shoulder RPE response to different bag designs for the stepladder workers.

The above table and figure show that significantly greater RPE responses were recorded for the standard bag than for the hip belt and backpack bag designs. This is similar to the results for the ground workers. These significant differences were between standard bag and hip belt bag (p=0.000136) and standard bag and backpack (p=0.000136).



Brackets with asterisk (*) indicate significant difference at p< 0.05).

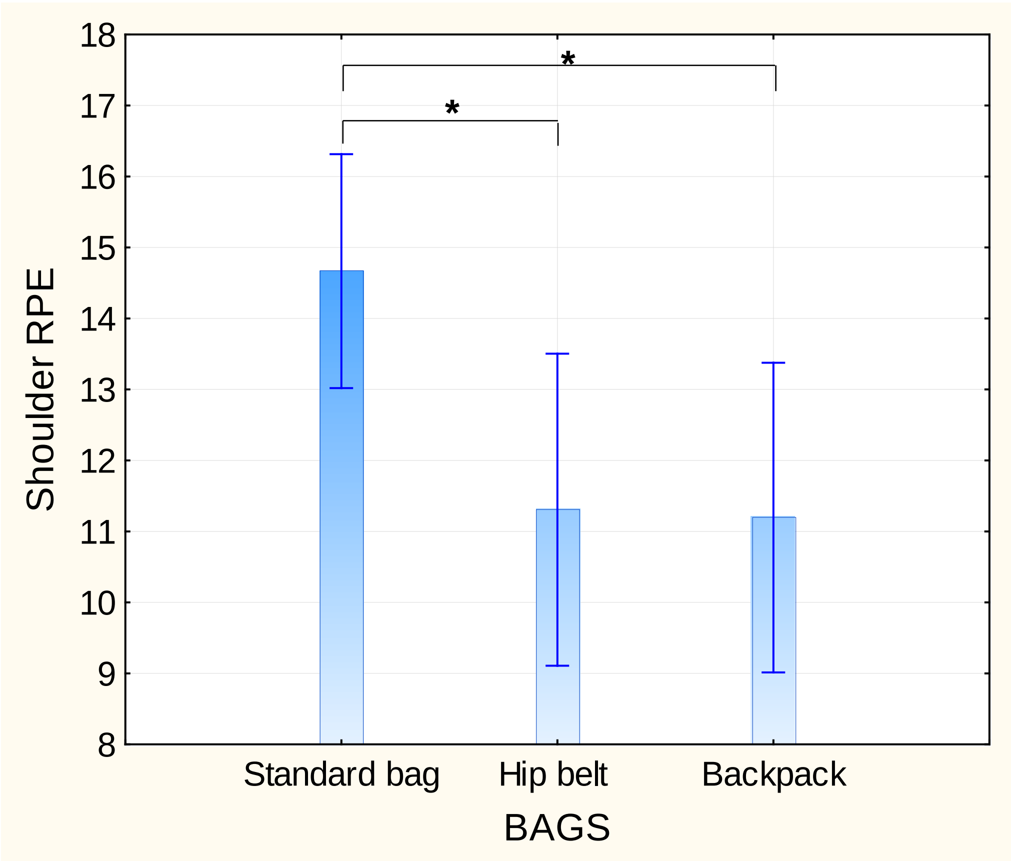
Figure 17: Mean lower back RPE response to different bag designs.

Again the standard bag required the highest perceived exertion and the backpack required the least. Significant differences exists between the standard bag and hip belt bag (p=0.00018) and also between the standard bag and the backpack bag (p=0.000142).

4.3.3.1.3 Tall ladder worker

Table IX: Descriptive stats means ± standard deviation; CV=coefficient of variation (%)

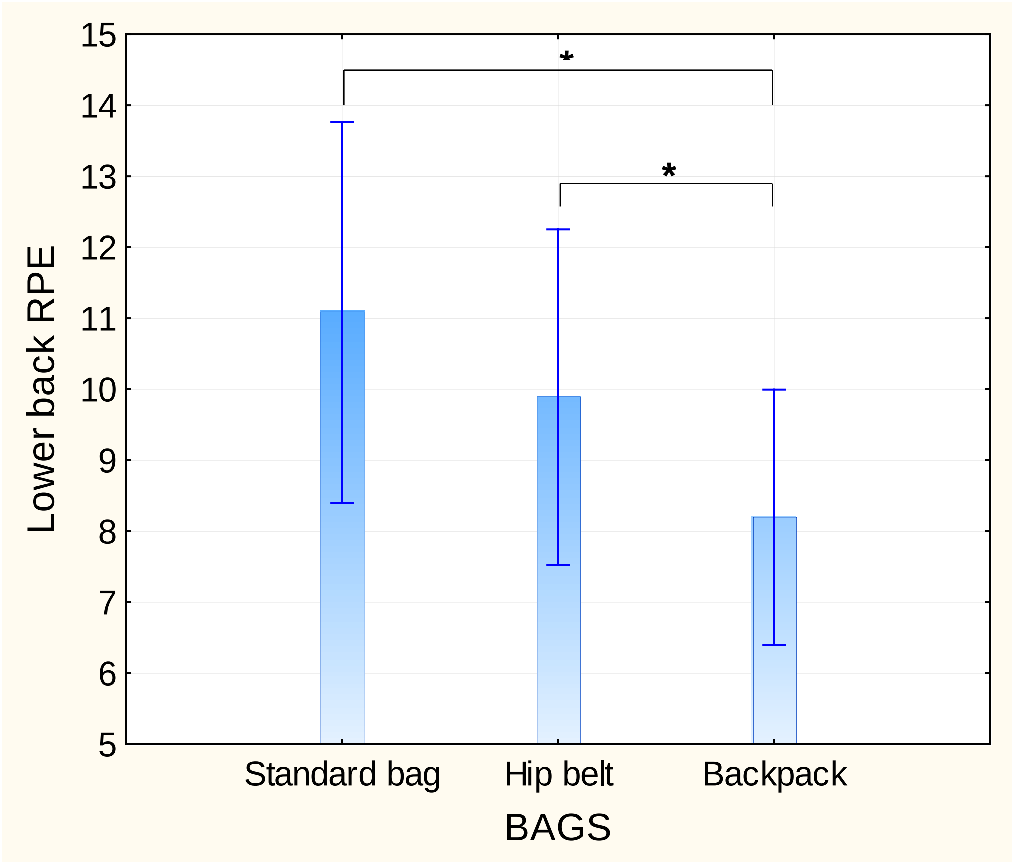
	Standard bag	**Hip belt bag**	**Backpack bag**
Shoulder RPE	14.67 ± 1.57 CV=10.70%	11.31 ± 2.33 CV=20.60%	11.19 ± 2.04 CV= 18.23%
Lower back RPE	11.08 ± 2.56 CV=23.10%	9.89 ± 2.76 CV=27.90%	8.19 ± 1.78 CV= 21.73%



Brackets with asterisk (*) indicate significant difference at p< 0.05).

Figure 18: Mean shoulder RPE response to different bag designs for the tall ladder workers.

A similar trend is observed here for the tall ladder worker group, where the standard bag elicited the highest RPE response and the hip belt and backpack, elicited the least. Significant differences in shoulder RPE for the tall ladder workers were found between standard bag and the hip belt bag (p= 0.0001) and the standard bag and the backpack bag (p=0.0001) only.



Brackets with asterisk (*) indicate significant difference at p< 0.05).

Figure 19: Mean lower back RPE response to different bag designs.

The standard bag required the highest perceived exertion and the backpack required the least. The hip belt bag unexpectedly, elicited high RPE responses for this worker group. Significant differences exists between the standard bag the backpack bag (p=0.000370) and between the hip belt and the backpack (p=0.0270).

4.4 Discussion

4.4.1 EMG

The general trend observed from the participants' responses is that mean muscle activity was less when using the backpack bag design compared to using the other two bag designs; the standard bag generally elicited the highest muscle activity. These results support various load carriage studies such as those by Murray & Miller (1985 &1989), Motmans *et al.* (2007), Corrigan & Xian Liu (2012) and Bao *et al*. (2013), who all found that the use of a backpack bag design in load carriage decreases muscle activity and muscular strain; since the load is now evenly distributed across the body (i.e. symmetrical). As hypothesized in the current study asymmetry was reduced with the use of the backpack bag design for the citrus harvesting task evident with the reduced muscle activity observed.

Descriptive stats in the previous section provide information for the left and right sides of the three muscle groups tested. In order to assess symmetry/asymmetry, it was essential to compare activity in the left and right sides of each muscle. Where muscle activity was similar in the left and right sides of the muscle, this indicated symmetry; but where muscle activity differed between sides, showed asymmetry. It was hypothesized that the greatest asymmetry for the selected muscle groups would occur when the participants were utilizing the standard bag design. The asymmetry ratio differed slightly for the different worker groups (since they performed slightly different harvesting tasks). However, asymmetry ratio when using the different bags and considering all participants were right handed showed that the right side (dominant side) was generally more activated than the left side (non-dominant). For example, the trapezius and anterior deltoid and the results show asymmetry. This was expected as the left and right trapezius performed different tasks e.g., during clipping the fruit, the right arm (trapezius) remained constantly elevated, while the left trapezius was collecting the harvested fruit. However, it must also be considered that because the single strap of the standard bag was placed on the right side of the body, certain tasks such as clipping, carrying a full load of fruit or carrying the ladder would increase the effort/muscle activation on the right side of the body. For this reason the other two bag designs were made to redistribute the load to the hips (hip belt bag) as well as the hips and both left and right shoulders (backpack design) and hence, reduce effort on the right side of the muscles. Asymmetry in the erector spinae was expected when using the standard bag due to the position of the load causing the spine to tilt towards the direction of the load. In a similar manner, the addition of the hip belt to this design as well as the backpack design was expected to produce more symmetry as the load would be now evenly distributed between the left and right sides of the body.

Motmans *et al.* (2007) found that for a unilateral means of load carriage similar to the one used in the current study, using a reference of 100%, EMG activity levels (%MVC) on the right side of the body, specifically the erector spinae and rectus abdominis (RA) were highest (206% / 209% right ES/RA and 203% / 201% left ES/RA) while carrying a single strap shoulder bag. They then concluded from their findings that asymmetry in muscle activity may indicate a failure of trunk stabilization and contribute to the development back pain and for this reason; shoulder bags must be avoided (Motmans *et al.*, 2007).

In the ground worker group, the asymmetry ratio for the backpack design for all muscle groups was between 0.9 and 1. This indicates high symmetry and supports research by Murray & Miller (1985 &1989), Motmans *et al.* (2007), Corrigan & Xian Liu (2012) and Bao *et al*. (2013), which suggests improved symmetry with the back pack design. However, Figure 11 showed unexpected results in this worker group, as the hip belt bag design elicited a greater asymmetry for the anterior deltoid in comparison to while using the standard bag (p= 0.001). This result obtained for the ground workers contradicts load carriage research by Earle-Richardson *et al*. from 2004, where the addition of the hip belt feature to a unilateral strap bag, was seen to displace/redistribute load more evenly across the body (specifically between the shoulder and the hip), as 71.4% of apple harvesters noted a reduction in back, neck and shoulder pain. This contradiction of the current study may be due to the large variation observed.

Amongst the stepladder workers, the least asymmetry for the anterior deltoid and the erector spinae was observed while using backpack design. There appeared to be more muscle activation in the right than left trapezius. This was expected since all participants were right handed and performed the clipping task with the right hand. This means that throughout the clipping task, the right shoulder was constantly elevated. As a result of the load distribution, as well as reduction of pressure on the shoulders from the single strap of the standard bag, the hip belt and backpack designs produced smaller asymmetry. This supports prior studies such as Earle-Richardson *et al,* (2004; 2006) and supports the alternative hypothesis of the current study.

As expected symmetry was highest in the different muscle when the tall ladder workers utilized the backpack (asymmetry ratio ranging from 1.1-1.2), this indicates that the right side was more activated than the left when using this bag design. No further interesting results were observed in this worker group.

4.4.2 RPE

The perceived exertion ratings recorded for the shoulders and lower back suggest that participants experienced significantly higher exertion when the standard harvesting bag design was used compared to the other two bag designs.

These results support Earle-Richardson *et al.* (2000 & 2004) who found that by using the hip belt bag design to harvest apples, the workers complained less of any musculoskeletal pain than when using a unilateral shoulder bag. This same study by Earle-Richardson *et al.* (2004) did however not compare their findings to a backpack design which elicited the lowest RPE ratings in the current study. This is the general trend across all the worker groups and for the selected body areas. The results obtained from the current results also concur with various load carriage research by Murray & Miller (1985 &1989), Motmans *et al.* (2006), Corrigan & Xian Liu (2012) and Bao *et al*. (2013), whose research suggested that a backpack bag design is more effective in eliminating asymmetry by distributing load across the body and hence, reduce muscular strain. It must be noted that the above studies were performed in a laboratory setting and utilized only objective measures such as EMG and gait analyses. However, it is safe to infer from their findings that if muscle activity and muscular strain was reduced, then subjective ratings of perceived exertion may also be reduced.

With regards to the different worker groups, it was expected that the ground workers would have the higher shoulder RPE scores than the other two worker group, when using the standard bag design, since they were required to work over head. The mechanical pressure acting on the right shoulder (the shoulder in which the single strap was placed) is aggravated further when this worker group work in an overhead posture (Motmans *et al.,* 2007; Corrigan & Xian Liu, 2012). However, this was not the case as all the worker groups provided similar mean shoulder RPE scores when using the standard bag. This could be as a result of subjective feedback, from the participants in the other two workers groups being biased, since they understood that this bag design should elicit the highest exertions.

It must be noted that the researcher assessed the overall harvesting task as opposed to individual harvesting cycles in order to simulate field work. However, it was anticipated that fatigue and hence, RPE responses would increase through the harvesting cycles; but, this was not the case. Instead, participants became more accustomed to the harvesting task across the cycles and hence perceived less exertion from cycle 1-3.   This could be due to the controlled laboratory environment where there was no environmental factor which field workers are exposed to, such as heat. Another reason for a reduction in perceived exertion through the cycles; the few number of harvesting cycles performed as well as the short duration of harvesting. It is expected that with more harvesting cycles performed perceived exertion would increase.

The RPE (subjective) and EMG (objective) responses for the shoulder/trapezius and lower back/erector spinae was observed and support each other. EMG results for the trapezius for all worker groups (except the step ladder worker group) reported the standard bag to require the most activation and the backpack, the least. This was also the case for the shoulder RPE responses. Similarly, the erector spinae (EMG) and lower back (RPE) support each other.

4.5 Conclusion, Limitations and Recommendations

The EMG and RPE results obtained from this phase of the study, support that the backpack bag is the best design to reduce muscular effort and asymmetry and the standard bag is the worst. This is evident as the workers perceived less exertion and had the lowest muscle activity when they made use of the backpack design while the opposite occurred when they used the standard bag. In conclusion, on the basis of the laboratory results, the null hypothesis is rejected and the alternative hypothesis accepted.

However, this study did have the following limitations that could have influenced the above results. Due to practical reasons no biomechanical responses were measured in the current study. For a holistic approach, biomechanical measures in addition to physiological and perceptual measures should be utilized in future studies. In addition, only three harvesting cycles were performed in this study. To reduce variability between cycles and to make the protocol more similar to what is performed in the field, more cycles should be performed. This will not only reduce variability but will also be a more accurate simulation to real citrus harvesting in which 50-80 cycles are performed throughout the course of the work day.

No cardiovascular variables were assessed in this study only bio-physiological (EMG) and perceptual (RPE) and should therefore be considered for future studies. Finally, participants were aware of the negative effects of the standard bag. For this reason, it is likely that a natural bias (reflected in the subjective feedback) to this bag was formed.

CHAPTER 5: FIELD STUDY

5.1. Introduction

The purpose of the second phase of this study was to introduce the new harvesting bag designs, developed at the beginning of the project, into the field and again compare these new designs to the standard bag design, but this time by measuring the workers' performance and subjective responses. It is highlighted in literature that there is a need for researchers to convey their findings from the laboratory into the field (Bao & Shahnavaz, 1989). However, important as this is, it must be mentioned that various factors obstruct/influence a smooth acceptance of laboratory findings (ergonomic interventions) into the field. Factors include workers' attitudes and behaviour to change and also limited or no incentive or gains from adopting the new intervention (Bao & Shahnavaz, 1989). This field component was an essential element of the greater project to assess whether the citrus workers and/or the company would benefit from the scientific findings obtained during the laboratory phase of this project. Variables such as RPE, total number of bags harvested per day, and worker acceptance/willingness were measured in this phase of the study to assess workers' perceived exertion, productivity and perceived usefulness and ease of use to the new bag designs in comparison to the standard bag design.

5.2 Methodology

The purpose of this field study was to compare, in a field setting, the workers' acceptance (usefulness and ease of use) and productivity between the standard harvesting bags and the two newly designed bags amongst the different citrus worker groups (ground, stepladder and tall ladder workers).

5.2.1 Experimental design

A partially repeated measures design was adopted for this phase of the project, as workers in the field are assigned to one worker group (i.e. ground worker, stepladder worker or tall ladder worker) and only always harvest fruits according to that specific group they belong to. A complete repeated measures design was therefore impossible for this phase. All workers from each population group were exposed to each of the bag designs with at least one to two full hours of habituation to the bag designs.

5.2.2 Statistical Hypotheses

The null hypothesis stated that the perceptual and productivity results of the standard harvesting bag design would be no different to those produced by the new bag designs when tested amongst the different worker groups in the field. The alternative hypothesis stated that there would be a significant difference.

Ho: $\mu_{SB} = \mu_{HB} = \mu_{BP}$

Ha: $\mu_{SB} \neq \mu_{HB1} \neq \mu_{BP}$

Where:

μ= Perceptual responses (RPE), productivity, (number of bags harvested/day) and workers' perceived usefulness and ease of use ratings

SB= standard bag design

HB-hip belt bag design

BP= backpack bag design

5.2.3 Independent variables

The independent variables selected were; *1)* bag design and *2)* worker groups. Descriptions and illustrations of all independent variables can be found in Chapter 4, section 4.2.4.

5.2.4 *Dependent variables*

5.2.4.1 Local Ratings of Perceived Exertion (RPE)

Local RPE (of the shoulders and lower back) were used for this phase of the study to provide subjective indications of how much muscular effort in the shoulders and lower back participants perceived while performing the harvesting subtasks, using the different bag designs and according to the different worker groups. A standard Xhosa RPE scale (as seen in Appendix L) was utilized. It was essential, in this phase, that the researcher and Xhosa translator read out the Xhosa RPE scale, as the workers were mostly non-English speakers and had low literacy levels - a problematic issue in most industrially developing countries (O'Neill, 2000 & 2005).

