The influence of skill and low back pain on peak and cumulative spine loads during wool harvesting.

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ABSTRACT

Sheep shearing is a physically demanding occupation, with high energy expenditure, spinal loads and risk of back injury. The cost of injury compensation and rehabilitation for this workforce is considerable. Although research shows the use of a commercially available trunk harness will significantly reduce spinal loads, there has been no investigation of worker skill on spinal loads and risk of injury. A higher skill level is accepted by the wool harvesting industry as improving quality of work and productivity. Others within the industry consider that increased skill lowers risk of injury by improving animal control and working in less demanding postures. Some research has shown a positive effect of skill within other occupations and tasks; such as a reduction in energy expenditure, spinal cumulative loads and asymmetric movements while others have shown no such effect.

The aims of this research are to quantify lumbo-sacral cumulative and peak forces experienced by workers in the wool harvesting industry, and to determine how skill and a history of low back pain requiring clinical intervention (LBP-Clin) impact on these loads. Following ethical approval a total of 140 participants (80 shearers and 60 wool handlers) were recruited and surveyed during formal shearing and wool handling competitions in Southern New Zealand. Each subject was then video-taped while executing 3 to 5 consecutive trials (dependent on skill level and competition requirements) of their normal task cycle. These video clips were analysed by using posture binning and load analysis software (3D Match) that incorporated 3D kinematics, external hand forces and anthropometric data to calculate the peak and cumulative loads on the L4/L5 segment. Cumulative loads were then extrapolated to an 8-hour work day. Correlation analysis was performed to determine collinearity between explanatory (independent) variables. Univariate linear regression models were initially used to determine the individual influence of skill and LBP-Clin on cumulative and peak spinal forces while multivariate linear regression models were used to determine the combined influence of skill and LBP-Clin on cumulative and peak spinal forces.

For shearers mean peak lumbo-sacral compression, joint anterior shear, joint anterior reaction shear, and extensor moments for shearers were 3828.7N, 230N, 458.3N, and 185.1Nm

respectively. For wool handlers these peak lumbo-sacral loads were 3194.2 N, 189.2 N, 391.4 N and 165.1 Nm. Mean cumulative compression, force weighted compression, joint anterior shear, joint anterior reaction shear, and extensor moments for shearers were 82.6 MN.s, 84.8 MN.s, 5.4 MN.s, 11.8 MN.s and 4.2MNm.s while these mean cumulative scores were considerably less for wool handlers at 48.7 MN.s, 48.9 N.s, 2.53 MN.s, 5.7 MN.s and 0.023 Nm.s. Skill was associated with decreased peak catch and drag compressive force for junior, intermediate and senior shearers and also decreased cumulative extensor moments for junior and senior wool handlers. LBP-Clin was only associated with an increased peak extensor moment during the catch and drag for shearers while LBP-Clin had no significant influence on any peak or cumulative force for wool handlers. The interaction variable for skill and LBP-Clin also showed no significant influence on peak or cumulative forces for either shearers or wool handlers. Although this study demonstrates minimal influence for skill or LBP-Clin (or their interaction) on cumulative and peak cumulative and anterior shear forces, the prevalence of LBP-Clin within each skill level increases considerably (particularly for shearers). Interestingly increased skill is also strongly predictive of a considerable increase in productivity (or tally). Thus increased skill appears to be primarily beneficial in terms of increased wool production and task efficiency.

Further research with a larger within-skill sample size and prospective design is needed to confirm these results. Other biomechanical factors such as body position within working postures, time spent in different postures, harvesting techniques, and non-sagittal postures and forces (medio- lateral shear and reaction forces) may also be linked to skill and LBP-Clin. Exploring the effect of these other biomechanical factors continues within the occupational biomechanics research team at the University of Otago. Similarly personal and psychosocial factors are recognised as being linked to injury and injury risk within the overlapping fields of ergonomics and occupational health. The part they play in injury risk within the wool harvesting occupations is unknown and is also under exploration. A recommendation for the wool harvesting industry is to continue with formal skill training as it does not appear to expose the worker to increased cumulative or peak spinal loading and it is strongly associated with productivity.

However the marked increase in working lifetime prevalence of LBP-Clin in this physically demanding occupation is clearly a problem and it may be that exposure to such high compressive and shear forces (independent of skill) exceeds yet to be determined cumulative loading thresholds that lead to risk of low back injury. While postural demands and non-sagittal forces during traditional shearing also need to be investigated, development of alternative upright posture wool harvesting strategies is an industry identified direction for reduction of injury risk that is biomechanically sound and now under investigation.

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List of Abbreviations

2D	Two-Dimensional
3D	Three-Dimensional
SD	Standard Deviations
ACC	Accident Compensation Corporation
AUD	Australian dollar
AWI	Australian wool innovation
BMI	Body Mass Index
CC	Cumulative compression
CEM	Cumulative extensor moment
CFWC	Cumulative force weighted compression
CJAS	Cumulative joint anterior shear
CJARS	Cumulative joint anterior reaction shear
CI	Confidence Intervals
EMG	Electromyography
HRC	Health Research Council
ICC	Intra class correlation
ISO	International Standards Organisation
KG	Kilogram
LBD	Low back disorder
LBP	Low Back Pain
LBP-Clin	Previous episode of Low Back Pain requiring to take time off and seek clinical intervention
MMH	Manual Material Handling
MVC	Maximum Voluntary Contraction
NIOSH	National Institute of Occupational Health and Safety
NZD	New Zealand dollar
PAL	Phase Alteration Lines
PC	Peak compression
PEM	Peak extensor moment

PJAS	Peak joint anterior shear
PJARS	Peak joint anterior reaction shear
SLAMP	Simplified Loading and Manipulation Platform
SPSS	Statistical Package for the Social Sciences
UoO	University of Otago
WBA	Warrie Back-Aid™

CHAPTER 1

INTRODUCTION

1. Introduction

New Zealand and Australia currently account for 35% of global wool production and dominate sheep wool exports to the international commodity markets [1-4]. New Zealand's economy in particular relies heavily on the agricultural sector with meat, dairy, wool and horticulture contributing to approximately 52% of export earnings [5]. In 2007, the New Zealand wool industry contributed NZD $1.2 billion as export income [5]. Despite high levels of productivity and cost efficiency, sheep shearing is ranked amongst the highest injury risk agricultural occupations [6-9] with much higher injury rates and rehabilitation cost in comparison to many other agricultural occupations [8]. It has been estimated that 90% of shearers experience moderate to severe low back pain (LBP) over their working life [6-9]. Some of the risk factors that contribute to the development of LBP include excessive lumbar compressive and shear forces [10, 11], cumulative loading [12-14], prolonged trunk flexion greater than 20^{o} [15], sustained postures [16-19], dragging, pulling and pushing activities [20, 21] that include asymmetric loading and fatigue as indicated by energy expenditure [22, 23], all of which are applicable to the wool harvesting industry. Such risk factors and high incidence of injuries has been a prime driver for further research into the wool harvesting industry working on ways to reduce injury prevalence, improving productivity and cost efficiency. Advancement in skill level has shown some beneficial effects on the reduction of cumulative loads and energy expenditure per sheep. It is therefore desirable to determine if advancing skill levels would influence (reduce) cumulative and peak loads and thereby influence (decrease) these incidence of LBP.

1.1 Wool harvesting industry in New Zealand

The wool harvesting industry consists of three main work tasks: sheep shearing, wool handling and wool pressing. (FIGURE 1.1) Shearing is the most readily identified occupation: involving prolonged hours in sustained flexed postures, in a job classified as very heavy work with high risk of back injuries [8, 18, 24, 25]. It is reported that shearers remain in a sustained stooped posture for 50–97% of their working day [6]. Wool handling is defined as a light to medium physically demanding job that requires lifting and throwing of the shorn fleece, wool evaluation skills, the ability to move around constantly between an number of work stations and sort shorn wool [24]. Wool handling also involves considerable amount of twisting of the body and neck and repetitive hand/ arm movements interposed with frequent bending and sweeping of the wool [26, 27]. Wool pressing is also physically demanding job that requires the wool presser to predominantly stand as well as move around while preparing and moving wool bales that will weigh from 150 to 200kgs (1471 to 1961.3N). Wool pressing predominantly involves considerable amount of heavy lifting, pulling, twisting of the body and neck and repetitive hand/ arm movements [28, 29].

1.2 Job task description

The tasks that each worker executes within their job description are as follows:

1. Shearers (usually male): Their task starts from catching and dragging the sheep from the holding pen to the shearing platform, shearing the sheep with the use of powered hand clippers ("handpiece") and finally guiding the shorn sheep from the shearing platform through an exit chute.

2. Wool handlers (usually female): The task of the wool handler encompasses wool gathering and throwing a fleece onto the sorting tables, wool sorting (skirting), placing the wool into different bins based on quality of the wool and finally sweeping the floor. The wool handler also uses a small flat stick or "broom" to sweep the wool away from the shearing platform towards the wool sorting worksite – often centred on the wool sorting table.

3. Wool pressers (usually male): Their job consists of fitting the wool pack into the press, loading the press, clipping the bale cap on, removing the bale from the press and finally using a trolley to stack bales weighing between 150 to 200kgs (1471 to 1961.3N) at a farmer designated site in the shearing shed. The presser fits the empty wool pack onto the pressing machinery by securing the open bale flaps to the device. The presser then loads the pack by gathering wool either from the wool sorting table and/ or from a pile of stacked wool, occasionally pressing the wool by stamping with his feet. For more

detailed description of work tasks refer to the publications by Tectra ™ titled wool handling [27] and wool pressing handbook [28].

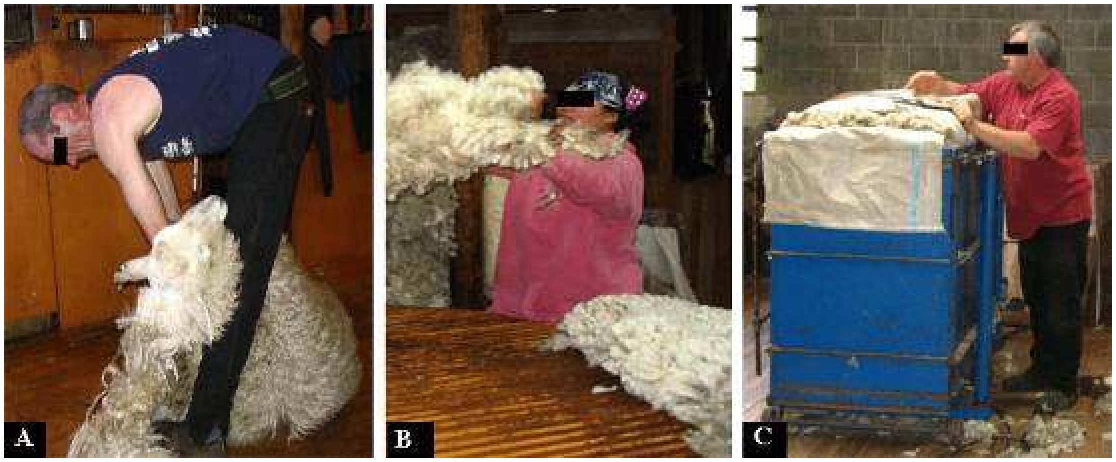

FIGURE 1.1 Wool harvesting encompassing the tasks of (A) shearing (B) wool handling and (C) wool pressing

1.3 Risk factors leading to development of occupational low back pain

Manual material handling (MMH) tasks such as lifting, pushing and pulling has been identified as the most probable cause of work related low back disorders (LBD) [30]. Occupational Health and Safety Australia (2001) rates injury risk on a 5 point scale, where 1 is the least risk and 5 is the maximum risk. This is calculated by considering the severity, duration and cost of the most severe injury or illness caused by the hazard as well as frequency rating (a composite rating, taking into account both the typical frequency of exposure of workers and others to the hazard and the frequency of reported injury or illness) [31]. The injury risk for shearers during lifting sheep, bending and slips are 3, 3, and 2 respectively [31].