This Xhosa RPE scale was presented once every hour to the participants over the duration they worked with a particular bag. The workers were then required to rate their perceived exertions according to this scale.

5.2.4.2 Productivity

Productivity refers to the ratio of output to input, i.e. the ratio of what is achieved to what was put in (Saari, 2006). In the context of this study, output was calculated as the average number of bags harvested per hour. A high productivity rate indicates that worker output is greater than input and vice versa. It was of interest in this phase to investigate the productivity effects of one bag design over the others in order to advise farm the farm workers, owners and/or managers accordingly.

5.2.4.3 Perceived Usefulness and Ease of Use (PUEU)

Perceived usefulness can be defined as the degree to which a worker (in this study a citrus harvester) believes that using a particular system/equipment (in this case the newly designed harvesting bag) will directly improve/enhance his/her job performance (Davies, 1989; Abu-Dalbouh, 2013). Perceived ease of use, on the other hand, is the degree to which a worker believes that a particular system/equipment (citrus harvesting bags) will be easy to use or operate, while improving the quality of their work (Davies, 1989; Abu-Dalbouh, 2013). It was important that general worker feedback be obtained for each bag design since the bags were designed specifically for the harvesters' use and any input (positive and/or negative) obtained from the workers using these bags would hold more value than that of laboratory participants.

The PUEU questionnaire, utilized by a few researchers such as Davies (1989) and Abu-Dalbouh (2013), is a questionnaire used to assess workers' perceptions of how useful and easy to use equipment is; for the purpose of this study, the workers' perceptions of how useful and easy to use they found each bag design. The PUEU questionnaire has been used and modified to fit the context of other studies including medical studies (Abu-Dalbouh, 2013), computer technology studies (Davies, 1989) and has been reported by the above authors to have high validity and reliability. Due to the similarities in the questions asked in the original PUEU questionnaire, the low literacy levels of the workers and translation issues (English – Xhosa), it was essential to ask questions in a manner that would not confuse the workers, hence only the two main concepts of the PUEU, namely "perceived usefulness" and "perceived ease of use" of the bags, were chosen to be asked. Specifically, the following two questions were selected to fit this specific agricultural context: *1) "how useful did you find this bag design"* and *2) "how easy to use was this bag design"*.

These questions were considered sufficient to capture the citrus workers' perceived acceptance of the new bag designs in comparison to the standard bag design. Each question was answered on a 5-point likert scale with options *"extremely useful/easy to use", "slightly useful/easy to use", "neutral", "slightly un-useful/un-easy to use",* and *"extremely un-useful/un-easy to use"* (see Appendix M).

5.2.5 Participant Sample

The participants recruited for the field phase of this project were citrus harvesters, working at a citrus farm in the Eastern Cape of South Africa. There were no restrictions on age, race, previous injury, and sex for participation. The workers fell within an age range of 18 to 69 years, and both male and female harvesters were included, as allocation of the workers to one of the three groups in the field (ground worker, step ladder worker and tall ladder worker) was sex-related. Participants were both experienced (having participated in harvesting tasks for at least one harvesting season or more) and non-experienced (the current harvesting season would be their first one - refer to Table X).

The sample for this second phase of the study included 17 citrus harvesters. Ideally, a total of 27 workers (9 workers per group) would have been required for complete randomization of the test conditions (bag designs). However, only six ground workers (five females and one male), two stepladder workers (one male, one female), and nine tall ladder workers (all males) volunteered to participate in this phase of the study. Furthermore, of the 17 workers who initially agreed to participate, eight discontinued the study- some for unknown reasons while others reported that they were not working quickly enough due to brief disruptions from participating in the study. For this reason, a total of only 9 participants completed all three conditions of the study. The resulting sample sizes for each of the worker groups were the result of the relatively small number of workers available at the citrus farm where the field phase of this project was conducted, and also due to the limited willingness of the workers to participate in the study. Despite a detailed briefing on the purpose of the project in Xhosa (the workers' mother tongue), there was great reluctance, particularly from the female workers, to participate.

The participants' statures and masses ranged from 1540-1800mm and 53-90kgs respectively (see Table X below for summary data). Although it would have been ideal to have an equal number of sexes represented within/across the different worker population groups, not all workers groups had both sexes represented (for example, the tall ladder worker group, comprised of only males.

Table X: Summary data for worker demographic group (means with standard deviations; CV = coefficient of variation)

	Ground Workers (n=1)	Stepladder Workers (n=1)	Tall Ladder Workers (n=7)	All Workers (n=17)
Sex	Female	Male	Males	1 Female; 8 Males
Age (years)	35.00 ± 0.0 CV= 0%	18.00 ± 0.00 CV= 0%	32.86±14.87 CV= 45%	31.88 ± 11.73 CV= 37%
Mass (kg)	75.00 ± 0.00 CV= 0%	53 ± 0.00 CV= 0%	67.86 ± 10.41 CV= 15%	67.00 ± 6.67 CV= 10%
Stature(mm)	1570 ± 0.00 CV= 0%	1540 ± 0.00 CV= 0%	1707.1 ± 60.2 CV= 4%	1673.3 ± 82.9 CV= 5%

5.2.6. Experimental Procedure

After ethical clearance had been granted for this phase of the research project from the Human Kinetics and Ergonomics Ethics Committee at Rhodes University, and permission had been obtained from the manager of the citrus farm selected for this phase of the study's data collection (refer to Appendices J and K), participants were approached in small groups by the researcher and a Xhosa speaking translator, to explain verbally (and in writing for the literature workers – see Appendix H) as well as through the use of demonstrations, the aim of the project, the new bag designs and the reasoning behind the new designs. Great care was taken in answering workers' questions and concerns, which mainly related to the capacity of the bags and how they would influence their harvesting routine, since the labourers were paid according to the number of bags harvested. Workers interested in participating signed a consent form (Appendix I) once the researcher and translator had verbally explained the risks, benefits, and confidentiality issues associated with the project. After this recruitment process, at least one to two hours of habituation per bag were performed for most of the participants. Although a longer habituation to the bag designs would have been ideal, due to time constraints, namely a 3 week harvesting window, as well as worker reluctance to harvest longer than necessary with the new bags, limited the time allocated to habituation. Participants were also familiarised with a Xhosa versions of the RPE scale and perceived usefulness and ease of use questions (Appendices L and M) during this habituation session.

After habituation had been performed, the actual data collection commenced. Depending on their randomization order (refer to Appendix F), each participant made use of one bag design for, ideally, the whole duration of one work shift. However, the amount of time spent using the different bag designs varied for different participants between 1-7 hours per day. This variation was largely as a result of 1) participants insisting on discontinuing the use of a bag design, and 2) environmental conditions, as harvesting sometimes started late into the morning since it could not take place when too much dew had settled over night on the trees and fruit, as this would tamper with the acidity content of the fruit and ultimately the fruit's quality. At the end of every hour of harvesting, RPE data were collected, and the number of bags harvested was recorded by referring to workers' control sheets. These control sheets indicated the quantity of bags harvested and were marked by the supervisor every time they emptied a full bag into the collection bin.

At the end of the work day, the perceived usefulness and ease of use questions were verbally presented to the workers by a Xhosa speaking translator. In addition, each time, after a harvester had emptied a full bag into the trailer and before the next cycle, dialogue between the translator and the worker was encouraged to obtain as much qualitative feedback on the bag designs as possible.

5.2.7 Data reduction and Statistical analyses

Descriptive statistics including means, standard deviations and coefficients of variation for all dependent variables (RPE, productivity and perceived usefulness and ease of use) were obtained and captured in the Statistica software StatSoft Inc. (2014). Analyses of Variance were conducted to determine any differences in responses due to the bag designs for each worker group. Significant differences were considered at a 95% confidence interval (p-value < 0.05) and Tukey post-hoc analyses where conducted where necessary. Correlation analyses were also performed to determine any interesting relationships between the dependent variables and he different worker demographics.

5.3 Results

Although data were collected for 17 participants, data for eight out of the 17 participants were incomplete, due to the participants refusing to use one or two of the bag designs. Presented in this section are the data for the nine participants who performed all three conditions.

The results for each dependent variable (local RPE, productivity, perceived usefulness and ease of use) are presented below, for the three different bag designs. First, combined workers responses are presented (due to small sample size), followed by the responses of each individual worker group. Detailed statistical results (p-values) can be found in Appendix P.

Correlation analysis between the dependent variables and worker demographics were also performed. Of interest here was to investigate whether a positive relationship between the dependent variables (e.g. RPE) and worker demographics such as; age, sex and worker experience existed. This information would be necessary to establish whether a certain bag design was more favourable for a particular demographic. See Appendix G for all correlation p-value.

Table XI: Descriptive statistics for variable responses (means ± standard deviations; CV=coefficient of variation presented as a percentage).

	Productivity	**RPE**	**Perceived usefulness**	**Perceived ease of use**
Standard bag	8.84 ± 1.95 CV=22.05%	9.68 ± 2.84 CV=29.34%	1.35 ± 0.79 CV=58.52%	1.24 ± 0.75 CV=60.48%
Hip belt bag	9.90 ± 2.11 CV=21.31%	7.98 ± 1.86 CV=23.31%	1.02 ± 0.09 CV=8.82%	1.07 ± 0.38 CV=35.51%
Backpack bag	5.68 ± 1.28 CV=22.54%	11.01 ± 2.70 CV=24.52%	2.00 ± 1.12 CV=56%	3.11 ±1.17 CV=37.62%

5.3.1 Local RPE

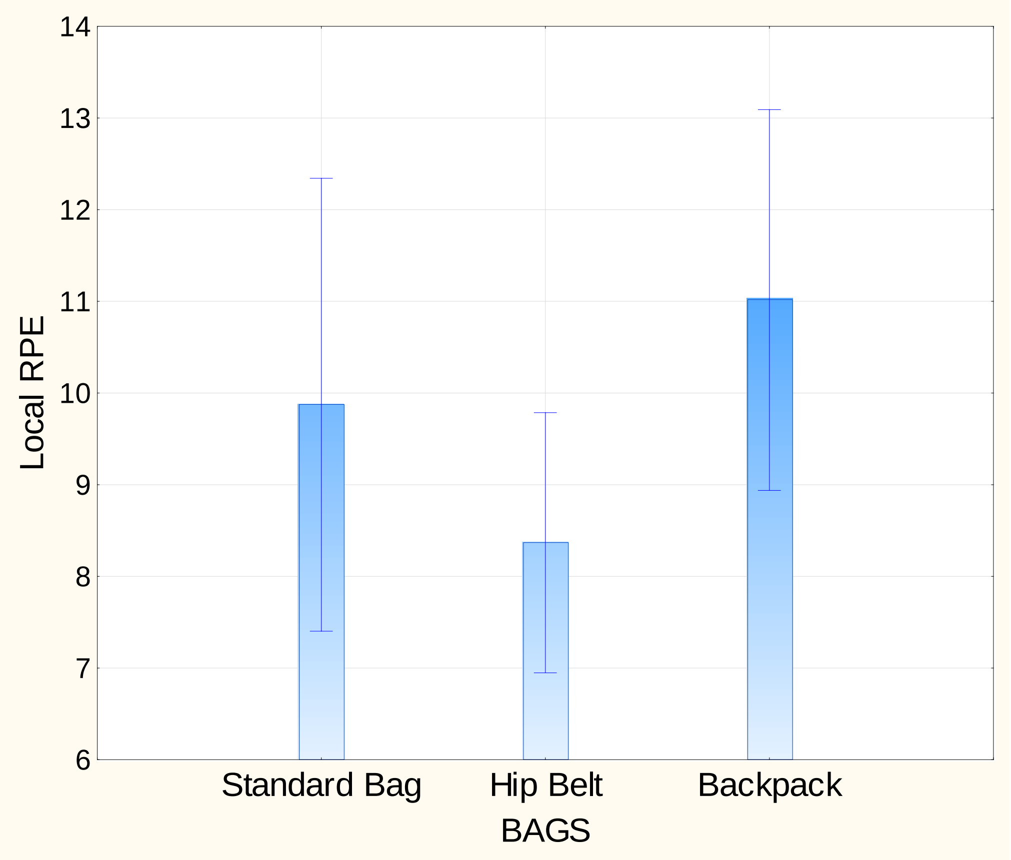


Figure 20: Mean shoulder RPE for all worker groups using the three different bag designs

When using the backpack bag design, the workers experienced the highest perceived exertion (11.01 ± 2.70), and perceived the least exertion when using the hip belt bag design (7.98 ± 1.86). When using the standard bag design, a mean RPE score of 9.68 (± 2.84) was obtained. However, no significant differences exist for RPE between the different bag designs (p=0.133).

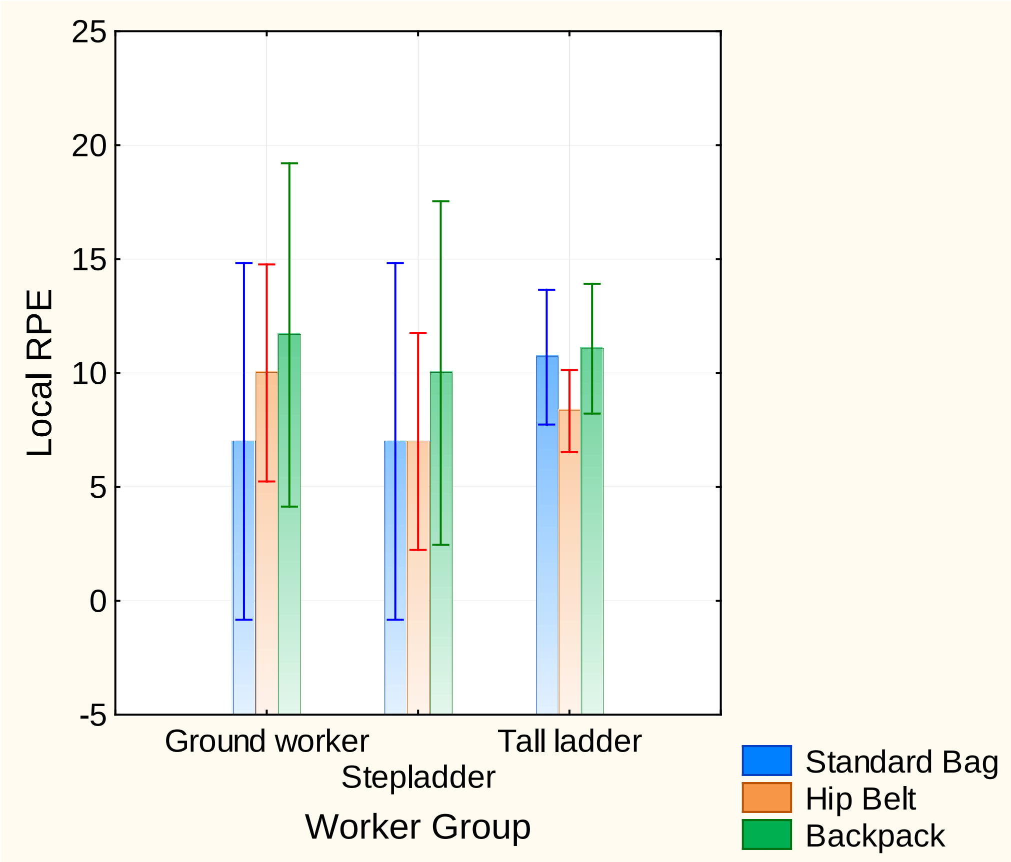
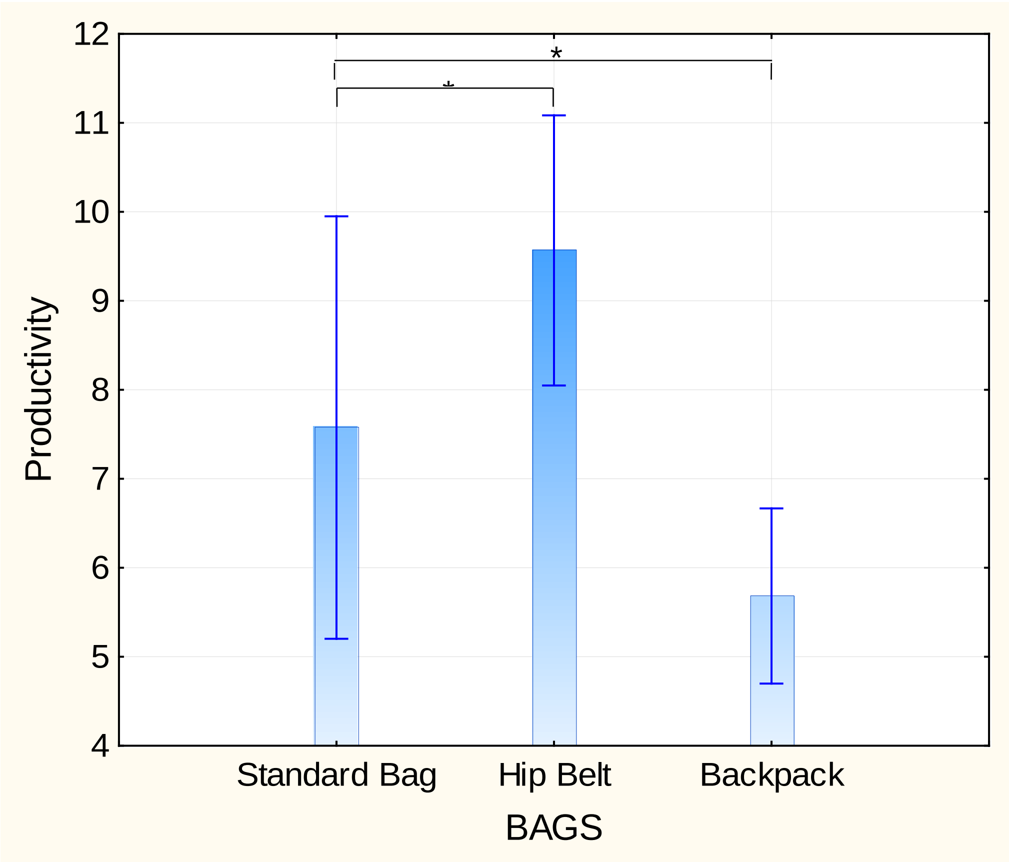


Figure 21: Mean RPE score (lower back) for each individual worker group when using the different bag designs.