Almost all of the biomechanical risk factors identified in introductory paragraph of this thesis are clearly applicable to the shearing workforce, where sustained stooped [6] and asymmetrical postures [32], peak and cumulative spinal loading [20, 33-35], energy expenditure [36] and specific tasks such as catching and dragging need to be addressed to reduce possible adverse structural changes of the lumbar spine and the development of LBP in shearers.

1.4 Injury rates in the wool harvesting industry

Sheep shearing is ranked amongst the highest injury risk agricultural occupations where it is estimated that 90% of shearers will experience moderate to severe occupational back pain over their working life [6-9]. A recent report from Australian Wool Innovation (AWI) shows an annual injury incidence rate for shearers as 112.8 injury claims per 1,000 shearers per year, and a frequency rate of 100.1 injuries per million hours of shearing [37]. Shearers also demonstrate three times the number of injury claims than the second ranked occupation for risk, and 10 times the Australian average [37].

An industrial report by AWI in 2007 showed that over a 5-year period approximately 3393 shearing injuries were reported in 6 wool-growing states of Australia (New South Wales, Queensland, Western Australia, Victoria, Southern Australia and Tasmania) resulting in an incidence rate of 679 new injuries per year [37]. These 3393 injuries cost the workers compensation authorities a total of AUD$110.1 million or AUD$22.0 million per year. The above injuries resulted in at least 173,624 days lost from work over the 5-year period, i.e. on an average 34,725 days lost per year. AWI also estimates that the above figures are conservative and do not include employer-paid days, permanent disabilities in New South Wales or unreported (no workers compensation claim made) injuries [37].

Injuries occurring in the wool industry have been further categorised by the causes leading to such injuries such as: animal handling injuries, hand piece injuries and a combination of animal handling and hand piece injuries [37]. Based on a case study in Victoria and South Australia it was estimated that animal handling injuries account for 38% (250 injuries per year) of all shearing injuries and 45% (AUD $10.4 million per year) of total estimated costs resulting in 18,504 days lost from work. The associated injury rate of animal handling over the 5 states (New South Wales, Western Australia, Victoria, Southern Australia and Tasmania) of Australia over a 5-year period is 40.6 new injuries per thousand shearers per year with the associated frequency rate of 49.0 shearer injuries per million shearer hours worked [37].

The injuries resulting from combined animal handling and shearing handpiece accidents account for 11% (75 injuries per year) of all shearing injuries and around 2.5% (AUD $0.6 million per year) of total estimated cost resulting in 657 days lost from work. The associated injury rate of combined animal handling and shearer handpiece over 5 states (New South Wales, Western Australia, Victoria, Southern Australia and Tasmania) of Australia over a 5-year period is 12.2 new injuries per thousand shearers per year while the associated frequency rate is 14.7 shearer injuries per million shearer hours worked [37].

Injuries resulting from shearing handpieces account for 25.2% (165 injuries per year) of all shearing injuries and 11% (AUD $2.3 million per year) of total estimated cost resulting in 3,707 days lost from work [37]. The associated injury rate of combined animal handling and shearer handpiece over the 5 states of Australia over a 5-year period is 26.8 new injuries per thousand shearers per year while the associated frequency rate is 32.4 shearer injuries per million shearer hours worked [37].

1.5 Cost of injury compensation in New Zealand and Australia

In Australia and New Zealand the number and cost of shearer back injury claims are between 4 to 6 times greater than other industrial workers [8, 38], [39, 40], [41]. In New Zealand, back injuries cost $5 million in compensation claims between 1994 and 2006 for a working population of approximately 2000 fulltime shearers [42],[9]. Australian data [40] has also shown shearers having a high level of injury claims at approximately 150 per 1000 shearers per year. Furthermore, 19.6% of injury claims were to the back accounting for 50% of the total cost of shearing injuries claims [39, 40]. AWI (2005) has compared both the incidence and frequency rate of shearers injuries as well as compared the above rates with other agricultural industries in Australia from the year 1992 to 2005 [37] (TABLE 1.1) suggesting that injuries related to shearing are numerous and the cost involved in compensation or rehabilitation is extremely high.

TABLE 1.1: Injury incidence rates. Adapted from AWI, wool harvesting OH&S injury and cost evaluation review.

Occupation	Incidence rates*	Frequency rate†
Shearer [37] 2004-05	136.6	97.3
Shearer Annual average 2000-01 to 2004-05[37]	115.0 (1.2:1)	105.8 (0.9:1)
Shearer Annual average 1999-00 to 2003-04 [37]	102.9 (1.3:1)	124.6 (0.8:1)
All agricultural industries 1992-93 (Worksafe Australia 1995)	49.1 (2.8:1)	28.6 (3.4:1)
All Australian industries 1992-92 (Worksafe Australia 1995)	25.5 (5.4:1)	17.3 (5.6:1)

*** injuries per thousand workers per year**

† injuries per million hours worked per year

Included in brackets is Shearer 2005-2005 rate relative to other years and industries.

1.6 Summary

Wool harvesting is an important industry within the Australian and New Zealand rural economies. Shearers have a high prevalence of LBP, with a considerable loss of work hours and cost of injury compensation and rehabilitation. Further research into the wool harvesting industry should focus on reducing prevalence of LBP and increasing productivity and cost efficiency.

CHAPTER 2

LITERATURE REVIEW

2. Literature review

2.1 Introduction

The need for research into shearing, animal handling and education for back care has been driven by two related factors; reducing injury in shearers, and improving wool harvesting productivity [43, 44]. Consequently, this has attracted research from various disciplines including biomechanics, ergonomics and physiology, as well as the allied health professions of physiotherapy and occupational therapy [45].