Figure 21 shows that again, when using the backpack design, all worker groups (the ground, step ladder and tall ladder workers) experienced the highest RPE exertion (11.67 ± 9.12, 7.00 ± 8.0 and 10.67 ± 1.1 respectively). For all worker groups the least exertion was experienced when using the hip belt bag design. The ground workers perceived that the standard bag required the least exertion (6.97 ±7.67) while the backpack had the highest exertion (11.67 ± 9.01). The step ladder workers perceived the highest exertion when using the backpack bag (10.04 ± 6.84) and the least exertion when using the standard bag design (6.65 ± 7.34), while the tall ladder workers perceived the highest exertion while using the standard and backpack bag design. Again, no significant differences were observed within each of the worker groups. Large variances exist for the ground worker and step ladder workers when using all bag designs.

The bag designs were also compared to one another as a function of selected worker demographics, such as sex, age and experience and although there were no significant differences, it was evident that there was a weak positive correlation between RPE and the worker demographics (sex- 0.46, age- 0.67 and experience- 0.74), while using the standard bag design, and a weak negative correlation for the other two bag designs; hip belt bag(r= -0.32, r= -0.45 and -0.55) backpack (r= -0.33, r= -0.66 and r= - 0.32).

5.3.2 Productivity



(Brackets with asterisk (*) indicate significant difference at p< 0.05).

Figure 22: Worker productivity for all worker groups combined when using the three different bag designs.

Using the backpack design, the workers were significantly less productive (p= 0.003) than when using the other two designs, with only 5.68 (± 1.28) bags being harvested per hour. Workers were most productive when they used the hip belt bag design (mean number of bags harvested per hour: 9.90 ± 2.11), followed by the standard bag design (8.84 ± 1.95 bags harvested per hour).

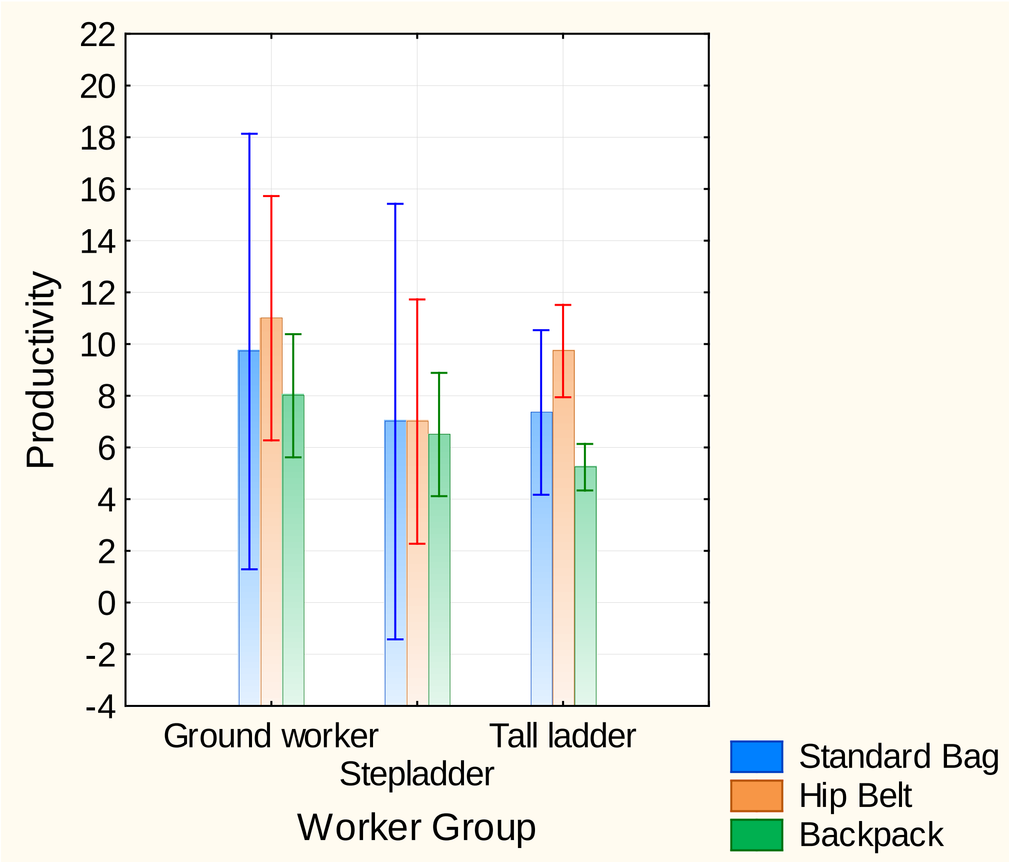


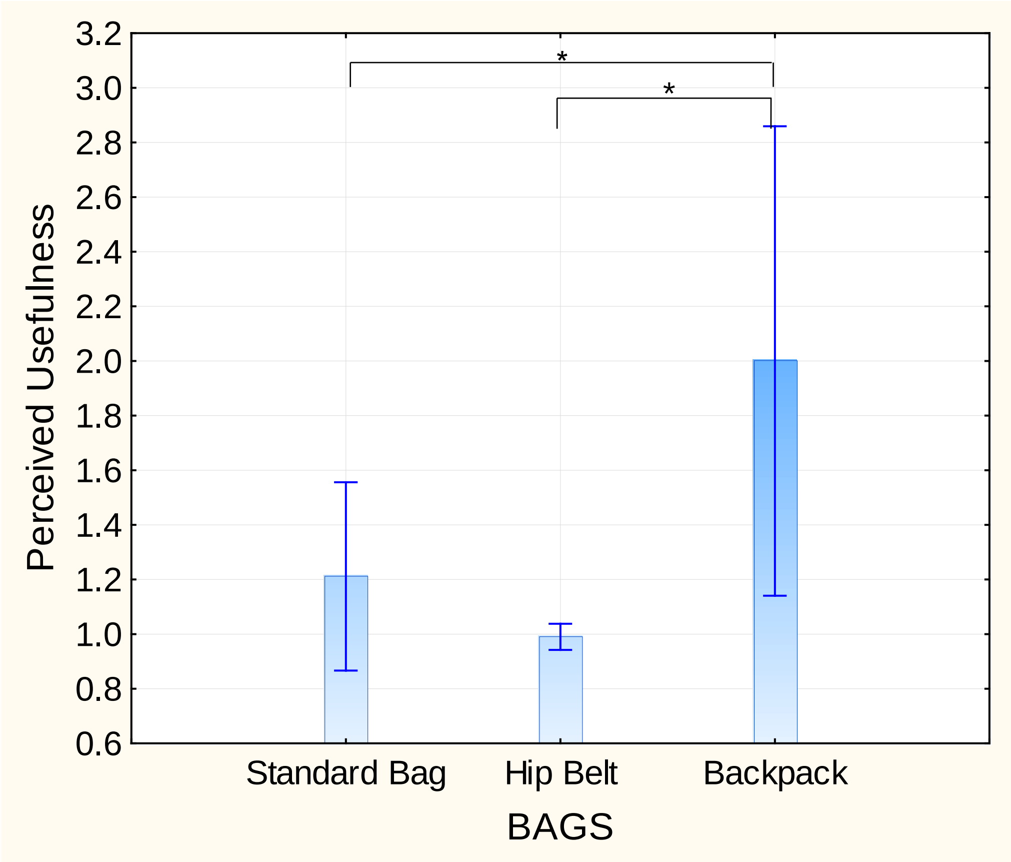
Figure 23: Mean productivity for each individual worker group when using the different bag designs

The figure above, shows that regardless of worker group, the workers were consistently most productive when using the hip belt bag design and least productive when using the back pack bag design. However, there was no significant difference observed in the interaction effect between the bag design and worker group (p=0.60).

Additional analyses with respect to worker demographics (age, sex and experience) were performed and, although all were statistically insignificant, the following general trends were observed: the female workers tended to be more productive than their male counterparts when using all three bag designs, the older workers (35+) were the most productive and the youngest worker age group (18-25) were the least productive. This is expected as all of the workers in the 35+ age range were all experienced and the younger ones were, for the most part, inexperienced. Lastly, all experienced workers performed better than the less experienced workers as they had already performed one harvesting season prior to this. There was a strong and negative correlation (r= -0.68, p= 0.91) between sex and productivity while using the backpack bag design. In using the other two bag designs, a negative and weak correlation existed. Between productivity and worker experience there was a strong and negative correlation when using the standard bag (r= -0.69, p= 0.12) and the hip belt bag designs (r= -0.77, p= 0.13); but for the backpack design, correlation between productivity and experience, was weak and negative (r= -0.43, p= 0.42). Lastly, for all three bag design's, there was a weak but positive relationship between productivity and age (r= 0.37-0.54 and p= 0.09). None of these correlations were however significant.

5.3.3 Perceived Usefulness and Ease of Use Questionnaire

5.3.3.1 Perceived Usefulness



Brackets indicate significant difference at p< 0.05.

Figure 24: Mean rating of perceived usefulness of the bag designs for all worker groups, (where 1=extremely useful, 2=slightly useful, 3= neutral 4=slightly un-useful and 5=extremely un-useful)

Collectively, the workers perceived the backpack design to be the least useful design with a large variability and a mean rating of 2.00 (± 1.20), whereas they considered the hip belt bag design to be the most useful, with a mean rating of 1.02 (± 0.09). The standard bag design had a usefulness rating of 1.35 (± 0.79). The usefulness rating of the backpack design was significantly higher (p= 0.023 and 0.013) (i.e. it was the least useful) than that of the other two bag designs.

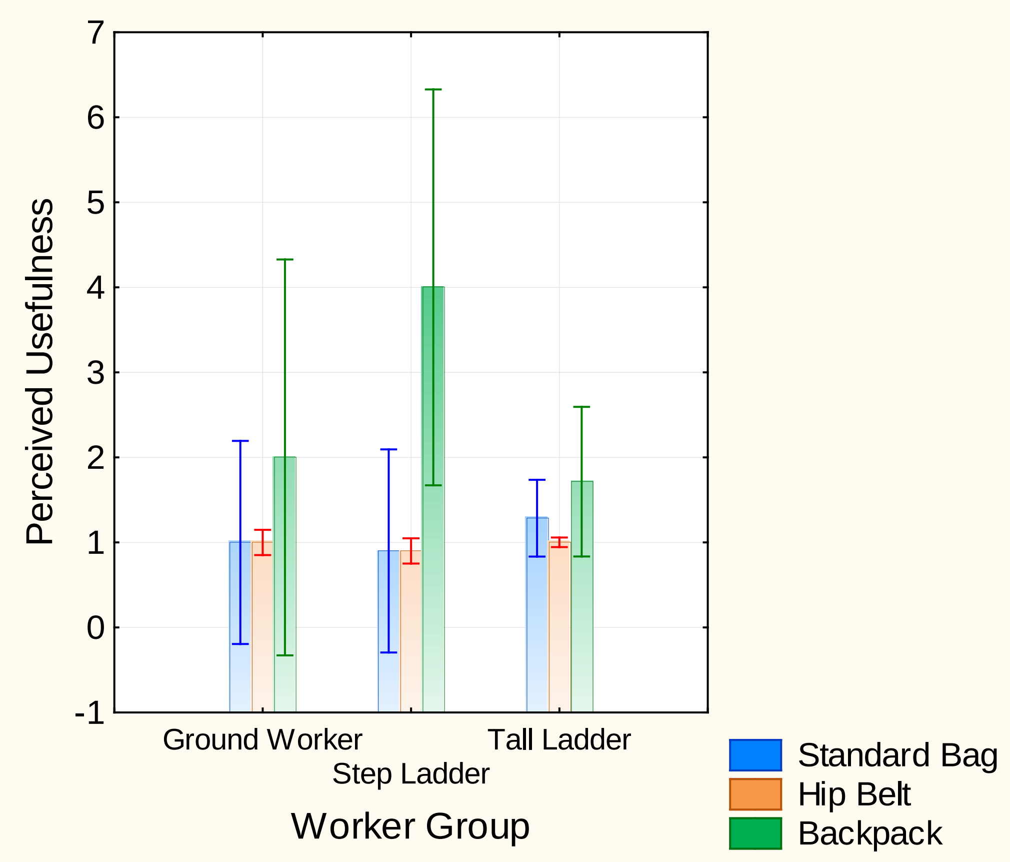
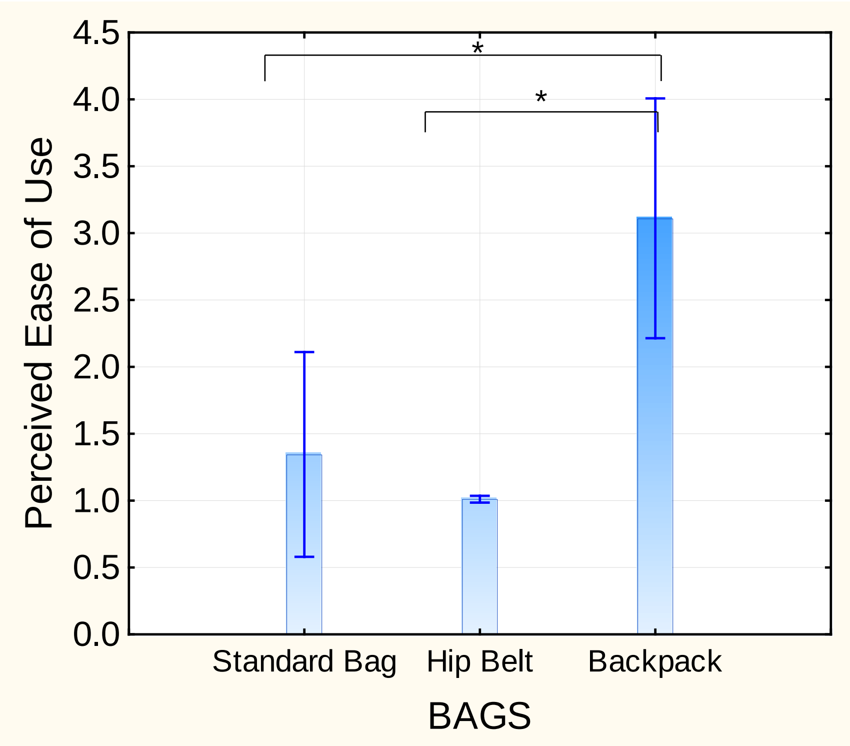


Figure 25: Mean usefulness rating for each individual worker group using the different bag designs (where 1=extremely useful, 2=slightly useful, 3= neutral 4=slightly un-useful and 5=extremely un-useful)

The results depicted in above show the mean usefulness ratings for each worker group. All worker groups found the backpack design to be the least useful (2.00 ±4.00, 4.00 ±8.01 and 1.80 ± 3.23 for ground workers, step ladder workers and tall ladder workers respectively) and the hip belt bag design the most useful (1 ± 0.12, and 0.9 ± 0.02). Irrespective of worker group, the backpack design had the greatest mean perceived usefulness rating compared to the other bag designs (2.00 ± 1.20), while the hip belt bag design was found to be the most useful across all three worker groups 1.02 (± 0.09). Large variability exists for all worker groups when using the standard and backpack bag designs while little or no variability exists when using the hip belt bag design. When analysing the data with respect to worker demographics (age, sex and experience) the following general trends were again observed, albeit the results were non-significant: the youngest worker group (18-25 years) seemed to find all three bags the least useful, while the oldest worker group (35+ years) had lower usefulness ratings, indicating that they found all three bags more useful than the other two worker age groups. The non-experienced workers found the all three bag designs to be less useful than the experienced workers. There were only very weak correlations and statistically insignificant differences between usefulness/ease of use and the worker demographics (age, sex and worker experience) for all three bag designs (Appendix G).

5.3.3.2. Perceived Ease of Use



Brackets indicate significant difference at p< 0.05).

Figure 26: Mean ratings for perceived ease of use for all worker groups, where 1=extremely easy to use, 2=slightly easy to use, 3= neutral, 4=slightly un-easy to use and 5=extremely un-easy to use.

The workers again collectively perceived the backpack design to be the least easy to use (3.11 ± 1.17) and the hip belt bag design the most easy to use (1.07 ± 0.25), as is depicted in Figure 26. For the standard bag the mean perceived ease of use rating was 1.24 (± 0.75). The ease of use rating of the backpack design was significantly higher (i.e. it was the most difficult to use) than that of the other two bag designs (p=0.044 and 0.11)- standard bag and hip belt bag designs respectively. Variability is large for the standard and backpack bag designs but small for the hip belt bag design.

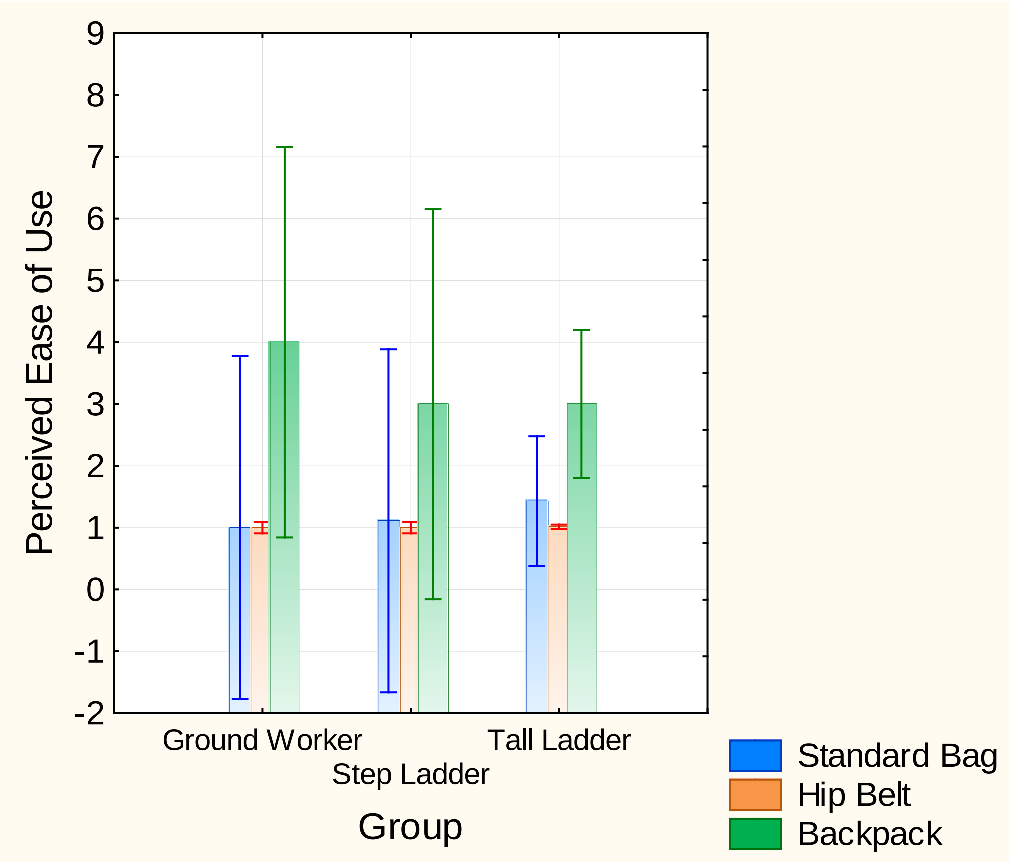


Figure 27: Mean rating of ease of use for each individual worker group using the different bag designs (where 1=extremely useful, 2=slightly useful, 3= neutral 4=slightly un-useful and 5=extremely un-useful).

When considering the perceived ease of use ratings per each individual worker group (Figure 27), all worker groups found the backpack design to be the least easy to use (4.00 ± 5.23, 3.00 ± 5.44 and 3.02 ± 2.33 for ground worker, step ladder worker and tall ladder worker group respectively) and the hip belt bag design the most easy to use (1.00 ±0.12, 0.97 ± 0.11 and 1.00 ± 0.14 respectively). The ground workers had the worst response to the backpack design, compared to the other two worker groups, with a mean perceived ease of use rating of 4.00 (± 0.01), and the best response (0.17 ± 0.41) when using the standard bag and hip belt bag designs.

The tall ladder and the stepladder workers had similar responses to the mean ratings of ease of use of the backpack and hip belt bag designs, with the back pack design receiving the worst ease of use ratings, and the hip belt design the best ratings. These differences were however not statistically significant. Again variability for the standard and backpack designs is large but small for the hip belt bag design

Although all were statistically insignificant, the following general trends were also observed: the youngest age group (18-25 years), found all three bag designs hard to use compared to the other two age groups, and the non-experienced workers had higher ease of use ratings for all three bag designs (i.e. they found the bag designs hard to use) compared to the experienced workers.

5.4 Discussion

It was evident from the current study that regardless of the worker groups, the backpack design was the least desirable design, as it elicited the highest perceived exertion, resulted in the lowest productivity rate and was found to be the least useful and most difficult to use.

Although no significant differences existed for perceived exertion between the bag designs, the RPE results obtained in this study support the results from studies by Earle-Richardson *et al.* (2004 & 2006), who, using the same RPE scale, found that by using the hip belt bag design the workers perceived less (7.06 ± 1.55), musculoskeletal effort than when using the standard bag to harvest citrus fruit (10.02 ± 1.42). These RPE results obtained from Earle-Richardson *et al.* (2004) are very similar to that obtained in the current study, where mean RPE using the hip belt bag was 7.98 (± 1.86) and using the backpack design was 9.68 (± 2.84). This thus provides evidence in support of the hip belt bag as a better design than the standard bag design. It must also be noted that these similar results in RPE were expected as more similarities than differences exist in the methodology of both studies. For example, both studies were performed in the field and on real citrus farm workers and the aim of both studies was also to provide evidence that an asymmetrical means of load carriage (from the standard harvesting bag) is detrimental to the workers musculoskeletal system. It must be noted however that Earle-Richardson and colleagues (2006) did not investigate the effects of a backpack design in their study; only standard harvesting bag and the hip belt bag design were studied.

From informal conversations and discussions with the participants of the current study, feedback about the hip belt bag design was generally positive, regardless of worker group or demographic. No significant correlations were found between bag design and selected worker demographics (sex, age and experience). However, various trends were identified which are mentioned in the results section of this chapter. For RPE, the experienced workers appeared to have higher ratings than the non-experienced workers. One can debate for and against this finding: the experienced workers are generally the older workers and as such are not as physically agile as the younger inexperienced workers. Hence they perceived greater exertion. Conversely, one could expect that since these experienced workers are familiar with the harvesting task requirements the exertion perceived would be less. For productivity, the females tended to be more productive than the males; the older and experienced workers were also more productive. A general observation in rural Eastern Cape as stated by (Van Weiss, 2005), is that females are generally the bread winners in the family. For this reason, the female workers are seen to work more efficiently in order to earn more money. In addition to this, since most of the female workers were ground workers, they did not spend time setting up, carrying and climbing up and down the ladders. This would improve time spent and hence productivity. As expected, the experienced workers (which were also the older workers) were familiar with the harvesting task from having participated in at least one harvesting season as such performed better.

The participants stated during the informal discussions that they preferred the hip belt design, mostly because it was not a drastic change (compared to the backpack design) from what they (specifically the experienced workers) were used to. They also acknowledged the improvement in load distribution, as they reported reduced pressure on the shoulders as a result of the addition of the hip belt. Figure 23 shows that when using the backpack bag design, the workers were significantly less productive and were most productive when using the hip belt bag design. The results were unexpected, as it was expected that using the backpack design would improve the workers' productivity, as much load carriage research, including studies by Murray & Miller (1985 &1989), Motmans *et al.* (2007), Corrigan & Xian Liu (2012) and Bao *et al*. (2013), all concluded that this bag design was the most effective in reducing asymmetry. Although productivity was not assessed in above-mentioned studies, one could infer that with a reduction in asymmetry (which will lead to decreased muscular exertion), worker output would increase. These studies also concluded, using objective measures only (EMG, gait, posture etc.), that a backpack bag design was more effective in eliminating asymmetry by re-distributing the load across the body, hence reducing muscular strain. The PUEU analyses, targeted at assessing perceived usefulness and ease of use for each bag design, were expected to have the lowest ratings (i.e. best responses) for the back pack design. However, the opposite occurred; namely the back pack design was found to have the highest ratings i.e. it was rated the least useful and most difficult to use bag design. The results from the current study clearly contradict the results in the above cited studies; it must however be noted that these cited studies were laboratory based studies and hence performed under controlled circumstances. Secondly, the participants' attitude towards change (i.e. the backpack design) is another aspect that was not accounted for in the above laboratory based studies. Most times, behavioural variables which often form a large part of the findings obtained in a field research are not accounted for in laboratory based research. This highlights the difficulties/challenges associated with lab/field research as the results from lab research often fail to predict in real life (Chapanis, 1967; Lofland & Lofland, 1984; Parasuraman *et al*., 2004).

Furthermore, conversations with the workers shed more light on the reasons for the workers dislike of the backpack design. Apart from this design being a drastic change from what they are used to, the workers also mentioned that 1) they found it difficult to empty fruit using this design, 2) the hood of this design restricted their range of motion due to protruding branches of the orange trees and 3) this bag was larger than the other bag designs, so the workers end up spending longer amounts of time to fill up the bag- this was however accounted for as they were then prompted to fill this bag design half way.

5.5 Conclusion, Limitations and Recommendations

From the results obtained from this phase of the study, a general trend in support of the hip belt bag design was established, even within the different worker demographic groups (age, sex and worker experience). The workers perceived less exertion and were more productive using the hip belt design; they also found this bag the most useful and easy to use. In contrast, the backpack bag design had significantly poorer responses when compared to the other two bag designs and this was evident in all the dependent variables assessed (RPE, productivity and PUEU). In conclusion, the null hypothesis must be rejected and the alternative hypothesis, accepted.

Data were obtained for 17 participants; however of these, eight participants either discontinued with the study or refused to use one or two of the bag designs. Hence, only complete data sets for the remaining nine participants were used in this study. In the future, in order to accurately compare these three bag designs, a larger sample size is recommended. To increase sample size, farm workers from multiple harvesting farms should be involved. Additionally, the researcher was only able to collect data for 4-6 working/harvesting hours, as opposed to the initially planned eight hours, due to environmental conditions; if a citrus fruit is harvested with any water or dew on it, the acidity of the fruit is tampered with. Hence, on most days, the trees were given 1-4 hours to dry before harvesting could commence.

CHAPTER 6: INTEGRATED DISCUSSION & CONCLUSION

6.1 Integrated Discussion

It is evident that the results obtained for the lab and field phases of this project contradict each other. The overall conclusion based on the results from the laboratory phase was that the backpack and the hip belt bag designs appeared to be the most preferred bag designs, due to less perceived exertion and muscle activation. In the field, citrus farm workers experienced the least amount of strain when using the hip belt bag design due to higher productivity rates, lower ratings perceived exertion and good usefulness and ease of use ratings, whilst the backpack bag design elicited the opposite responses. It was hypothesized that for both phases of the project, the backpack bag design would be the most preferred bag design since previous literature from Murray & Miller (1985 &1989), Motmans *et al.* (2007), Corrigan & Xian Liu (2012) and Bao *et al*. (2013), concur that this bag design is the most likely to promote a symmetrical means of load carriage, which is essential to prevent and/or reduce musculoskeletal strain by redistributing load evenly across the body. However, this was not entirely the case from the results obtained during the field phase of the current project. Earle-Richardson *et al.* (2000 & 2004) conducted a lab and field study, assessing the effectiveness of hip belt bag design. The subjective feedback (RPE) obtained from both phases of their study correspond; perceived exertion was lowest when using the hip belt bag compared to the standard bag. This was not the case in the current study as RPE results for the lab and the field phase contradict each other. In the lab, as expected, RPE results were lowest when using the hip belt and the backpack designs, but in the field RPE were the highest when using the backpack and lowest when using the hip belt and standard bags. These discrepancies between the lab and the field results emphasize the need to take ergonomic interventions designed and tested in the lab, back into the field. It is of utmost importance to introduce the laboratory findings to the field, in order to benefit the real workers, under real life settings (Bao & Shahnavaz, 1989). However, a major the challenge in a lab/field approach is that results from the lab often fail to predict real life scenarios. For example, measuring productivity in the lab will not be the same as measuring in the field. This is because the lab participants were Rhodes University students and not real work-hardened citrus harvesters who rely on harvesting citrus as a source of income. Similarly, EMG measured in the field setting compared to the lab would differ due to uneven ground, uncontrolled weather condition, the interference of branches and leaves of real trees, rather than metal simulations, etc. The variables measured in the different phases were selected in an attempt to account for both situations. Ratings of perceived exertion and muscle activity were analysed in the lab due to the rather invasive nature of the EMG equipment which would have made the workers feel awkward and possibly disrupted worker productivity. RPE, productivity and usability were assessed in the field, since workers have a direct interest in the comfort and ease of use (preventing pain and discomfort) and productivity (earning a living). Hence, a combination of both a lab and field approach was necessary in order to accurately investigate these bag designs.

To further promote the need for laboratory and field interactions, O'Neill (2000 & 2005) referred to the "economic cycle of diseases" as a reason for poor job performance/productivity amongst farm workers in IDC's. This is evident as all of the workers that participated in this study were in some way affected by this negative spiral of the economic cycle of diseases. They received low/minimal income, lived impoverished lives with inadequate food intake (and high levels of substance abuse), and had little or no education and poor housing conditions. The same author also reiterated that this cycle of diseases remains on-going unless there is a change through the use of ergonomic interventions or lab-field interactions, which could boost worker capacity by reducing the worker input required and increasing output (O'Neill, 2000). This negative spiral may have influenced the field results; for example, 1) the workers being poorly educated, may have had less understanding and hence a greater apprehension to the unknown; in this case, the backpack design. 2) The workers had a fear of making less income if they used the unfamiliar back pack design. 3) The older / experienced workers passing on a negative perception of the backpack design to the younger ones.

Although these factors were considered as possible obstacles and measures were put into place to prevent them from interfering, they still had a significant impact. During the data collection for the lab phase, the participants were well informed verbally and in written form of the aim of the project and, although the researchers expectations (of the backpack design eliciting the best responses) were not revealed to the lab participants, it is possible that these participants picked up on these and formed bias in subjective responses (RPE) to this bag design, in an attempt to please the researcher. However, during the field data collection, possible worker defiance towards the researcher (young, non-Xhosa speaking, female academic), may have rebelled them against the researchers expectations. Furthermore, it must be reiterated that the worker's attitudes to a drastic change (i.e. backpack design) may also have resulted in the negative perception towards this design, which in turn negatively affected their performance/productivity rate, as well as their perception of usefulness and ease of use of this bag. The backpack is a drastically different design from the standard bag and the hip belt bag design (which is what the farm workers were familiar with) and required a change in picking style/movements. Davies (1993) and Brown *et al.* (2002) highlight the behavioural responses on user acceptance levels on man-machine interaction. It was conclusive from both studies that with increasing level of change in a computer operating system, 75% of the participants either quit or became frustrated. The above studies support the current study as a negative attitude was developed towards the backpack design due to it being very unfamiliar.

Hence it was evident during the data collection phase that the farm workers, particularly the experienced ones (i.e. those that had previously harvested citrus for at least one season), were against utilizing the backpack design - this eventually resulted in the workers discontinuing or from the onset completely refusing to utilize this bag design. This reluctant attitude to the bag designs was expected to a certain degree, since this occurs when implementing any ergonomic interventions, particularly where a participatory approach is not used (Jeyeratnam, 1992; Dempsey, 2007). Had the farm workers been involved with the design process of the backpack design, as in studies by Anderson (1992), Norman & Wells (2007) and Dempsey (2007), they would maybe have been more willing to try and more accepting of the bag design. Unfortunately, a small sample size was used in this study due to a limited available number of workers in the selected citrus farm and only a selected few of these workers were willing to participate in the study.

6.2 Integrated Conclusion, Limitations and Recommendations

This research project combined a laboratory and field approach to determine which one of three harvesting bag designs best reduced muscular and perceived effort and improved productivity while harvesting citrus fruit. The aim of redesigning the standard harvesting bag was to reduce the asymmetrical means of load carriage required by this bag. It has been highlighted in previous literature that asymmetry may lead to musculoskeletal disorders as a result of high muscle activity and mechanical pressure on muscles. Hence, of interest in this study, was to improve symmetry of the standard harvesting bag design.

In the laboratory phase of this study, muscle activity and local ratings of perceived exertion of the shoulders and back were assessed on student volunteers. The results from the laboratory phase indicate that, overall, the backpack bag design yielded the best responses, while the standard bag yielded the worst for all three worker groups. This was evident as 1) the muscle activation required when using the backpack design was significantly less when using the backpack design, compared to the others, and 2) subjective ratings of perceived exertion when using the backpack design again were significantly less than when using the standard bag. The results obtained in this phase support the alternative hypothesis of the study. A holistic approach is however recommended for future studies of this kind, since no biomechanical or cardiovascular responses were assessed. This could be seen as a limitation to this study as it does not allow for a holistic approach. Secondly, more harvesting cycles (no less than 10) should be performed to replicate harvesting cycles in the field, as large response variability was found between the three harvesting cycles performed in the laboratory phase of this study and more harvesting cycles may reduce this variability. Finally, since participants were already aware from the start that the standard bag was considered the worst of the three bags, due to the information provided during the initial briefing, negative perceptions may have been formed which might have influenced any subjective feedback obtained.

In the field phase, productivity, perceived exertion and user acceptance were assessed using citrus harvesters. The results indicate that the hip belt bag design yielded the best responses for all variables, while the backpack design produced the worst results. This means that citrus farm workers were more productive, perceived less effort and found the hip belt bags design the most useful and easy to use. The opposite was however seen for the back pack bag design. The findings in this phase did not support the hypothesis of the study. A major limitation in this phase however was the small sample size as a result of the workers' reluctance to participate. For future studies, a larger sample size must be considered as well as collecting data from workers on more than one citrus farm. Secondly, where environmental conditions are not an obstacle, data should be collected for a full work day (7-8 hours). Also, for a more holistic approach, other measures (biomechanical, physiological etc.) should be considered.

CHAPTER 7: REFERENCES

Abu-Dalbouh, M.H. (2013). A questionnaire approach based on the technology acceptance model for mobile tracing on patient progress application. *Journal of Computer Science,* 9(6): 763-770.

Alkner B.A., Tesch P.A, & Berg H.E. (2000). Quadriceps EMG/force relationship in knee extension and leg press. *Medicine and Science in Sports and Exercise,* 32(2): 459-463.

Anderson, E.R. (1992). Economic evaluation of ergonomic solutions: Part II - the scientific basis. *Journal of Industrial Ergonomics,* 10: 173-178.

Armstrong, T.J., Young, J., Woolley, C., Ashton, J.H., & Kim, H. (2009). Biomechanical aspects of fixed ladder climbing: style, ladder tilt and carrying. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 53(14): 935-939.

Bao, S., & Shahnavaz, H. (1989). The promise and problems of ergonomics applications in the Peoples Republic of China. *Applied Ergonomics,* 20(4): 287-292.

Bao, S., Silverstein, B., & Stewart, K. (2013). Evaluation of an ergonomics intervention among Nicaraguan coffee harvesting workers. *Journal of Ergonomics,* 56(2): 166-181.

Bembridge, T.J. (1987). Considerations in agricultural extension for less developed areas in Southern Africa. In: *Extension strategies for the year 2000*. SASAE Conference, Cape Town South Africa.

Borg, G. (1970). Perceived Exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine,* 2(2): 92-98.

Borg, G.A.V. (1998). *Borg's Rating of Perceived Exertion and Pain Scales*. Human Kinetics: Champaign, IL.

Boutcher, S.H. (2011). High-intensity intermittent exercise and fat loss. *Journal of Obesity,* 22(3): 223-245.

Brown, S.A., Massey, A.P., Montoya-Weiss, M.M., & Burkman, J.R. (2002) User acceptance of mandated technology. *European Journal of Information System*, 11(4): 283-295.

Burgess, K., & Robert G. (1984). *In the Field: An Introduction to Field Research.* Hemel Hempstead: George Allen & Unwin.

Chapman, L., & Meyers, J. (2001). Ergonomics and Musculoskeletal Injuries in Agriculture: Recognizing and Preventing the Industry's Most Widespread Health and Safety Problem. *American Journal of Industrial Medicine,* 38: 463-480.

Chapanis, A. (1967). The relevance of laboratory studies to practical situations. *Ergonomics,* 10(5): 557-577.

Citrus Academy (2006). *Integrated Production Guidelines for Export Citrus* – Vol 4: Harvesting and Packing Citrus, Citrus Research International, Nelspruit.

Coppock, G.E. (1961). Picking Citrus fruits by mechanical means. *Florida Agricultural Experiment Station Journal.* 2(17): 82-86.

Corlett, E.N., & Bishop, R.P. (1976). A technique for assessing postural discomfort. *Ergonomics,* 19(2): 175-182.