2.2. Summary of research on the wool harvesting industry

A detailed literature review was undertaken to determine what is currently known about injury research in the wool harvesting industry. Electronic searches using the keywords sheep, shearing, wool, wool harvesting, injury and LBP were undertaken using the following databases: Cumulative Index to Nursing and Allied Health Literature (1982 to May 2006); Evidence Based Medicine Reviews: Cochrane Database of Systematic Reviews; EMBASE (1988 to week 19 of 2006); Ovid MEDLINE® (1966 to May 2006); Ovid OLDMEDLINE® (1950 to 1965); and PsycINFO (1806 to May 2006). The reference lists from the above articles were also checked to include relevant publications that may have been missed.

Publications were included if they met the following criteria: if they presented research on sheep shearing or on occupational health disorders in sheep shearing, and they were available in English. Database searches identified ten journal articles, and reference lists identified eleven additional publications, including three journal articles, six conference proceedings, one dissertation and one doctoral thesis. Personal communication also identified one further doctoral thesis. A total of seventeen publications were reviewed (Refer to TABLE 2.1 for a summary of each study.

TABLE 2.1: Summary of research undertaken on sheep shearing

Study	Study characteristics	Aims of study	Results
Poole and Ross, 1983[36]	Study type: cross-sectional (26 shearers) Method: indirect calorimetry. Statistical tests: descriptive; T-test.	Estimating the energy cost during shearing; estimating the difference in energy consumption between senior and intermediate shearers.	There was no significant difference ($p < 0.05$) in the energy cost, respiratory exchange equivalent, and oxygen consumption per unit time for both categories of shearers. However, senior shearers consumed less energy per sheep than intermediate shearers.
Gmeinder, 1986[6]	Study type: cross-sectional (32 shearers) Methods: questionnaires, direct observation. Statistical test: descriptive.	Establishing the incidence of LBP among shearers in Western Australia; promoting further research.	90% of shearers suffered from moderate to severe LBP. Shearers were in a stooped posture for 50–85% of their working time.
Ross, 1988[46]	Study type: cross-sectional (11 shearers) Method: EMG. Statistical test: descriptive.	Documenting the trunk muscle EMG activity of shearers during sheep shearing: (1) erector spinae muscles: longissimus dorsi and iliocostalis lumborum; (2) abdominal muscles: external oblique and rectus abdominus.	While shearing, a brief period of activity was noted for erector spinae and triceps; no muscle activity was noted for the abdominal muscles. While catching sheep, more than 50% of activity was noted in the erector spinae muscles.
Stuart, 1991[47]	Study type: cross-sectional	Assessing the fitness levels in improver shearers; evaluating the	Shearers had an above average to good physical condition when compared with the general population of Australian

	(142 improver shearers) Methods: spirometer, skinfold, cycle ergometer, hand-grip dynamometer. Statistical test: descriptive.	demands of sheep shearing.	men of a similar age. Shearing falls under the category of "very heavy work". The average daily energy cost of a working shearer is in excess of 5,000 Kcal.
Webster and Lush, 1991[48]	Study type: cross-sectional (8 young/inexperienced, 5 experienced shearers) Methods: skinfold, cycle ergometer. Statistical test: descriptive.	Estimating the energy consumption, strain and subjective effort between inexperienced and experienced shearers during shearing and crutching.	Crutching seemed to be as arduous as shearing. Inexperienced shearers were working hard to shear 100–120 sheep/day; there was a poor correlation between speed and energy cost, and their cardiovascular fitness was "fair" to "poor". The oxygen consumption for the experienced shearers was higher than the inexperienced shearers, while the fitness level of this group was "average".
Gun and Budd, 1995[49]	Study type: longitudinal (35 shearers, 8 wool pressers) Methods: personal characteristics; energy expenditure; thermal environment; heat exchange; physiological and subjective response; productivity. Statistical tests: T-test (for between-group differences), regression analysis (with occupation as a co-variate).	Determining the effect of the thermal environment, personal characteristics, and the behavioural response of drinking water on physiological strain, thermal comfort and productivity.	The thermal environment rose from 12^{o} C to 15^{o} C throughout the morning, and peaked at 2 pm (45^{o} C). The amount of energy expended by the shearers and wool pressers was an average of 400 W. Shearers expended an average of 390 W. The core body temperature of the shearers was between 37.1^{o} C and 38.4^{o} C.

Milosavljevic et al, 2000[50]	Study type: cross-sectional (22 shearers) Method: EMG. Statistical test: non-parametric Wilcoxon signed-ranks test.	Documenting the EMG activity of trunk muscles while sheep shearing, with and without the aid of a back harness (Warrie Back Aid^{TM}).	Shearers without the harness demonstrated low levels of extensor and abdominal muscle activity, as well as prolonged periods of electrical silence. Shearers using the harness experienced reduced ($p < 0.001$) activity of the right lumbar extensors.
Harvey et al, 2002[20]	Study type: cross-sectional (8 shearers) Methods: force platforms, Statistical tests: MANOVA; post-hoc multiple pairwise comparisons.	Determining the combination of different types of floor surfaces and slopes used in the wool harvesting industry that would reduce the forces required to drag a sheep.	The texture with the lowest mean dragging force was wooden battens arranged parallel to the drag (horizontal force: 388 N; slope: 359 N), while the texture with the highest mean dragging force was steel mesh (horizontal force: 423 N; slope: 394 N). A sloping surface of 1:10 (5.6º) constructed of wooden battens arranged parallel to the direction of the drag could help reduce the dragging force by up to 15%.
Payne et al, 2002[21]	Study type: cross-sectional (7 shearers) Methods: cycle ergometer, metabolic testing systems. Statistical tests: two-way ANOVA; post-hoc analysis.	Estimating the amount of energy consumed by a shearer during the five commonly used drag paths; identifying the drag paths that had the least risk of injury.	There were significant differences ($p < 0.0005$) in the rate that the individual shearers consumed oxygen. However, there was no significant difference ($p = 0.16$) in the rate of oxygen consumption between the respective drag paths. The drag path considered to have the least risk of injury had the shortest distance and involved minimal rotation of the sheep, commonly used by right-handed shearers. This drag path is found in recently constructed shearing sheds.
Marshall and Burnett,	Study type: cross-sectional (5 shearers)	Examining the biomechanics of stooped shearing techniques;	While stooped shearing, the mean compressive forces on the lower back (L5/S1) were, on average, 2,585 N. The