Corrigan, L., Law, N.Y., & Law, N.H. (2010). *The hockey bag survey*. Unpublished Master's Thesis, University of Espoo, Finland

Corrigan. L., & Xian Li., J (2012). The effect of ice hockey bag load carrying on the muscle activities of the trunk of young males during gait – a progress report. *30th Annual Conference of Biomechanics in Sports – Melbourne*

Cowie, H.A., Hughson, G.W., Creely, K.J., Graham, M.K., Hutchison, P.A., & Aitken, R.J. (2005). *An occupational hygiene assessment of the use and control of isocyanates in the UK*. Sudbury: HSE Books. (Research Report No. 311).

Cross, N. (2006). *T211 Design and Designing*: Block 2, page 99. Milton Keynes: The Open University.

Davies, F.D. (1989). Perceived usefulness, perceived ease of use, and user of acceptance of information technology. *Proceedings : MIT Quarterly.* Michigan, 12-17 August 2001: 243-265.

Davies, F.D (1993). User acceptance of information technology: system characteristics, user perceptions and behavioural impacts. *International Journal of Man-Machine Studies,* 38(3): 475-487.

Davis, K.G. (2007). Understanding the ergonomic risk for musculoskeletal disorders in the United States agricultural sector. *American Journal of Industrial Medicine*. 50(7): 501-511.

Dempsey, P.G. (2007). Effectiveness of ergonomic interventions to prevent musculoskeletal disorders: Beware of what you ask. *Journal of Industrial Ergonomics,* 37: 169-173.

Department Of Agriculture, Forestry and Fisheries (2011). URL: http://www.nda.agric.za/. Last accessed 18 April 2013.

Devita, P., Hong, D, & Hamill, J. (1991). Effects of asymmetric load carrying on the biomechanics of walking. *Journal of Biomechanics*, 24: 1119-1129.

Drury, C.G. (1983). Task analysis methods in industry. *Applied Ergonomics*, 14(1): 19-28.

Earle-Richardson, G., Jenkins, P., Fulmer, S., Mason, C., Burdick, P., & May J. (2005). An ergonomic intervention to reduce back strain among apple harvesters in New York State. *Applied Ergonomics,* 36 (3): 327-334.

Earle-Richardson, G., Kirkhorn, S.R., (2006). Repetitive Motion Injuries. In Lessenger, J.E., (Ed.), Agricultural Medicine: A Practical Guide. Pp. 324-338. New York: Springer.

Earle-Richardson, G., Fulmer, S., Jenkins, P., Mason, C., Bresee, C., & May, J. (2004). Ergonomic analysis of New York apple harvest work using a posture-activities-tools-handling (PATH) work sampling approach. Journal of Agricultural Safety Health, 10: 163-176.

Eastern Cape Development Cooperation (2012). URL: http://www.ecdc.co.za/opportunities/agriculture_and_minerals. Last accessed 9 April 2013.

Fathallah, F.A. (2010). Musculoskeletal disorders in labour-intensive agriculture. *Applied Ergonomics,* 41: 738-743.

Grimmer, K., Dansie, B., Milanese, S., Pirunsan, U., & Trott, P. (2002). Adolescent standing postural response to back pack loads: a randomized control experimental study. *BMC Musculoskeletal disorders,* 3(10): 208-345

Grimmer K, & Williams M. (2000). Gender-age environmental associates of adolescent low back pain. *Applied Ergonomics*, 31**:** 343-360.

Gross, J.M., Fetto, J., & Rosen, E. (2009). *Musculoskeletal examination.* Oxford: Wiley Blackwell.

Goh, J.H., ThambyaH, A, & Bose, K. (1998). Effects of varying back pack forces in the lumbosacral spine during walking. *Journal of Biomechanics*, 13(1): 188-198.

Jeyeratnam, J. (1992). *Occupational health in developing countries*. Oxford: Oxford University Press.

Johnson, P., Diaper, D., & Long, J. (1985). Tasks, skills and knowledge: task analysis for knowledge based description. In B. Shackel (ed.): Human-Computer Interaction (pp17-25). INTERACT'84, Elsevier Science.

Jutras, P.J., & Coppock, G.E. (1958). Mechanization of citrus fruit picking. *Florida State Horticulture Society,* (201-204).

Kirwan, B., & Ainsworth, L. (Eds.) (1992). *A Guide to Task Analysis*. London: Taylor and Francis.

Kudryk, I.A. (2008). *A biomechanical analysis of specialized load carriage technique and the development of an assistive load carriage device.* Unpublished Master's thesis, Queen's University, Kingston, Ontario, Canada.

Lofland, J., & Lofland, L.H. (1984). *Analysing Social Settings: A guide to qualitative observation and analysis*. Belmont: Wadsworth Pub. Co.

Mackie, H.W., Stevenson, J.M., Reid, S.A., & Legg, S.J. (2005). The effect of simulated school load carriage configurations on shoulder strap tension forces and shoulder interface pressure. *Applied Ergonomics,* 36(2): 119-206.

McCurdy, S.A., & Carroll, D.J. (2000). Agricultural injury. *American Journal of Industrial Medicine,* 38: 463-480.

Meyers, J.M, Miles, J.A., Faucett, J., Janowitz, I., Tejeda, D.G., & Duraj, V. (2000). *High risk tasks for musculoskeletal disorders in agricultural field work*. In: Paper presented at IEA 2000/HFES 2000 Congress, San Diego, CA.

Meyers, J.M, Miles, J.A., Faucett, J., Janowitz, I., Tejeda, D.G., & Kabashim, J.N. (1997). Ergonomics in agriculture: workplace priority setting in the nursery industry. *American Journal of Industrial Hygiene,* 58(2): 121-126.

Meyers, J.M, Miles, J.A., Faucett, J., Janowitz, I., Tejeda, D.G., & Weber, E. (2001). Priority risk factors for back injury in agricultural field work: vineyard ergonomics. *Journal of Agromedicine,* 8(1): 37-52.

Mirka, G.A. (1991). The quantification of EMG normalization error. *Ergonomics,* 34(3): 343-52.

Monaghan, P.F., Forst, L.S., Tovar-Aguilar, J.A., Bryant, C.A., Israel, G.D., Gonzalez, S.D., Thompson, Z., Zhu, Y., & McDermott, R.J. (2011). Preventing eye injuries among citrus harvesters: the community health worker model. *American Journal of Public Health*, 101(12): 2269-2274.

Motmans, R.R.E.E., Tomlow, S., & Vissers, D. (2007). Trunk muscle activity in different mode of carrying schoolbags. *Ergonomics*,49: 127-138.

Moynes D., Perry J., Antonelli, D. (1986). Electromyographic and motion analysis of the upper extremity in sports. *Journal of American Physiotherapy Association,* 66(12): 1905-1911.

Murray, E., Alderman, P., Coppola,W., Grol, R., Bouhuijs, P., & Van Der Vleuten, C. (2001). What do students actually do on an internal medicine clerkship? A log diary study. *Medical Education*, 35(12): 1101–1107.

Murray, G., & Miller, W. (1985). *Harness for shoulder supported bag*. USA: Murlyn Enterprises.

Murray, G., & Miller, W., (1989). *Load Carriage: weighted and non-weighted*. USA: Murlyn Enterprises.

Myers, J.R. (1998). Injuries among farm workers in the United States, 1994. *National Institute for Occupational Safety and Health.* Publication No. 98-153.

Nel, E., & Davies, J. (1999). Farming against the odds: an examination of the challenges facing farming and rural development in the Eastern Cape province of South Africa*.* *Applied Geography*, 19 (3): 253-274.

Nell, E.J., & Errouaki, K. (2008). *Conceptual Analysis, Fieldwork and Model Specification: Laying Down the Blueprints for a Klein-Nell Model,* MS. New York: The New School.

Norman, R. & Wells, R. (1998). *Ergonomic interventions for reducing musculoskeletal disorders: an overview, related issues and future directions.* Unpublished Thesis, University of Waterloo, Waterloo, Ontario Canada.

Oddson, L.I.E., & De Luca, C.J. (2002). Activation imbalances in lumbar spine muscles in the presence of chronic low back pain. *Journal of Applied Physiology,* 94: 1410-1420.

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

O'Neill, D.H. (2005). The promotion of ergonomics in industrially developing countries. *International Journal of Industrial Ergonomics,* 35: 163-168.

Parasuraman, A., D. Grewal and R. Krishnan (2004). Marketing Research. USA: Houghton Mifflin

Company. Pascoe, D.D., Wang, Y.T., Shim, D.M., & Kim C.K. (2010). Influence of carrying book bags on gait cycle and posture in youths. *Journal of Applied Ergonomics*, 40(6): 631-640.

Philips, B. (2006). South African Citrus Industry: Findings and Observations. *Conference report: Australian Citrus Growers Association Conference.* Australia, 13-16 August 2006: 1-30.

Qureshi, Y., & Shamus, E. (2012). Unilateral shoulder bags: can they be worn in a way to reduce postural asymmetry? *The Internet Journal of Allied Health Sciences and Practices,* 10(4): 134-145.

Rogan, A., & O'Neill, D.H. (1993). Ergonomics aspects of crop production in tropical developing countries: a literature review. *Journal of Applied Ergonomics*, 24 (6): 371-386.

Saari, S. (2006). Productivity, theory and measurement in business. European Productivity Conference, Espoo, Finland.

Sarig, Y. (1993). Robotics of fruit harvesting: a systematic review. *Journal of Agricultural Engineering Research*, 54(4): 265-280.

Scott, P.A. (2008). Global inequality and the challenge for ergonomics to take a more dynamic role to readdress the situation. *Applied Ergonomics,* 39: 495-499.

Shahnavaz, H. (1996). Making ergonomics a worldwide concept. *Ergonomics,* 39(12): 1391-1402.

Shahnavaz, H. (2000). Role of ergonomics in the transfer of technology to industrially developing countries. *Ergonomics*, 43(7): 903-987.

Sherman, K. (2003). An evaluation of fatigue and performance changes during intermittent overhead work. Unpublished Master's thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Sheppard, B.J. (2012). *Musculoskeletal and perceptual responses of batsmen comparing high- and moderate-volume sprints between the wickets.* Unpublished Master's Thesis, Rhodes University, Grahamstown, South Africa.

Smith, B., Ashton, K.M., Bohl, D., & Clark, R.C. (2006). Influence of carrying a backpack on pelvic tilt, rotation, and obliquity in female college students. *Gait & Posture,* 23: 263-267.

Statistics South Africa (2009). URL: www.statssa.gov.za/publications/P0302/P03022009. Last accessed 19 March 2013.

Statistics South Africa (2012). URL: www.statssa.gov.za/publications/SAStatistics/SAStatistics2011.pdf. Last accessed 19 February 2013.

Schuman, S.H. (2008). Ergonomics in Agriculture. *Journal of Agromedicine,* 8(1): 9-18.

Spedding, C.R.W. (1996). *Agriculture and the citizen*. London: Chapman & Hall.

Tortora, G.J., & Derrickson, B.H. (2005). *Principles of Anatomy and Physiology.* Eleventh Edition. New York: John Wiley & Sons.

Van Weiss, S.M., (2005). Measuring perceived black economic empowerment: The case of South African wine industry. *Agrekon* 45(4): 381-405.

Whitney, J.D., & Coppock, G.E. (1984). Harvest mechanization of Florida oranges destined for processing. *American Journal of Social Agricultural Engineering,* 5(84): 149-155.

Whitney, J.D., & Harrell, R.C. (1989). Status of citrus harvesting in Florida. *Journal of Agricultural Engineering,* 42: 285-299.

Wisner, A. (1985). Ergonomics in industrially developing countries. *Ergonomics,* 28(8): 1213-1224.

APPENDICES FOR PHASE 1

Appendix A: Product Design Specification (PDS) , Procedure and Product Alternatives.

In order to redesign the standard harvesting bag, the researcher, utilized numerous literature on load carriage research as well as performing informal pilot studies. Three designs (excluding the standard harvesting bag) were chosen- hip belt design, backpack design and the side-by-side pocket design. However, only two of these were tested in the actual study. The latter design was eliminated from the study due to time constraints.

The criteria for designing these new bags are seen in the PDS checklist in the areas listed below:

1. **<u>PERFORMANCE:</u>**
    - Product must be useful/relevant, safe and easy to use (manoeuvre) for the harvesting of citrus fruits.
    - Product must encourage a more symmetrical means of load carriage ie distribute load evenly around the body, decrease muscle activity, reduce shoulder compression forces, increase range of motion ;
    - Product must be durable, big and strong enough to 1) carry loads of 13-15kgs, 2) to be used for at least 3-5 harvesting seasons, 3) to be used regardless of weather and environmental conditions.
    - Product materials used should be light in weight. Product height and weight are essential.
2. **<u>ECONOMY:</u>**
    - Use of product should improve worker productivity by reducing muscular strain and hence, allowing workers to harvest fruits faster and for longer periods of time.
3. **<u>PRODUCTION COSTS AND TIME :</u>**
    - Product must be cheap, quick and easy to produce

4. **<u>APPEARANCE/AESTHETICS</u>**
    - Product appearance not important at this stage.

Appendix B: Letter of Information to Participants

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

HUMAN KINETICS & ERGONOMICS
Tel: (046) 603 8471 • Fax: (046) 603 8934 • e-mail: c.christie@ru.ac.za/j.mcdougall@ru.ac.za

Dear participant

Thank you for offering to participate in this Masters Research study titled: ***A laboratory evaluation of the biomechanical, physiological and perceptual responses of the standard harvesting bag in comparison to two re-designed harvesting bags for citrus workers in the Eastern Cape of South Africa*** This letter will inform you of the aim of this study, the protocols and equipment to be used as well as any benefits and/or risks that you may be exposed to.

Purpose

The current citrus harvesting bag used is a single strap shoulder bag which promotes asymmetrical load carriage. Carrying load asymmetrically means that the weight of the load is unevenly distributed around the body and may have a negative impact on the musculoskeletal system. Yet, these bags are still being used to harvest fruits such as citrus, farmed in the Eastern Cape of South Africa. Two alternative options to the standard harvesting bag have been designed The purpose of this study is to assess the effects of the old harvesting bag design (single strap bag) with the two newly developed designs (hip belt bag design and back pack bag design) to determine whether the loading on the musculoskeletal system has been improved.

Your participation in this project may assist in improving the working conditions of citrus harvesters in the Eastern Cape and possibly worldwide.

Procedure

After you have read, understood and given your consent to participate in this study, you will be immediately assigned to one of three worker groups -1) ground worker (females only), 2) stepladder worker (females only) and 3) tall ladder worker (males only). All male participants automatically belong to the tall ladder worker group but the female participants will be randomly assigned by drawing numbers out of a hat. If you pick any number from 1-12 and 13-24 you will be assigned to the ground worker group and the step ladder worker group respectively. You will then be habituated to all equipment and materials that is to be used during this study. You will be required to wear proper training shoes and comfortable clothing (preferably gym wear). This habituation may take several sessions until you are completely comfortable with the task requirements. The task requirements involve the execution of the subtasks performed during harvesting and will be explained shortly. You will then be required to come to the laboratory on three more days that are most convenient for you within the space of two weeks. Each session will consist of the same protocol (i.e. tasks performed), with only the bag designs differing. The researcher and assistant will place surface/skin electrodes on selected muscle groups (erector spinae, trapezius, anterior deltoid). These areas will be shaved (if necessary), cleaned with alcohol swabs to improve electrical signals and also marked with a permanent marker for accurate placements in consecutive testing sessions. These electrodes will feed into a DataLogger device and provide me with information on your muscle activity while you are performing the tasks. The placement of these electrodes is safe and non-invasive. An MVC (maximum voluntary contraction) protocol will be performed at the start of each testing session and for each muscle. This protocol will serve to obtain baseline/reference reading for your muscle activity. For the MVC protocol, you will be required to perform certain movements while the researcher opposes that motion. You will also be familiarized with this during the habituation sessions. This MVC protocol will take approximately two minutes to perform. After electrodes have been placed, and the MVC's have been performed, you will be required to wear a Crossbow CXTA dual axis tilt sensor/ inclinometer. This device is a small rectangular sensor that will be taped against your back and also attaches to the DataLogger device. This sensor will give information about spinal movements as you perform the tasks.

You will be required to come into the lab on a few occasions/days. The first day will be an introductory and a habituation session- this should take about one hour. Habituation may occur over more than one day as it is an essential phase. Hence, if you are still uncomfortable with the task requirements, you will be encouraged to come for an extra or more habituation sessions. The next three occasions you come into the lab after your habituation session/s will be for the actual data collection. For the three different testing days you will be required to perform three cycles of the harvesting task according to the worker group you have been assigned to (to ensure proper data analysis). One cycle will comprise of walking with one bag design (either single strap bag design, a hip belt bag design and backpack bag design) from one of three harvesting stations (simulating harvesting trees) to another, climb up a ladder (stepladder or tall ladder depending on the worker group you are assigned) pick fruits, climb down ladder, repeat this for two more harvesting stations, and then empty the fruits you have harvested from the bag into a harvesting container (1.25m high off the ground and 1070mm wide). After one cycle has been performed, the maximum weight you will be carrying but only for a very short distance will be 13kgs. After emptying the fruit local Ratings of Perceived Exertion in the lower back and left and right shoulders will be recorded before you begin the second of three cycles to obtain information about how hard you feel your muscles are working. The pace at which you perform this procedure will be entirely up to you. However, the researcher and assistant will ensure that you are performing at a pace that is smooth and continuous and not overly fast by asking you to slow down and/or speed up a little. The overall time taken for each testing session will be about one hour.

<u>Risks and benefits</u>

There are a number of risks associated with this study. However, these risks have been minimized. There is the risk of falling off the ladders but this risk will be reduced as the researcher will ensure that you are sufficiently habituated to climbing on the ladders, i.e. make sure you are comfortable with the height of the ladder and working on the ladder. There will be safety mats provided to reduce impact of falls from the ladders (if any), and a research assistant will hold the ladder to ensure ladder stability while you climb onto it to perform the task.

The risk of feeling slight discomfort while researcher is taking off the EMG electrodes (which are stuck to your skin) may be experienced. However, the researcher will ensure that there is little or no hair in the area that electrodes are placed and in taking off the electrodes researcher will ensure to peel off the electrodes from skin surface slowly. There is risk of getting cuts from shaving (excess body hair) to ensure the electrodes stick properly to your skin; however researcher and assistants will ensure that the shaving process is performed with utmost care and new blades will be used for each participant. There is also a risk of allergic reactions to the electrodes. However, researcher has level 3 first aid training and is aware of immediate assistance or treatment for allergic reactions.

There is a risk of experiencing muscular pain or discomfort (such as the neck, back and shoulders) from the weight of the bags, fatigue and performing unaccustomed tasks during or after the session. However, this will be minimized by you taking a one minute rest break in between cycles and by the researcher encouraging you to take four rest days in between testing sessions respectively for muscle recovery purposes.

For benefits, participation in this study will ensure that you gain some knowledge into the research field of Ergonomics and prevention of musculoskeletal disorders amongst citrus harvesters. On a greater scale, the overall project would be beneficial to increase worker productivity and reduce injury rates as risks and stressors of the job may be reduced or completely eliminated through the interventions strategies developed.

Privacy, Anonymity and Confidentiality

Be assured that your privacy and anonymity will be protected at all times. This is achieved through the use of participant codes. You will have the option to withdraw participation at any time, without any negative consequences. Feed-back will be provided to you as I will have your contact details (email). This feedback will exclude any personal information as all results will be reported as summative data (i.e. the combined data of all participants). The overall results of my study will remain open to all but only to be used as a reference for future scientific research and to gain an in-depth understanding in this area.

With your verbal and written consent, photographs may be taken to use for illustrative purposes in the thesis. However, any identifying features of yours will be blocked out.

Thank you again for your willingness to participate in this study. If you require any additional information kindly contact me.

Yours sincerely,

Elizabeth Bassey-Duke

(Masters student at Human Kinetics and Ergonomics Department)

Supervisor Details:

Miriam Matisson

m.mattison@ru.ac.za

Appendix C: Informed Consent Form

I, ______________________________, have been fully informed of the following research project titled; ***"A laboratory evaluation of the biomechanical, physiological and perceptual responses of the standard harvesting bag in comparison to two re-designed harvesting bags for citrus workers in the Eastern Cape of South Africa"***

I have read and understood the information letter provided by the researcher and I fully understand the testing procedures that are to occur. I am aware of all the risks, benefits as well as all that is expected of me as a participant. All risks and benefits associated with this study have been explained to me both verbally and in writing. I am able to ask questions, speak out if there are any misunderstandings and even withdraw my participation without any consequences.

I hereby accept responsibility together with the researcher, in the event of any accident or injury as a direct result of the testing protocol. By voluntarily consenting to participate in this research, I accept joint responsibility together with the Human Kinetics and Ergonomics Department, in that should any injury occur due to the protocol, the department will cover any fees incurred and take steps to rehabilitate the injury. I do however waive any legal recourse against the researcher, or against Rhodes University, and will take full responsibility in the event that the injury is shown to be self-inflicted and/or due to non-compliance with the researcher's instructions.

I realize that my anonymity will be preserved throughout the study through the use of coding instead of my name; however, I am aware that my results may be published as part of a combined group's results for statistical purposes. I am aware that during this study photographs may be taken for illustrative purposes in the final project; however, my identity will be completely protected through blocking out any identifying features. I consent that photographs may/may not (circle appropriate option) be taken during the research study for illustrative purposes if my identity is kept completely anonymous.

I am fully aware of the above information and I hereby give my consent to voluntarily participate in this study.

	Signature	**Date**
Participant	---	
RESEARCHER	---	
WITNESS 1	---	
WITNESS 2	---	

Appendix D: Borg's RPE SCALE (English Version)

Instructions: Please point out your perceived exertion or how hard you feel you are working.,

RATINGS OF PERCEIVED EXERTION

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

Appendix E: Randomization Order

Ground workers

Participant	Condition
1 and 7	A B C
2 and 8	A C B
3 and 9	B A C
4 and 10	B C A
5 and 11	C A B
6 and 12	C B A

Stepladder workers

Participant	Condition
13 and 19	A B C
14 and 20	A C B
15 and 21	B A C
16 and 22	B C A
17 and 23	C A B
18 and 24	C B A

Tall ladder workers

Participant	Condition
25 and 31	A B C
26 and 32	A C B
27 and 33	B A C
28 and 34	B C A
29 and 35	C A B
30 and 36	C B A

Where: A- Standard bag design; B- Hip belt bag design; C- Backpack bag design

Appendix F: Data Collection Sheet

Time and Motion Analysis

Participant code: ____________

Condition: ___________

TASK	CYCLE 1	CYCLE 2	CYCLE 3
Set up ladder			
Climb up ladder			
Pick fruit			
Climb down ladder			
Move from station 1-2			
Set up ladder			
Climb up ladder			
Pick fruit			
Climb down ladder			
Move from station 2-3			
Set up ladder			
Climb up ladder			
Pick fruit			
Climb down ladder			
Move from station 3–empty			
Empty fruit			
RPE			

Appendix G: Statistica Analyses

Bag for each muscle group for ground workers

Left trapezius

Repeated Measures Analysis of Variance (GROUND WORKER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 11.75852

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	27979.81	1	27979.81	202.3666	0.000000
Error	1520.89	11	138.26		
BAGS	580.89	2	290.45	5.1713	0.014425
Error	1235.63	22	56.16		

Tukey HSD test; variable DV_1 (GROUND WORKER EMG.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 56.165, df = 22.000

Cell No.	BAGS	SB 32.675	HB 28.117	BP 22.844
1	SB		0.314993	0.010838
2	HB	0.314993		0.219229
3	BP	0.010838	0.219229	

Right trapezius

Repeated Measures Analysis of Variance (GROUND WORKER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 13.11440

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	25785.94	1	25785.94	149.9290	0.000000
Error	1891.86	11	171.99		
BAGS	827.45	2	413.73	2.8502	0.079305
Error	3193.45	22	145.16		

Left anterior deltoid

Repeated Measures Analysis of Variance (GROUND WORKER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 12.20765

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	21825.14	1	21825.14	146.4510	0.000000
Error	1639.30	11	149.03		
BAGS	448.40	2	224.20	4.5585	0.022063
Error	1082.02	22	49.18		

Tukey HSD test; variable DV_1 (GROUND WORKER EMG.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 49.183, df = 22.000

Cell No.	BAGS	SB 28.617	HB 20.033	BP 25.217
1	LAD -SB		0.017578	0.472887
2	LAD-HB	0.017578		0.189598
3	LAD-BP	0.472887	0.189598	

Right anterior deltoid

Repeated Measures Analysis of Variance (GROUND WORKER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 12.87117

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	40494.85	1	40494.85	244.4350	0.000000
Error	1822.34	11	165.67		
BAGS	146.09	2	73.05	0.4857	0.621728
Error	3308.91	22	150.41		

Left erector spinae

Repeated Measures Analysis of Variance (GROUND WORKER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 8.013436

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	7024.395	1	7024.395	109.3884	0.000000
Error	706.367	11	64.215		
BAGS	54.834	2	27.417	0.3839	0.685658
Error	1571.088	22	71.413		

Right erector spinae

Repeated Measures Analysis of Variance (GROUND WORKER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 7.170660

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	6664.001	1	6664.001	129.6035	0.000000
Error	565.602	11	51.418		
BAGS	114.699	2	57.349	1.8414	0.182214
Error	685.178	22	31.144		

Bag for each muscle group for stepladder workers

Left Trapezius

Repeated Measures Analysis of Variance (STEP LADDER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 10.61096

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	17703.19	1	17703.19	157.2323	0.000000
Error	1238.52	11	112.59		
BAGS	495.53	2	247.77	6.2573	0.007057
Error	871.11	22	39.60		

Tukey HSD test; variable DV_1 (STEP LADDER EMG.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 39.596, df = 22.000

Cell No.	BAGS	SB 27.342	HB 18.798	**BP 20.387**
1	LT SB		0.008384	0.033224
2	LT HB	0.008384		0.811814
3	LT BP	0.033224	0.811814	

Right Trapezius

Effect	Repeated Measures Analysis of Variance (STEP LADDER EMG.sta) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 16.78337 SS	Degr. of Freedom	MS	F	p
Intercept	24460.96	1	24460.96	86.83904	0.000001
Error	3098.50	11	281.68		
BAGS	592.25	2	296.12	4.77887	0.018901
Error	1363.23	22	61.97		

Cell No.	Tukey HSD test; variable DV_1 (STEP LADDER EMG.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 61.965, df = 22.000 BAGS	SB 31.500	HB 24.943	**BP** **21.758**
1	RT SB		0.126197	0.016307
2	RT HB	0.126197		0.590124
3	RT BP	0.016307	0.590124	

Left anterior deltoid

Effect	Repeated Measures Analysis of Variance (STEP LADDER EMG.sta) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 11.09213 SS	Degr. of Freedom	MS	F	p
Intercept	35293.88	1	35293.88	286.8597	0.000000
Error	1353.39	11	123.04		
BAGS	105.52	2	52.76	0.7534	0.482541
Error	1540.67	22	70.03		

Right Anterior deltoid

Effect	Repeated Measures Analysis of Variance (STEP LADDER EMG.sta) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 11.78916 SS	Degr. of Freedom	MS	F	p
Intercept	42045.50	1	42045.50	302.5198	0.000000
Error	1528.83	11	138.98		
BAGS	1492.42	2	746.21	4.9468	0.016823
Error	3318.62	22	150.85		

Cell No.	Tukey HSD test; variable DV_1 (STEP LADDER EMG.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 150.85, df = 22.000 BAGS	SB 37.700	HB 39.683	**BP** **25.142**
1	RAD SB		0.917770	0.050886
2	RAD HB	0.917770		0.021825
3	RAD BP	0.050886	0.021825	

Left Erector spinae

Effect	Repeated Measures Analysis of Variance (STEP LADDER EMG.sta) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 8.873554 SS	Degr. of Freedom	MS	F	p
Intercept	9209.281	1	9209.281	116.9581	0.000000
Error	866.140	11	78.740		
BAGS	384.180	2	192.090	5.9018	0.008873
Error	716.054	22	32.548		

Cell No.	Tukey HSD test; variable DV_1 (STEP LADDER EMG.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 32.548, df = 22.000 BAGS	SB 19.909	HB 16.161	**BP** **11.913**
1	LES SB		0.262959	0.006545
2	LES HB	0.262959		0.185260
3	LES BP	0.006545	0.185260	

Right Erector spinae

Effect	Repeated Measures Analysis of Variance (STEP LADDER EMG.sta) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 11.31042 SS	Degr. of Freedom	MS	F	p
Intercept	12386.21	1	12386.21	96.82348	0.000001
Error	1407.18	11	127.93		
BAGS	1298.35	2	649.17	6.14757	0.007570
Error	2323.17	22	105.60		

Tukey HSD test; variable DV_1 (STEP LADDER EMG.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 105.60, df = 22.000

Cell No.	BAGS	SB 26.117	HB 18.103	BP 11.427
1	RES SB		0.159601	0.005597
2	RES HB	0.159601		0.270335
3	RES BP	0.005597	0.270335	

Bag for each muscle group for tall ladder workers

Left Trapezius

Repeated Measures Analysis of Variance (TALL LADDER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 14.58345

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	18027.99	1	18027.99	84.76692	0.000002
Error	2339.45	11	212.68		
BAGS	99.44	2	49.72	0.26831	0.767138
Error	4076.83	22	185.31		

Right Trapezius

Repeated Measures Analysis of Variance (TALL LADDER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 15.83992

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	23132.89	1	23132.89	92.19846	0.000001
Error	2759.94	11	250.90		
BAGS	52.17	2	26.08	0.15822	0.854621
Error	3626.87	22	164.86		

Left anterior deltoid

Repeated Measures Analysis of Variance (TALL LADDER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 14.53089

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	39574.47	1	39574.47	187.4263	0.000000
Error	2322.62	11	211.15		
BAGS	869.26	2	434.63	4.2388	0.027725
Error	2255.81	22	102.54		

Tukey HSD test; variable DV_1 (TALL LADDER EMG.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 102.54, df = 22.000

Cell No.	BAGS	SB 28.525	HB 39.958	**BP 30.983**
1	LAD SB		0.029292	0.824476
2	LAD HB	0.029292		0.098817
3	LAD BP	0.824476	0.098817	

Right Anterior deltoid

Repeated Measures Analysis of Variance (TALL LADDER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 18.72189

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	38756.48	1	38756.48	110.5719	0.000000
Error	3855.60	11	350.51		
BAGS	2364.17	2	1182.09	4.6567	0.020588
Error	5584.60	22	253.85		

Tukey HSD test; variable DV_1 (TALL LADDER EMG.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 253.85, df = 22.000

Cell No.	BAGS	SB 32.767	HB 42.758	**BP 22.908**
1	RAD SB		0.294100	0.303242
2	RAD HB	0.294100		0.015589
3	RAD BP	0.303242	0.015589	

Left Erector spinae

Repeated Measures Analysis of Variance (TALL LADDER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 5.842995

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	9352.502	1	9352.502	273.9408	0.000000
Error	375.547	11	34.141		
BAGS	180.788	2	90.394	5.1032	0.015111
Error	389.692	22	17.713		

Tukey HSD test; variable DV_1 (TALL LADDER EMG.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 17.713, df = 22.000

Cell No.	BAGS	SB 17.935	HB 17.458	**BP 12.961**
1	LES SB		0.958635	0.022075
2	LES HB	0.958635		0.040199
3	LES BP	0.022075	0.040199	

Right Erector spinae

Repeated Measures Analysis of Variance (TALL LADDER EMG.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 12.63092

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	11621.20	1	11621.20	72.84180	0.000004
Error	1754.94	11	159.54		
BAGS	382.47	2	191.23	3.07129	0.066626
Error	1369.83	22	62.27		

Asymmetry ratios

Ground workers

Repeated Measures Analysis of Variance (GW.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .5898281

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	156.5321	1	156.5321	449.9379	0.000000
Error	3.8269	11	0.3479		
BAGS	4.8656	2	2.4328	4.4360	0.024067
Error	12.0652	22	0.5484		
MUSCLES	0.9884	2	0.4942	2.7506	0.085857
Error	3.9526	22	0.1797		
BAGS*MUSCLES	2.0298	4	0.5074	2.0743	0.100403
Error	10.7641	44	0.2446		

Tukey HSD test; variable DV_1 (GW)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = .54842, df = 22.000

Cell No.	**BAGS**	SB 1.0840	HB 1.5022	BP 1.0256
1	SB		0.063515	0.940450
2	HB	0.063515		0.031622
3	BP	0.940450	0.031622	

Stepladder workers

Repeated Measures Analysis of Variance (SL.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .4988860

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	156.8814	1	156.8814	630.3313	0.000000
Error	2.7378	11	0.2489		
BAGS	0.1325	2	0.0662	0.1915	0.827109
Error	7.6103	22	0.3459		
MUSCLES	2.1650	2	1.0825	6.9817	0.004489
Error	3.4110	22	0.1550		
BAGS*MUSCLES	1.6423	4	0.4106	1.6714	0.173697
Error	10.8085	44	0.2456		

No significance between the bag designs

Tall ladder workers

Effect	Repeated Measures Analysis of Variance (TL.sta) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .6551912 SS	Degr. of Freedom	MS	F	p
Intercept	149.0577	1	149.0577	347.2308	0.000000
Error	4.7220	11	0.4293		
BAGS	1.8015	2	0.9007	1.5385	0.236923
Error	12.8801	22	0.5855		
MUSCLES	0.1213	2	0.0606	0.1934	0.825526
Error	6.8972	22	0.3135		
BAGS*MUSCLES	1.0596	4	0.2649	1.1573	0.342582
Error	10.0716	44	0.2289		

No significance between bag designs

MVC

Ground workers (left muscles)

Effect	Repeated Measures Analysis of Variance (GW.sta) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 13.66016 SS	Degr. of Freedom	MS	F	p
Intercept	53018.24	1	53018.24	284.1277	0.000000
Error	2052.60	11	186.60		
BAGS	3811.10	2	1905.55	23.1109	0.000004
Error	1813.96	22	82.45		
MUSCLES	597.94	2	298.97	4.6067	0.021325
Error	1427.77	22	64.90		
BAGS*MUSCLES	486.19	4	121.55	2.1732	0.087695
Error	2460.97	44	55.93		

Ground workers (Right muscles)

Effect	Repeated Measures Analysis of Variance (GW.sta) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 8.667 SS	Degr. of Freedom	MS	F	p
Intercept	65548.32	1	65548.32	872.4963	0.000000
Error	826.40	11	75.13		
BAGS	7396.48	2	3698.24	23.5597	0.000003
Error	3453.40	22	156.97		
MUSCLES	574.42	2	287.21	2.0994	0.146406
Error	3009.74	22	136.81		
BAGS*MUSCLES	513.83	4	128.46	1.3529	0.265714
Error	4177.80	44	94.95		

Stepladder workers (left muscles)

Repeated Measures Analysis of Variance (SL)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 12.35329

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	57931.03	1	57931.03	379.6170	0.000000
Error	1678.64	11	152.60		
BAGS	4275.32	2	2137.66	26.4294	0.000001
Error	1779.40	22	80.88		
MUSCLES	372.03	2	186.02	4.2687	0.027133
Error	958.69	22	43.58		
BAGS*MUSCLES	613.20	4	153.30	3.1096	0.024455
Error	2169.14	44	49.30		

Stepladder workers (Right muscles)

Repeated Measures Analysis of Variance (SL)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 15.07584

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	74495.42	1	74495.42	327.7678	0.000000
Error	2500.09	11	227.28		
BAGS	4397.25	2	2198.62	13.6854	0.000138
Error	3534.42	22	160.66		
MUSCLES	2829.72	2	1414.86	17.6194	0.000027
Error	1766.63	22	80.30		
BAGS*MUSCLES	553.30	4	138.32	1.1619	0.340599
Error	5238.39	44	119.05		

Tall ladder workers (left muscles)

Repeated Measures Analysis of Variance (TL)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 10.36201

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	53996.27	1	53996.27	502.8925	0.000000
Error	1181.09	11	107.37		
BAGS	3126.89	2	1563.45	10.8671	0.000522
Error	3165.14	22	143.87		
MUSCLES	1162.01	2	581.00	6.8465	0.004878
Error	1866.94	22	84.86		
BAGS*MUSCLES	943.24	4	235.81	2.7292	0.040989
Error	3801.66	44	86.40		

Tall ladder workers (right muscles)

Repeated Measures Analysis of Variance (TL.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 10.98723

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	55520.64	1	55520.64	459.9151	0.000000
Error	1327.91	11	120.72		
BAGS	1584.49	2	792.24	3.4317	0.050446
Error	5078.93	22	230.86		
MUSCLES	1023.98	2	511.99	6.3439	0.006679
Error	1775.53	22	80.71		
BAGS*MUSCLES	382.27	4	95.57	1.0082	0.413534
Error	4170.61	44	94.79		

LOCAL RPE

Ground workers- Shoulders

Repeated Measures Analysis of Variance (GW Spreadsheet1.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 4.680714