2004[51]	Methods: three video cameras, force plates, EMG equipment. Statistical test: descriptive.	comparing the effectiveness of a new robotic sheep manipulator (SLAMP5).	mean anterior shear forces were 382 N. The average trunk angle was 4.7^{o} above the horizontal. Trunk rotator activity was higher while stooped shearing than while using the sheep manipulator. The sheep manipulator allowed shearers to maintain a more upright posture which decreased the compressive ($<$ 1,350 N) and shear forces ($<$ 260 N). Except for the right erector spinae, all extensors had greater activity while using the sheep manipulator.
Milosavljevic et al, 2004[34]	Study type: cross-sectional (6 open, 6 senior shearers) Methods: four-camera motion analysis system and retro-reflective surface markers. Statistical test: descriptive; comparative T-test.	Quantifying and determining whether a commercially available harness (Warrie Back Aid^{TM}) would reduce the magnitude of cumulative and anterior shear forces produced while undertaking the three wool harvesting tasks.	The use of the harness reduced ($p < 0.01$) the peak and mean compressive forces at the thoraco-lumbar region for task 1 by 12.9% and 8.1%, for task 2 by 17.3% and 17.1% and for task 3 by 14.0% and 11.5%, respectively. Similarly, the use of the harness reduced ($p < 0.01$) the anterior shear forces for task 1 by 34.4%, for task 2 by 44.4%, and for task 3 by 33.5%.
Milosavljevic et al, 2005[50]	Study type: cross-sectional (64 shearers, 64 non-shearers) Methods: questionnaire, camera and retro-reflective markers, computer-aided design software. Statistical tests: paired T-test, stepwise linear	Determining whether adaptive postural and movement characteristics were evident in the spine and hip of shearers; determining whether adaptive changes had any association with either a current or previous history of LBP.	Shearers had significantly less ($p < 0.001$) lumbar extension, significantly greater ($p < 0.001$) hip flexion, and significantly different ($p < 0.001$) spinal sagittal posture. Shearers with a previous history of LBP requiring clinical intervention ($n = 31$) did not demonstrate any significant loss in lumbar flexion. A previous history of LBP requiring clinical intervention was associated with a younger age.

	regression, intra-class correlation coefficients.		
Milosavljevic et al, 2006[32]	Study test: cross-sectional (6 open, 6 senior shearers) Method: four-camera motion analysis system and retro-reflective surface markers. Statistical test: descriptive.	Describing the three- dimensional magnitude, asymmetry and variability of movement at the thoraco-lumbar and lumbo-sacral joint centres for the three wool harvesting tasks.	Movements at the thoraco-lumbar junction are predominantly three-dimensional, involving flexion with varying amounts and directions of lateral flexion and axial rotation. However, at the lumbo-sacral junction, the movements were mainly constrained to two axes of motion involving flexion and right-side lateral flexion.
Gregory et al, 2006[33]	Study type: cross-sectional (6 open, 6 senior shearers) Method: four-camera motion analysis system and retro-reflective surface markers. Statistical test: three-way ANOVA.	Analysing the peak and cumulative spinal loads in two classes of shearers (open and senior), with and without the aid of a back harness (Warrie Back Aid^{TM}); determining the effectiveness of the harness.	There was no significant difference in the percentage of time spent in flexion with and without the aid of the harness while shearing. The time spent in the axially twisted posture decreased significantly ($p = 0.0016$) with the use of the harness, while the amount of time spent in the neutral posture increased ($p = 0.0002$). The use of the harness significantly reduced ($p < 0.001$) the peak and cumulative joint compression, extensor moment, joint shear and shear reaction.
Schneiders, 2006[52]	Study type: cross-sectional (6 open, 6 senior shearers) Method: four-camera motion analysis system and retro-reflective surface markers.	Determining the effect of a back harness (Warrie Back Aid^{TM}) on the three-dimensional kinematics and EMG activity of the trunk in shearers.	Shearing involves an endurance-based muscle activity and the adoption of quasi-static posturing, combined with complex asymmetrical trunk motion for extensive periods of time. The use of the harness had no effect on the time taken to shear or the trunk kinematics. However, it resulted in reductions in trunk extensor activity. There are statistically significant reductions in the activity of left multifidus (p =

	Statistical tests: paired T-test and descriptive.		0.01), right multifidus (p = 0.001), right iliocostalis (p = 0.004), and right longissimus (p = 0.002) with the use of the harness.
Gregory et al, 2007[53]	Study type: cross-sectional (6 open, 6 senior shearers) Method: four-camera motion analysis system and retro-reflective surface markers. Statistical test: three-way ANOVA.	Analysing the peak and cumulative loads on the shoulder in two classes of sheep shearers (open and senior), with and without the aid of a back harness (Warrie Back Aid™).	The use of the harness significantly reduced the maximum and cumulative joint compression (p = 0.0003), extensor moment (p = 0.0004), joint shear (p = 0.0005), and shear reaction (p = 0.0003). However, it significantly increased the peak and cumulative medio-lateral reaction shear (p = 0.014), lateral bend moment (p = 0.019), and axial twist moment (p = 0.049). Open shearers had a significantly lower peak axial twist moment (p = 0.003) in the right direction, as well as cumulative axial twist (p = 0.025), than senior shearers. However, open shearers had a higher cumulative flexor moment (p = 0.023) than senior shearers.
Pal et al, 2008[54]	Study type: descriptive, detailed literature review Statistical test: descriptive.	Reviews the injury risk associated with LBP in the wool harvesting industry.	Summarised shearing as a physically strenuous occupation, with a high risk of low back injury and high energy expenditure. Shearers work in sustained flexion using asymmetric three-dimensional spinal movements and under considerable cumulative spinal loading. Suggests future research: 1. redesign the shearing workplace to reduce injury risk 2. identify the causal relationship between LBP, cumulative spinal loading, observed structural and tissue changes in shearers, and the risk of back injury 3. analyse the task demands in wool sorting and wool pressing, and to identify how skill affects performance, productivity and injury risk in the sheep shearing, wool sorting and wool pressing tasks

Of the various research studies that have been conducted on shearers the most extensive research area on the task demands and injury risks of shearing is in the field of biomechanics, including modelling of spinal compressive and shear forces, spinal kinematics and spinal EMG activity. Other areas of research include energy demand and postural adaptations. The various research studies conducted for the wool harvesting industry are described in detail below:

2.2.1 Biomechanics

2.2.1a Biomechanics – spinal compressive and shear forces

Milosavljevic et al. [34, 55] reported mean and peak compressive spinal forces (± 95% CI) during shearing of 1624N (±138.1N) and 1891N (±171.5N) at the thoraco-lumbar joint and 2471N (±226.0N) and 2822N (±254.7N) at the L5/S1 joint respectively. Although L5/S1 compressive values were generally less than the NIOSH action limit (3433N) some shearers exceeded this.[34] Although mean and peak anterior shear forces were 320N (±29.3N) and 345N (±30.1N) at the thoraco-lumbar joint and 376N (±67.8N) and 458N (±78.8N) at the L5/S1 joint a number of shearers also exceeded the University of Waterloo anterior shear action limit of 500N [56]. These results are consistent with the studies of Marshall and Burnett [51] and Payne et al. [21] who reported mean L5/S1 spinal compressive and anterior shear loads during traditional shearing of 2585N and 382N, and 2276N and 385N respectively.

2.2.1b Biomechanics - dragging force

Harvey et al. [20] analysed the lumbo-sacral forces generated while dragging sheep over various platform surfaces. Mean dragging lumbo-sacral forces for different floor textures and slopes ranged from 359N to 423N, close to the maximum acceptable limits of drag forces in males. They also found that a 1:10 (5.6º) forward sloping surface constructed of wooden battens arranged parallel to the direction of the drag could reduce these dragging forces by up to 15%.

2.2.1c Biomechanics - cumulative spinal forces

With the spinal compressive forces generally below the NIOSH action limit [33, 41, 53, 56] Gregory et al. [33] hypothesized that the back pain experienced by shearers might be a result of cumulative spinal loading over a working lifetime rather than the result of peak loads. They reported daily cumulative L5/S1 loading in shearers of 85MNs. This was considerably higher than other-at-risk occupations such as autoworkers (20MNs) and health care providers (15MNs) as reported by Kumar [13] and Normal et al. [14].

2.2.1d. Biomechanics – robotic sheep manipulator

Marshall and Burnett [51] assessed the effectiveness of a robotic sheep manipulator (SLAMP5) in reducing frequency of stooped postures, low back forces and electromyography (EMG) activity. When using this device the mean lumbo-sacral compressive and anterior shear forces were reduced considerably from 2585N and 382N in stooped shearing to 1350N and 254N respectively. In addition shearers demonstrated a more upright working posture and decreased EMG activity of the trunk rotators yet greater activity of the right erector spinae.

2.2.1e. Biomechanics – shearing back harness

Milosavljevic et al. [34] tested the effectiveness of a commercially available back harness (Warrie Back Aid™ - WBA™) (FIGURE 2.1) on the spinal forces generated during shearing. The harness substantially reduced the compressive forces by 13% at the thoraco-lumbar joint and 20% at the lumbo-sacral joint and also reduced anterior shear forces by 40% at the thoraco-lumbar and 30% at the lumbo-sacral joint. Gregory et al. [33] also supported the effectiveness of the shearing back harness for reducing both peak and cumulative compressive and shear forces.

2.2.1f. Biomechanics - cumulative upper limb forces

Gregory et al. [53] analysed the shoulder postures and cumulative shoulder moments in open and senior class shearers both with and without the use of the back harness. Shearers spent a considerable amount of time in flexed and abducted shoulder postures resulting in high shoulder cumulative loads. The mean cumulative moment on the right shoulder during flexion was 286.9NMs and during abduction was 98.7NMs. The use of harness significantly reduced the time spent in shoulder flexion (by 10%) and abduction (by 4%) and significantly reduced cumulative net shoulder flexion, abduction and adduction moments by 21%, 14% and 42% respectively.