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	15123.00	1	15123.00	690.2614	0.000000
Error	241.00	11	21.91		
BAGS	53.56	2	26.78	31.9398	0.000000
Error	18.44	22	0.84		
CYCLES	581.06	2	290.53	45.7815	0.000000
Error	139.61	22	6.35		
BAGS*CYCLES	9.56	4	2.39	3.7840	0.009926
Error	27.78	44	0.63		

Tukey HSD test; variable DV_1 (Spreadsheet1)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 6.3460, df = 22.000

Cell No.	BAGS	SB 15.111	HB 10.306	BP 10.083
1	SB		0.000136	0.000136
2	HB	0.000136		0.926042
3	BP	0.000136	0.926042	

Stepladder workers- shoulders

Repeated Measures Analysis of Variance (GW 2Spreadsheet1.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 1.997262

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	16850.01	1	16850.01	4224.058	0.000000
Error	43.88	11	3.99		
BAGS	304.80	2	152.40	53.234	0.000000
Error	62.98	22	2.86		
CYCLES	40.57	2	20.29	23.241	0.000004
Error	19.20	22	0.87		
BAGS*CYCLES	12.37	4	3.09	7.093	0.000169
Error	19.19	44	0.44		

Cell No.	Tukey HSD test; variable DV_1 (GW 2Spreadsheet1.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 2.8628, df = 22.000 BAGS	SB 14.861	HB 11.444	BP 11.167
1	SB		0.000136	0.000136
2	HB	0.000136		0.768080
3	BP	0.000136	0.768080	

Tall ladder workers- Shoulders

Effect	Repeated Measures Analysis of Variance (SL 2Spreadsheet1.sta) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 5.217491 SS	Degr. of Freedom	MS	F	p
Intercept	16576.33	1	16576.33	608.9265	0.000000
Error	299.44	11	27.22		
BAGS	280.39	2	140.19	86.0729	0.000000
Error	35.83	22	1.63		
CYCKLES	48.50	2	24.25	20.2168	0.000010
Error	26.39	22	1.20		
BAGS*CYCKLES	6.61	4	1.65	1.7956	0.146801
Error	40.50	44	0.92		

Cell No.	Tukey HSD test; variable DV_1 (SL 2Spreadsheet1.sta) Approximate Probabilities for Post Hoc Tests Error: Within MSE = 1.6288, df = 22.000 BAGS	SB 14.667	HB 11.306	BP 11.194
1	SB		0.000136	0.000136
2	HB	0.000136		0.927885
3	BP	0.000136	0.927885	

Ground workers –back

Effect	SS	Degr. of Freedom	MS	F	p
	Repeated Measures Analysis of Variance (gwback2Spreadsheet1.sta) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 3.651483				
Intercept	8321.333	1	8321.333	624.1000	0.000000
Error	146.667	11	13.333		
BAGS	145.722	2	72.861	12.3041	0.000259
Error	130.278	22	5.922		
CYCELS	5.056	2	2.528	5.7861	0.009569
Error	9.611	22	0.437		
BAGS*CYCELS	1.389	4	0.347	0.6962	0.598652
Error	21.944	44	0.499		

Tukey HSD test; variable DV_1 (gwback2Spreadsheet1.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 5.9217, df = 22.000

Cell No.	BAGS	SB 10.417	HB 8.0556	**BP 7.8611**
1	1SB		0.001382	0.000670
2	HB	0.001382		0.938878
3	BP	0.000670	0.938878	

Stepladder workers –back

Repeated Measures Analysis of Variance (sl back2Spreadsheet1.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 2.934756

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	9937.926	1	9937.926	1153.856	0.000000
Error	94.741	11	8.613		
BAGS	222.741	2	111.370	22.702	0.000004
Error	107.926	22	4.906		
CYCLES	15.685	2	7.843	7.508	0.003269
Error	22.981	22	1.045		
BAGS*CYCLES	4.148	4	1.037	1.433	0.239164
Error	31.852	44	0.724		

Tukey HSD test; variable DV_1 (sl back2Spreadsheet1.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 4.9057, df = 22.000

Cell No.	BAGS	SB 11.611	HB 8.7778	**BP 8.3889**
1	SB		0.000180	0.000142
2	HB	0.000180		0.739879
3	BP	0.000142	0.739879	

Tall ladder workers-back

Repeated Measures Analysis of Variance (tl back2Spreadsheet1.sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 5.151247

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	10208.33	1	10208.33	384.7069	0.000000
Error	291.89	11	26.54		
BAGS	151.72	2	75.86	11.5321	0.000375
Error	144.72	22	6.58		
CYCLES	5.06	2	2.53	0.9158	0.414909
Error	60.72	22	2.76		
BAGS*CYCLES	52.22	4	13.06	7.2409	0.000143
Error	79.33	44	1.80		

Tukey HSD test; variable DV_1 (tl back2Spreadsheet1.sta)
Approximate Probabilities for Post Hoc Tests
Error: Within MSE = 6.5783, df = 22.000

Cell No.	BAGS	SB 11.083	HB 9.8889	**BP 8.1944**
1	SB		0.141969	0.000370
2	HB	0.141969		0.027028
3	BP	0.000370	0.027028	

APPENDICES FOR PHASE 2

Appendix H: Letter of Information to Participants (Xhosa Version)

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

HUMAN KINETICS & ERGONOMICS
Tel: (046) 603 8471 • Fax: (046) 603 8934 • e-mail: c.christie@ru.ac.za/j.mcdougall@ru.ac.za

Mthathi nxaxheba

Enkosi ngokundivumela ndenze uphando nzulu lweMasters Research yam. Umxholo woluphando luthi: : ***A field investigation into the perceptual responses, productivity effects and worker acceptance of two newly designed citrus harvesting bags in comparison to the standard harvesting bags amongst citrus workers in the Eastern Cape of South Africa.***

Ndingathanda unazisa ngeenjongo zoluphando, imigaqo nezixhobo ezathi zisetyenziswe kunye nenzuzo okanye imingeni oyakuthi udibane nayo ngexesha lophando.

Injongo yesifundo

Injongo yoluphando kukufumana eyona ngxowa ichanekileyo yovuna apho sijonga indlela oxhamleka ngayo xa usenza lomsebenzi ngale ngxhowa. Eyona nto esifuna ukuyiphanda kuxhamleka kwakho xa usebenzisa lengxhowa seyikho, sibone yeyiphi engcono kukhupiswano nezizintsha.

Umgaqo nqubo

Xa uvumile uthatha inxaxheba koluphando, kuzonyanzeleka usebenzise zombini ezingxowa, apho ngemini enye usebenzise leseyikho ingxhowa, ngenye imini usebenzise enye entsha ingxowa, uzoziqhela. Xa usoqhelene neziingxhowa, kuzonyanzeleka usebenzise uhlobo olunye ngamini nganye xa usenza umsebenzi wakho wosuku ngesiqhelo.

Qho nge-yure usasebenza nje, umphandi uzokubuza imibuzo yokuba uziva njani ngokusebenzisa ingxhowa ethile, (uzoboniswa icwecwe elinamanani abonisa ukudinwa ngokwahluka kweengxhowa othe wazisebenzisa – "RPE scale"). Umphandi uzokuncedisa ngokuphendula imibuzo yokuba ibenjani imiphumela yokusebenzisa ezangxhowa kwaye aphinde abale iingxhowa othe wazenza nye-yure kumsebenzi wosuku ekuboniseni umsebenzi wakho wemini (productivity).

Imingeni neenzuzo

Zimbalwa kakhulu imingeni yoluphando.

1. Umnegi wokuqala kungaqheli usebenzisa uhlobo olutsha lengxhowa, apho lonto izokwenza ungasebenzi kamnandi. Umphandi uzame kangangoko kubelula ukuziqhelisana noluhlobo lwegxhowa.
2. Kuzobakho umngeni wokuziva ungakhululekanga xa usebenza ujongiwe ngumphandi nabancedisi bakhe. Umphandi uyokwzenza ngoqinisekileyo ukuba kukho imvisiswano.

Iinzuzo zoluphando;

1. Uzokufumana ulwazi ngoluphando malunga ngendlela zuvuna ngendlela eyiyo, ekuncediseni nomziba wakho ungabibuhlungu.
2. Ukuba umphathi womsebenzi uyavuma, ingxhowa ethe yayeyona isebenzisa kamnandi iyokusetyenziswa ngumnntu wonke ekuncediseni indlela enisebenza ngayo kwaye zinqande izinto ezingunobangela umzimba wakho abebuhlungu.

Imfihlo yeenkcukaca zomthathi nxaxheba

Ungumthathi nxaxheba, uzokwazi ukuyeka phakathi koluphando ukuba awusafuni ukuqhebekeka nalo, ngaphandle kwemvume yomphathi wakho.

Zonke iinkcukaca zakho zizogcinwa zifihlakele.

Ukuba ufuna ukwazi iziphumo zoluphando, uzokwazi ukuzifumana emveni kokuba uphando lugqityiwe.

Iziphumo zoluphando zizokwazi ufunyanwa ngabanye abaphandayo ngalemeko yophando.

Ukuba umthathi nxaxheba uyavuma, imifanekiso izothathwa xa besebenza ekuncediseni oluphando. Umphandi uzozama kangangoko ukufihla ubuso kunye nezinye izinto zomthathi nxaxhaba kulemifanekiso.

Ndiyabulela ngokuzithobileyo ngokundincedisa ngokuphando. Ukuba ufuna ezinye iinkcukaca malunga noluphando, ndizocela undibambe ngomnxeba (contact details).

Letter of information to participant (English Version)

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

HUMAN KINETICS & ERGONOMICS
Tel: (046) 603 8471 • Fax: (046) 603 8934 • e-mail: c.christie@ru.ac.za/j.mcdougall@ru.ac.za

NB: This letter of information will be verbally communicated to the recruited participants with the aid of an English–Xhosa translator.

Dear participant

Thank you for offering to participate in this phase of my Masters Research study. This phase is titled: ***A field investigation into the perceptual responses, productivity effects and worker acceptance of two newly designed citrus harvesting bags in comparison to the standard harvesting bags amongst citrus workers in the Eastern Cape of South Africa.***

I would like to inform you of the aim of this study, the protocols and equipment to be used as well as any benefits and/or risks that you may be exposed to.

Purpose of study

The purpose of this study is to investigate, in terms of your perceived exertion, productivity/performance and your acceptance, whether the standard harvesting bag (show participants bag) is any different than these two new bag designs (show participants bag and have them handle it for a few minutes).

Procedure

Once you have consented to participating, you will be asked to use each of the two bags for a full day each to get used to them. Once you are familiar with how to use the bags, you will be required to use one of the three different bags for a whole day to perform your harvesting tasks as per normal. On the two other days, you will be required to make use of the other two bag designs. Every hour during the work shift, 1) the researcher will ask you to indicate how hard you feel you are working as a result of the bag (show participants RPE scale and how to use it), 2) the researcher will assist you in completing a questionnaire that assesses how useful and how easy to use the bag was, and 3) the researcher will count and record how many bags you were able to harvest every hour throughout the work day, which will indicate your productivity.

Risks and benefits

There are very few risks associated with this study.

1. There is a risk of you not being familiar with the new bag designs, and hence feeling uncomfortable while using it. However, the researcher has designed the bags to minimize this risk.
2. There is risk of emotional discomfort from the researcher and research assistants watching and monitoring you for brief moments during the course of the day while you perform your job. However, researcher will ensure that this monitoring is done in the most subtle manner.

The benefits of participating in this study;

1. You will gain some knowledge into the research field of Ergonomics and prevention of musculoskeletal disorders amongst citrus harvesters.
2. If allowed by the manager, the new bag design that elicited the best responses could be permanently used by you to perform your job more efficiently and with a lower risk of discomfort and musculoskeletal disorder as a result of your job demands.

Confidentiality and Anonymity

You will have the option to withdraw participation at any time, without any negative consequences from your manager /supervisor.

All personal information will be kept anonymous and confidential.

You will be entitled to feed-back, but this feedback will exclude any personal information as all results will be reported as a group report.

The results of my study will remain available for researchers in a similar research field, but only to be used as a reference for future research to gain in-depth understanding in this area.

Photographs may be taken to use for illustrative purposes in the overall thesis, but only if you consent to it. However, any identifying features of yours will be blocked out.

Thank you again for your willingness to participate in this study. If you require any additional information kindly contact me (hand out card to each worker with researcher's contact details).

Appendix I: Informed Consent Form (Xhosa version)

Ndingu, ______________________________, ndixelelwe yonke into ekufuneka ndiyazi malunga noluphando ***"A field investigation of the perceptual, productivity effects and worker acceptance of two newly designed citrus harvesting bags in comparison to the standard harvesting bags amongst citrus workers in the Eastern Cape of South Africa."*** Ndiyavuma ukuthathi nxaxheba koluphando.

Ndaziswe ngayoyonke into ekumele ndiyazi ngoluphando, ngokuxelelwa nobhalelwano. Ndiyayazi imingeni neenzuzo zoluphando.

Ndiyayazi ukuba xa ndifuna ukurhoxa koluphando, ndingakwazi nanini na ngaphandle kwemvume yomnye umntu. Ndiyayazi ukuba iinkcukaca zam zaziwa ngumphandi yedwa kwaye zizofihlwa kwabanye abantu, ndikhuseleke. Ndiyavuma ukuba ezinkcukaca zikoluphando zingasetyenziswa kolunye uphando.

	Signature	Date
Umthathi nxaxheba	---------------	-------------
UMPHANDI	----------------	-------------
INGQINA 1	----------------	-------------
INGQINA 2	---------------	-------------

INFORMED CONSENT FORM (English Version)

N.B: This is for the farm workers and will be read out by a translator in Xhosa

I, ______________________________, have been fully informed of the following phase of this research project titled; ***"A field investigation of the perceptual, productivity effects and worker acceptance of two newly designed citrus harvesting bags in comparison to the standard harvesting bags amongst citrus workers in the Eastern Cape of South Africa."*** I hereby give my consent to participate in this phase of the study out of my own accord.

I have been fully informed (verbally and in writing) of the procedures involved as well as any potential risks and benefits associated herewith, as far as they are currently known by the researchers involved.

I understand that I may withdraw my participation from this study at any time without consequences. I am aware that my anonymity, will be protected at all times. I also agree to all information being collected and aggregated to be published and used for statistical and/or scientific purposes.

	Signature	Date
Participant	---------------	-------------
RESEARCHER	----------------	-------------
WITNESS 1	----------------	-------------
WITNESS 2	----------------	-------------

Appendix J: Letter of Information to Farm Owner

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

HUMAN KINETICS & ERGONOMICS
Tel: (046) 603 8471 • Fax: (046) 603 8934 • e-mail: c.christie@ru.ac.za/j.mcdougall@ru.ac.za

Dear ____________

Thank you for agreeing to allow your workers to participate in this phase of my Masters Research study. This phase of the overall study is titled: ***A field investigation into the perceptual responses, productivity effects and worker acceptance of two newly designed citrus harvesting bags in comparison to the standard harvesting bags used by citrus workers in the Eastern Cape of South Africa.***

I would like to inform you of the aim of this study, the protocols and equipment to be used, as well as any benefits and/or risks that you and/or your workers may be exposed to.

Purpose of study

As part of the greater master's project, I have developed two alternative harvesting bag designs to the conventional harvesting one. This study is a two phase study. In the first phase, extensive measurements are performed in the laboratory to evaluate the physiological, biomechanical and perceptual effects of the current and the newly designed harvesting bags. The purpose of this second phase of the study is to investigate in the field setting, the productivity effect, perceptual responses and the workers' acceptance to the conventional citrus harvesting bag in comparison to the two newly designed citrus harvesting bags, which were designed based on research of the scientific literature. There is evidence-based research which proves that the current harvesting bags used promote asymmetrical load carriage and as such increases the risk of musculoskeletal disorders amongst citrus farm harvesters, but can also lead to increased fatigue and thus decreased productivity.

Procedure

After your consent has been obtained, I will recruit at least 27 harvesters by addressing them in an informal group setting. Your workers' participation in this study must only be voluntary. The requirements, risks and benefits of the study will be verbally communicated and demonstrated to your workers with the aid of a translator to ensure that they understand as best as possible what this research is about. Thereafter, the new bag designs will be given to recruited workers to use and habituate themselves with. This habituation will be done informally and workers will be required to spend a day each, using the bags during the harvesting process to habituate themselves to the different bag designs. The actual testing protocol, which will follow the habituation period, will last for a maximum of two weeks. After this process has occurred, your workers will then be required to, on three separate days, use each bag design to perform their daily jobs, with the researcher or an assistant monitoring them for brief moments throughout the course of the work day. The data that will be collected during the course of the day will include: 1) the number of full bags harvested hourly, 2) the workers' subjective measure of how much musculoskeletal strain they had experienced using a local Ratings of Perceived exertion scale (they would be familiarised with this scale earlier on) and 3) workers responses to a brief questionnaire that will assess their perception of how useful and how easy to use the bags were.

Risks and benefits

There are very few risks associated with this study:

Your workers may be at risk of experiencing discomfort from using a harvesting bag that they are not familiar with. However, through the habituation period, they will become accustomed to it. Also, during the bag design specification phase, the researcher took into consideration manouvreablility, ease of use, and balance when using the bags. Hence, this risk of discomfort and risk of injury and accidents should theoretically be minimal. Secondly, they might feel pressure with the researcher monitoring them for brief moments. However, the researcher will ensure monitoring is done in the most subtle manner.

For you, there is a risk of low output as workers' productivity (number of bags harvested) may be marginally reduced as they may need a few hours to get accustomed to the new bag. However, as stated earlier this is a low risk as this was considered by the researcher during the bag design specification.

You will benefit from this study by gaining knowledge in the field of Ergonomics and the prevention of musculoskeletal disorders. Also, if you permanently implement one of the new bag designs, in the long run, your worker productivity may improve and your workers experience less fatigue by using the new bag designs.

Confidentiality and Anonymity

You as the farm manager will have the option to withdraw your workers' participation (as will your workers as individuals) at any time, without any negative consequences to you. All personal information (workers' names, farm name, and your name) will be kept anonymous and confidential. You will be entitled to feed-back, but this feedback will exclude any personal information of participants and all results will be reported as a summative report. The results of my study will remain available for researchers performing research in a similar field, but only to be used as a reference for future research to gain in-depth understanding in this area. With yours' and your workers' consent, photographs of the workers during the working process may be taken to use for illustrative purposes in my final thesis. However, any features identifying your farm premises or your workers will be blocked out.

Thank you again for your willingness to participate in this study. If you require any additional information kindly contact me.

Yours sincerely,

Elizabeth Bassey-Duke

(Masters student at Human Kinetics and Ergonomics Department)

g09b0781@campus.ru.ac.za; **0735110372**

Supervisor Details: Miriam Mattison: m.mattison@ru.ac.za; **0823194626**

Appendix K: Informed Consent for Farm Owner

I, ______________________________, have been fully informed of the following phase of this research project titled; **"*A field investigation of the perceptual, productivity effects and worker acceptance of two newly designed citrus harvesting bags in comparison to the standard harvesting bags amongst citrus workers in the Eastern Cape of South Africa."*** I hereby give my consent for this phase of the study to be conducted on my farm and for the farm labourers to participate in this study, as far as they are willing to participate out of their own accord.

I have been fully informed (verbally and in writing) of the procedures involved as well as any potential risks and benefits associated herewith, as far as they are currently known by the researchers involved.

I understand that I may withdraw my / my labourers' participation from this study at any time without consequences. I am aware that my anonymity, that of the labourers and the farm will be protected at all times. I also agree to all information being collected and aggregated to be published and used for statistical and/or scientific purposes.

	Signature	Date
Farm owner/manager	---------------	-------------
RESEARCHER	----------------	-------------
WITNESS 1	----------------	-------------
WITNESS 2	----------------	-------------

Appendix L: Borg's RPE SCALE (Xhosa Version)

RPE SCALE

6.
7. KANCINCI KAKHULU
8.
9. KANCINCI
10.
11. KANCINANE NOKO
12.
13. NZINYANA
14.
15. NZIMA
16.
17. NZIMA KAKHULU
18.
19. NZIMA KAKHULU KANYE
20.

Appendix M: Perceived Usefulness and Ease of Use (Xhosa & English)

1. **Ingxhowa ethile iluncedo ekuthini?**
   (How useful was this bag?)

   a) Iluncedo kakhulu (extremely useful)
   b) iluncedo kancinci (slightly useful)
   c) Kancinci noko (neutral)
   d) Ayi' luncedo nzinyana (slightly un-useful)
   e) Ayi' luncedo kakhulu (extremely un-useful)

2) **Ingxhowa ethile ilula ekuthini?**
   (How easy to use was this bag)

   a) Ilula kakhulu (extremely easy to use)
   b) 2) ilula kancinci (slightly easy to use)
   c) 3) ilula kancinane noko (Neutral)
   d) 4) ayikho' lula nziyana (slightly un-easy)
   e) 5) Ayikho' lula (extremely un-easy)

Appendix N: Data Collection Sheet

Participant code: ________________________ (e.g. GWO1)

Day 1:

Condition _____

	Hour 1	Hour 2	Hour 3	Hour 4	Hour 5	Hour 6	Hour 7	Hour 8
Harvested bags								
RPE								

Perceived usefulness ____________________

Perceived ease of use______________________

Day 2:

Condition _____

	Hour 1	Hour 2	Hour 3	Hour 4	Hour 5	Hour 6	Hour 7	Hour 8
Harvested bags								
RPE								

Perceived usefulness ____________________

Perceived ease of use______________________

Day 3:

Condition _____

	Hour 1	Hour 2	Hour 3	Hour 4	Hour 5	Hour 6	Hour 7	Hour 8
Harvested bags								
RPE								

Perceived usefulness ____________________

Perceived ease of use______________________

Appendix O: Randomization Order

PARTICIPANT	CONDITION
GW01	ABC
GW02	ACB
GW03	BCA
GW04	BAC
GW05	CAB
GW06	CBA
SL01	ABC
SL02	ACB
TL01	ABC
TL02	ACB
TL03	BAC
TL04	BCA
TL05	CAB
TL06	CBA
TL07	ABC
TL08	BAC
TL09	BCA

WHERE:

A- Standard bag design, B- Hip belt bag design and C- Backpack bag design

GW= ground worker, SL= stepladder worker and TL= tall ladder worker

RPE

Tukey HSD test; variable DV_1 (Spreadsheet1_(Recovered).sta)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 7.8361, df = 17.998

Cell No.	Group	BAGS	GW-SB 7.0000	GW-HB 10.000	GW-BP 11.670	SL-SB 7.0000	SL-HB 7.0000	SL-BP 10.000	TL-SB 10.693	TL-HB 8.3286	**TL-BP 11.066**
1	GW	RPE-SB		0.996339	0.947621	1.000000	1.000000	0.996837	0.937796	0.999934	0.899218
2	GW	RPE-HB	0.996339		0.999945	0.996837	0.996837	1.000000	1.000000	0.999639	0.999988
3	GW	RPE-BP	0.947621	0.999945		0.951079	0.951079	0.999956	0.999994	0.963891	1.000000
4	SL	RPE-SB	1.000000	0.996837	0.951079		1.000000	0.996339	0.937796	0.999934	0.899218
5	SL	RPE-HB	1.000000	0.996837	0.951079	1.000000		0.996339	0.937796	0.999934	0.899218
6	SL	RPE-BP	0.996837	1.000000	0.999956	0.996339	0.996339		1.000000	0.999639	0.999988
7	TL	RPE-SB	0.937796	1.000000	0.999994	0.937796	0.937796	1.000000		0.801394	0.999999
8	TL	RPE-HB	0.999934	0.999639	0.963891	0.999934	0.999934	0.999639	0.801394		0.669495
9	TL	RPE-BP	0.899218	0.999988	1.000000	0.899218	0.899218	0.999988	0.999999	0.669495	

Productivity

Tukey HSD test; variable DV_1 (Spreadsheet1_(Recovered).sta)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = 5.5077, df = 11.697

Cell No.	Group	BAGS	GW-SB 9.7100	SW-HB 8.0000	GW-BP 11.000	SL-SB 7.0000	SL-HB 6.5000	SL-BP 7.0000	TL-SB 7.3543	**TL-HB 5.2357**	TL-BP 9.7286
1	GW	Prod-SB		0.996717	0.999542	0.993803	0.982275	0.993803	0.985152	0.691654	1.000000
2	GW	Prod-BP	0.996717		0.912270	0.999996	0.999904	0.999996	0.999999	0.962710	0.998017
3	GW	Prod-HB	0.999542	0.912270		0.940101	0.894067	0.940101	0.856244	0.411840	0.999777
4	SL	Prod-SB	0.993803	0.999996	0.940101		1.000000	1.000000	1.000000	0.997714	0.965277
5	SL	Prod-BP	0.982275	0.999904	0.894067	1.000000		1.000000	0.999989	0.999786	0.917093
6	SL	Prod-HB	0.993803	0.999996	0.940101	1.000000	1.000000		1.000000	0.997714	0.965277
7	TL	Prod-SB	0.985152	0.999999	0.856244	1.000000	0.999989	1.000000		0.345880	0.232389
8	TL	Prod-BP	0.691654	0.962710	0.411840	0.997714	0.999786	0.997714	0.345880		0.005013
9	TL	Prod-HB	1.000000	0.998017	0.999777	0.965277	0.917093	0.965277	0.232389	0.005013	

Usefulness

Tukey HSD test; variable DV_1 (Spreadsheet1_(Recovered).sta)
Approximate Probabilities for Post Hoc Tests
Error: Between; Within; Pooled MSE = .38218, df = 13.301

Cell No.	Group	BAGS	GW-SB 1.0000	GW-HB 1.0000	GW-BP 2.0000	SL-SB .90000	SL-HB .90000	SL-BP 4.0000	TL-SB 1.2857	TL-HB 1.0014	**TL-BP 1.7143**
1	GW	Useful-SB		1.000000	0.835271	1.000000	1.000000	0.073403	0.999937	1.000000	0.967657
2	GW	Useful-HB	1.000000		0.835271	1.000000	1.000000	0.073403	0.999937	1.000000	0.967657
3	GW	Useful-BP	0.835271	0.835271		0.927525	0.927525	0.410349	0.967657	0.832843	0.999937
4	SL	Useful-SB	1.000000	1.000000	0.927525		1.000000	0.011082	0.999422	1.000000	0.934778
5	SL	Useful-HB	1.000000	1.000000	0.927525	1.000000		0.011082	0.999422	1.000000	0.934778
6	SL	Useful-BP	0.073403	0.073403	0.410349	0.011082	0.011082		0.023112	0.011027	0.070135
7	TL	Useful-SB	0.999937	0.999937	0.967657	0.999422	0.999422	0.023112		0.957539	0.735325
8	TL	Useful-HB	1.000000	1.000000	0.832843	1.000000	1.000000	0.011027	0.957539		0.200014
9	TL	Useful-BP	0.967657	0.967657	0.999937	0.934778	0.934778	0.070135	0.735325	0.200014	

Correlation analyses between variables and worker demographics

1. Local RPE

RPE and sex

Correlations (Spreadsheet1_(Recovered).sta)
Marked correlations are significant at p < .05000
N=9 (Casewise deletion of missing data)

Variable	Means	Std.Dev.	Sex	RPE-SB	RPE-HB	RPE-BP
Sex	1.88889	0.333333	1.000000	0.335169	-0.331687	-0.090995
RPE-SB	9.87222	3.213556	0.335169	1.000000	-0.178590	0.222903
RPE-HB	8.36667	1.846619	-0.331687	-0.178590	1.000000	-0.130081
RPE-BP	11.01444	2.701620	-0.090995	0.222903	-0.130081	1.000000

Repeated Measures Analysis of Variance (Spreadsheet1_(Recovered).sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 2.857954

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	996.6119	1	996.6119	122.0156	0.000011
Sex	0.1276	1	0.1276	0.0156	0.904045
Error	57.1753	7	8.1679		
BAGS	14.6463	2	7.3231	1.0425	0.378399
BAGS*Sex	12.6380	2	6.3190	0.8995	0.429013
Error	98.3447	14	7.0246		

RPE and age

Correlations (Spreadsheet1_(Recovered).sta)
Marked correlations are significant at p < .05000
N=9 (Casewise deletion of missing data)

Variable	Means	Std.Dev.	Age	RPE-SB	RPE-HB	RPE-BP
Age	31.22222	14.88101	1.000000	0.199064	-0.123880	-0.528784
RPE-SB	9.87222	3.21356	0.199064	1.000000	-0.178590	0.222903
RPE-HB	8.36667	1.84662	-0.123880	-0.178590	1.000000	-0.130081
RPE-BP	11.01444	2.70162	-0.528784	0.222903	-0.130081	1.000000

Repeated Measures Analysis of Variance (Spreadsheet1_(Recovered).sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 2.625036

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2425.183	1	2425.183	351.9442	0.033903
Age	50.412	7	7.202	1.0451	0.639425
Error	6.891	1	6.891		
BAGS	30.392	2	15.196	3.0938	0.244274
BAGS*Age	101.159	14	7.226	1.4711	0.477307
Error	9.824	2	4.912		

RPE and experience

Correlations (Spreadsheet1_(Recovered).sta)
Marked correlations are significant at p < .05000
N=9 (Casewise deletion of missing data)

Variable	Means	Std.Dev.	Experience	RPE-SB	RPE-HB	RPE-BP
Experience	1.33333	0.500000	1.000000	0.045381	-0.175997	-0.034547
RPE-SB	9.87222	3.213556	0.045381	1.000000	-0.178590	0.222903
RPE-HB	8.36667	1.846619	-0.175997	-0.178590	1.000000	-0.130081
RPE-BP	11.01444	2.701620	-0.034547	0.222903	-0.130081	1.000000

Repeated Measures Analysis of Variance (Spreadsheet1_(Recovered).sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 2.856194

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2267.870	1	2267.870	277.9987	0.000001
Experience	0.198	1	0.198	0.0243	0.880590
Error	57.105	7	8.158		
BAGS	30.183	2	15.091	1.9190	0.183426
BAGS*Experience	0.887	2	0.443	0.0564	0.945389
Error	110.096	14	7.864		

2. Productivity

Productivity and sex

Correlations (Spreadsheet1_(Recovered).sta)
Marked correlations are significant at p < .05000
N=9 (Casewise deletion of missing data)

Variable	Means	Std.Dev.	Prod-SB	Prod-HB	Prod-BP	Sex
Prod-SB	7.576667	3.088458	1.000000	0.690646	0.620812	-0.259029
Prod-HB	9.566667	1.974684	0.690646	1.000000	0.409431	-0.272196
Prod-BP	5.683333	1.281005	0.620812	0.409431	1.000000	-0.678178
Sex	1.888889	0.333333	-0.259029	-0.272196	-0.678178	1.000000

Repeated Measures Analysis of Variance (Spreadsheet1_(Recovered).sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 3.124048

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	764.6717	1	764.6717	78.35008	0.000048
Sex	12.9801	1	12.9801	1.32997	0.286664
Error	68.3178	7	9.7597		
BAGS	21.7488	2	10.8744	3.91925	0.044497
BAGS*Sex	0.4890	2	0.2445	0.08811	0.916161
Error	38.8446	14	2.7746		

Productivity and age

Correlations (Spreadsheet1_(Recovered).sta)
Marked correlations are significant at p < .05000
N=9 (Casewise deletion of missing data)

Variable	Means	Std.Dev.	Age	Prod-SB	Prod-HB	Prod-BP
Age	31.22222	14.88101	1.000000	0.369312	0.544987	0.323495
Prod-SB	7.57667	3.08846	0.369312	1.000000	0.690646	0.620812
Prod-HB	9.56667	1.97468	0.544987	0.690646	1.000000	0.409431
Prod-BP	5.68333	1.28101	0.323495	0.620812	0.409431	1.000000

Repeated Measures Analysis of Variance (Spreadsheet1_(Recovered).sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .4776505

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1540.495	1	1540.495	6752.113	0.007747
Age	81.070	7	11.581	50.762	0.107668
Error	0.228	1	0.228		
BAGS	65.250	2	32.625	120.366	0.008240
BAGS*Age	38.791	14	2.771	10.223	0.092576
Error	0.542	2	0.271		

Productivity and experience

Correlations (Spreadsheet1_(Recovered).sta)
Marked correlations are significant at p < .05000
N=9 (Casewise deletion of missing data)

Variable	Means	Std.Dev.	Experience	Prod-SB	Prod-HB	Prod-BP
Experience	1.333333	0.500000	1.000000	-0.694521	-0.772276	-0.433253
Prod-SB	7.576667	3.088458	-0.694521	1.000000	0.690646	0.620812
Prod-HB	9.566667	1.974684	-0.772276	0.690646	1.000000	0.409431
Prod-BP	5.683333	1.281005	-0.433253	0.620812	0.409431	1.000000

Repeated Measures Analysis of Variance (Spreadsheet1_(Recovered).sta)
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 2.194024

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1223.320	1	1223.320	254.1307	0.000001
Experience	47.602	1	47.602	9.8887	0.016274
Error	33.696	7	4.814		
BAGS	51.620	2	25.810	12.4353	0.000786
BAGS*Experience	10.276	2	5.138	2.4754	0.120088
Error	29.058	14	2.076		

3. Usefulness

Usefulness and sex

Correlations (Spreadsheet1_(Recovered).sta)
Marked correlations are significant at p < .05000
N=9 (Casewise deletion of missing data)

Variable	Means	Std.Dev.	Useful-SB	Useful-HB	Useful-BP	Sex
Useful-SB	1.211111	0.448454	1.000000	0.620404	0.448755	0.176532
Useful-HB	0.990000	0.062450	0.620404	1.000000	0.017903	-0.060048
Useful-BP	2.000000	1.118034	0.448755	0.017903	1.000000	0.000000
Sex	1.888889	0.333333	0.176532	-0.060048	0.000000	1.000000

Usefulness and age

Correlations (Spreadsheet1_(Recovered).sta)
Marked correlations are significant at p < .05000
N=9 (Casewise deletion of missing data)

Variable	Means	Std.Dev.	Useful-SB	Useful-HB	Useful-BP	Age
Useful-SB	1.21111	0.44845	1.000000	0.620404	0.448755	-0.208330
Useful-HB	0.99000	0.06245	0.620404	1.000000	0.017903	0.126437
Useful-BP	2.00000	1.11803	0.448755	0.017903	1.000000	-0.473329
Age	31.22222	14.88101	-0.208330	0.126437	-0.473329	1.000000

Usefulness and experience

Correlations (Spreadsheet1_(Recovered).sta)
Marked correlations are significant at p < .05000
N=9 (Casewise deletion of missing data)

Variable	Means	Std.Dev.	Experience	Useful-SB	Useful-HB	Useful-BP
Experience	1.333333	0.500000	1.000000	0.148659	-0.240192	0.447214
Useful-SB	1.211111	0.448454	0.148659	1.000000	0.620404	0.448755
Useful-HB	0.990000	0.062450	-0.240192	0.620404	1.000000	0.017903
Useful-BP	2.000000	1.118034	0.447214	0.448755	0.017903	1.000000

4. Ease of Use

Ease of use and sex

Correlations (Spreadsheet1_(Recovered).sta)
Marked correlations are significant at p < .05000
N=9 (Casewise deletion of missing data)

Variable	Means	Std.Dev.	Sex	Ease-SB	Ease-HB	Ease-BP
Sex	1.888889	0.333333	1.000000	0.130093	0.125000	-0.285714
Ease-SB	1.345556	0.996081	0.130093	1.000000	-0.130093	0.608217
Ease-HB	1.011111	0.033333	0.125000	-0.130093	1.000000	-0.035714
Ease-BP	3.111111	1.166667	-0.285714	0.608217	-0.035714	1.000000

Ease of use and age

Correlations (Spreadsheet1_(Recovered).sta)
Marked correlations are significant at p < .05000
N=9 (Casewise deletion of missing data)

Variable	Means	Std.Dev.	Age	Ease-SB	Ease-HB	Ease-BP
Age	31.22222	14.88101	1.000000	-0.220280	-0.131599	0.243199
Ease-SB	1.34556	0.99608	-0.220280	1.000000	-0.130093	0.608217
Ease-HB	1.01111	0.03333	-0.131599	-0.130093	1.000000	-0.035714
Ease-BP	3.11111	1.16667	0.243199	0.608217	-0.035714	1.000000

Ease of use and experience

Correlations (Spreadsheet1_(Recovered).sta)
Marked correlations are significant at p < .05000
N=9 (Casewise deletion of missing data)

Variable	Means	Std.Dev.	Ease-SB	Ease-HB	Ease-BP	Experience
Ease-SB	1.345556	0.996081	1.000000	-0.130093	0.608217	0.520373
Ease-HB	1.011111	0.033333	-0.130093	1.000000	-0.035714	-0.250000
Ease-BP	3.111111	1.166667	0.608217	-0.035714	1.000000	0.357143
Experience	1.333333	0.500000	0.520373	-0.250000	0.357143	1.000000