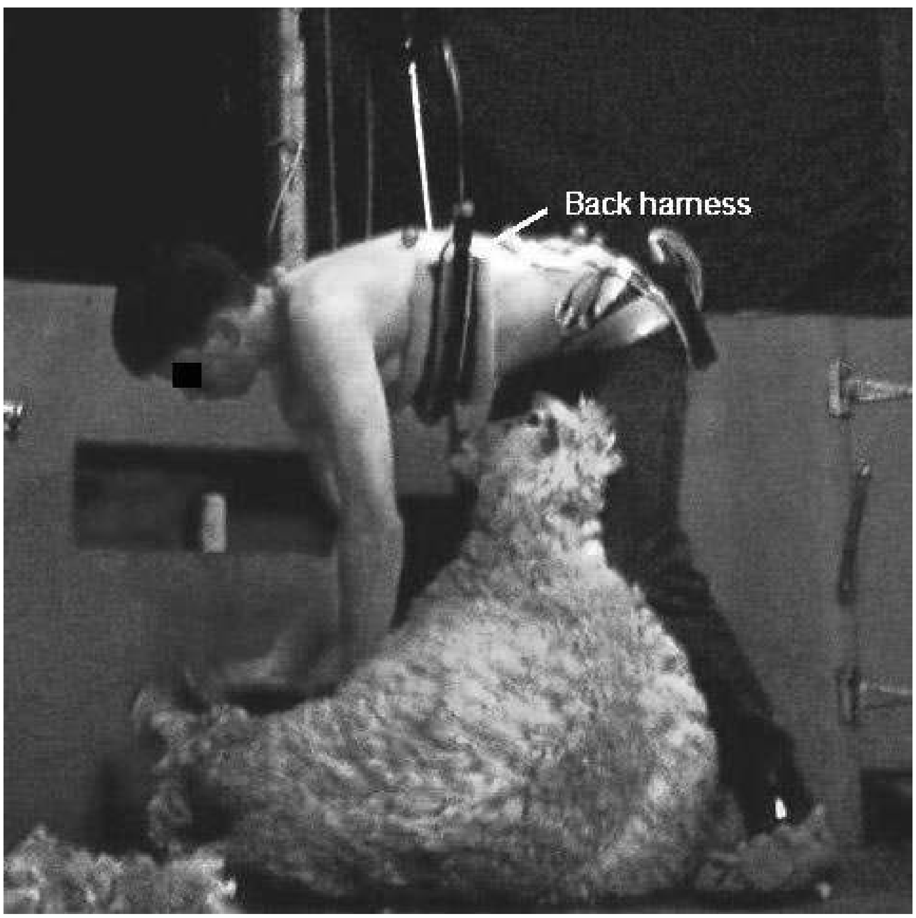

FIGURE 2.1: Shearing sheep with the support of a back harness

2.2.2 Kinematics - 3D thoraco-lumbar and lumbo-sacral joint movements

Milosavljevic et al. [32, 55] analysed the magnitude and variability (± 95%CI) of movements at the thoraco-lumbar and lumbo-sacral joints during three tasks presenting greatest risk in shearing. Thoraco-lumbar movements were predominantly three-dimensional involving flexion ranging from 32.0^o to 42.0^o ($\pm 5.0^o$) with varying amounts and directions of lateral flexion (from 13.0^o left to 5.0^o right, $\pm 5.0^o$) and axial rotation (from 12.0^o left to 2.0^o right, $\pm 5.0^o$). Lumbo-sacral movements mainly involved flexion ranging from 38.0^o to 48.0^o ($\pm 5.0^o$) and right side lateral flexion ranging from 5.0^o to 10.0^o ($\pm 3.0^o$) with only minor amounts of rotation. Schneiders [52] found marked between-shearer variability in trunk motion even though shearers use patterned and repeatable techniques. Milosavljevic et al. [32] argued that this 3D spinal movement asymmetry is consistent with the movement patterns of heavy work occupation at high risk of low back injury.

2.2.3 Muscle activity EMG activity of trunk muscles during shearing

Ross et al. [57] found minimal erector spinae and abdominal muscle activity during the tasks of shearing. In a sample of 12 right handed senior and open class shearers Milosavljevic et al. [58] and Schneiders [52] identified specific shearing movements where low levels of lumbar extensor and abdominal oblique activity were present(< 30% MVC values). The use of the back harness significantly reduced the right trunk extensor activity but had no effect on the abdominal muscle activity. With low levels of muscle activity these authors suggest that in the event of sudden or unexpected loading the muscles role as a protective and support mechanism of the spine may well be diminished and that the risk of harm may increase [52, 58]. The low levels of EMG activity and the magnitude of the sustained flexion angles are in agreement with literature describing the flexion-relaxation [59] phenomenon of spinal extensors.

2.2.4 Energy demand and thermal regulation

Using indirect calorimetry, cycle ergometry, and heart rate telemetry, four studies demonstrated that shearing meets the definition of a physically strenuous profession [21, 36, 47, 48]. Dragging sheep to shearing platforms appears to be the most physically demanding task consuming 51% more oxygen than the rest of the tasks combined.[48] Dragging sheep is also identified as having a high risk of low back injury [21], involving considerable amounts of trunk rotation and manoeuvring of sheep [35]. Payne et al. [21] found that dragging technique and drag paths did not influence energy expenditure, reinforcing the findings of others that shearers appear to self-regulate their exertion level [47, 60]. Consequently they conclude that although better shearing shed design might not reduce energy expenditure it might assist in decreasing workshop complexity, thus reducing injury risk, and subsequently improving productivity [21]. With respect to the whole shearing task Poole and Ross [36] measured the oxygen consumption in shearers of different skill levels and found that the higher skilled (senior-level) shearers consumed less oxygen per sheep than the less skilled (intermediate-level) shearers. The mean (SD) rate of oxygen utilization for senior shearers was 2.5 (0.93) L/sheep significantly lesser than intermediate shearers 4.46 (1.01) L/sheep. They estimated a considerable energy cost for one day's sheep shearing similar to eight hours of jogging at approximately 7km/hr, or alternatively cycling for 8 hours at 15km/hr [61, 62].

Gun and Budd [49] investigated physiological strain, thermal comfort and productivity (daily tally) of shearers in typical hot worksites on Australian farms in summer. With recorded workplace air temperatures ranging from 19° to 41°C the thermal environment in 43% of these worksites exceeded the International Standards Organisation (ISO) [63] upper temperature threshold (29°C) for a heavy work classification. Although sweat losses in 45% of shearers exceeded ISO 7933 thresholds no observable dehydration was noticed as the shearers replaced 72% of their sweat loss with fluid intake during the working day. Interestingly such an increase in environmental temperature appeared to have no negative effect on shearing productivity. Although these ISO occupational health guidelines for thermal working environment were exceeded in these worksites it is interesting to note that this increase in environmental temperature and increased health risk appeared to have no negative effect on shearing productivity suggesting appropriate physiological coping strategies – at least for these sampled shearers in these conditions. Consequently, the authors suggest that the variations in physiological strain and tally might be attributed more to individual differences in aerobic capacity and work rate rather than as a direct indicator of exceeding thermal discomfort thresholds in the shearing worksite [49].

2.2.5 Postural adaptations

Milosavljevic et al. [50] investigated structural adaptations as a result of sustained flexed posture by comparing lumbar and hip sagittal range of motion and standing postures in shearers and non-shearers. They observed shearers gain more hip flexion but have a marked loss in lumbar extension. The mean value of lumbar extension for shearers was 9.8^{o}, significantly ($p<0.001$) lower than non-shearers (14.0^{o}). Shearer had a significantly higher ($p<0.001$) mean hip flexion of 87.4^{o} than non-shearers (73.4^{o}) and also appear to adopt a more lordotic lower lumbar curvature with a less kyphotic mid to lower thoracic region with no observed changes in the pelvic tilt angulation. The lower thoracic curvature for shearers (21.4 radians/metre) was significantly ($p=0.009$) flatter than non-shearers (2.48 radians/metre). Interestingly these kinematic and postural adaptations were found to be independent of either previous or current episodes of LBP [50] arguing for a primary structural adaptation of the spine to the forces and sustained work postures of this occupation.

2.3 Definition of terminologies

a) Peak loading is defined as the highest instance of loading at a joint and is dependent on several factors including greatest horizontal moment arm, lowest vertical height, highest external load [64].

b) Cumulative loading occurs when structures under load deform in a time-dependent manner and cause alterations in the load tolerance thresholds as a result of prior loading

[65] and is defined as the force or moment time integral (takes into account the duration and repetitiveness of load exposure). [65]. The cumulative loading is of lower magnitude than peak forces but is applied in a repeated or sustained manner. To calculate the cumulative load a person sustains, firstly the cumulative load for the task is determined and then this load is extrapolated over a desired time frame (which could be for an hour, shift, week, year or working lifetime) [64].

c) Reaction shear is also defined as the anterior-posterior shear force at L4/L5 spinal segment influenced by body weight and the load in the hands [64]. Reaction shear is produced by dynamic push/pull/lift/lower forces on the hands combined with the shear, if any, produced by the weight of the upper body but with no account for the effects of spinal curvature on shear forces [66]. Reaction shear is highly dependent on trunk posture and similarly joint compression, joint moment and joint shear are also dependent on trunk posture however factors such as the high initiation of the lift due to application of external load and other postural factors makes them more stable variables across different tasks [64].

d) Joint shear is defined as the 'bone on bone' or the net joint force after the muscle shear force from the single muscle equivalent model had been combined with the reaction shear force [67]. Shear forces are created during manual material handling and are generated as a result of external loads and reaction forces from a forward flexed upper body, modulated by the lumbar spinal curvature. When the lumbar spine is fully flexed the interspinous ligaments become taut and because of their oblique orientation, impose anterior shear forces [66]. These shear forces are reduced if the lumbar spine is not fully flexed and some lordotic spine curvature is maintained because in the mid range spine posture with spinal extensors arranged to reduce anterior shear forces [10].

2.4 Spinal loading

For manual material handling (MMH) pushing, pulling and spinal loading and working in prolonged static back postures are the most identifiable risk factors for the development of LBP

[30]. Conventionally back injury has been considered a consequence of a single cause or event and has been the focus of much research [30].

More recently there has been an increased awareness of back injury occurring from cumulative loading of the spine over a prolonged period of time and a number of investigations have attempted to quantify cumulative loads associated with MMH [13, 68-70].

Sbriccoli et al. [71] showed that on a feline spinal model [17, 72] a single sustained (10 mins) lumbar flexion event results in increased laxity of the spinal ligaments, discs and facet capsules leading to significant alterations of lumbar muscle activity. They [71] also explored for evidence of this phenomenon in humans [73] and found that cyclic and prolonged lumbar flexion (7 hrs) resulted in similar changes to those observed in their feline spinal model study [17, 72].

Sbricolli et al. observed that loading the spinal viscoelastic tissues activates the paraspinal muscles [71] and if this load is applied over a prolonged period of time it creates alterations in the response. The initial effect of prolonged loading appears to result in inhibitory changes to reflex activation of the paraspinal muscles with resultant microdamage and consequential acute inflammation of the viscoelastic tissues [71]. The long term effect of this loading will putatively result in irreversible changes in the viscoelastic tissues, chronic inflammation, pain and increase in the muscular activity [71].

Structural failure of musculoskeletal components can occur in either acute or chronic conditions with most studies concentrating on analysing peak forces in activities with known physical stressors [74-76]. Studies have also shown that repeated exposure to loads well below the threshold for causing traumatic, instantaneous injury can result in eventual fatigue failure of the vertebral endplate [77] Researchers have determined the adverse effects from repetitive loading on spinal structures by in-vitro studies [78-80] and radiographic investigations [77], where a decrease in the vertebral height, derangement of the sagittal alignment of the lumbar vertebrae and injuries to inter-vertebral disc or endplate fractures are taken as objective measures to determine spinal damage occurring as a result of overloads.

Some researchers have previously used a model of constant tissue tolerance to explain biomechanical risk associated with back injuries in workers. More recently others [10] [81] have proposed a time-varying load-tolerance model based on an assumption of tissue tolerance decreasing with repeated loading, suggesting that the threshold for injury decreases with loads acting over a long period of time [10,81]. This concept of injury occurrence is influenced by the interaction of many factors such as the force (compressive and shear), the duration of each task or the sum total of the duration of a series of task, years of working exposure and postural factors [30, 81].

2.5 Cumulative loads

Kumar [13] suggests that LBP occurring as a result of cumulative load is similarly characterised with pain and/or injury and requires more investigation as a risk factor in the development of LBP. Low back pain associated with cumulative loading also appears to be associated with posterior muscle stiffness/spasms, limited range of motion and weakness [71] and is consistent with the time-varying load-tolerance model of McGill [10] and Marras [82]. In general, cumulative or repetitive loading models are based on an argument of each exposure giving rise to micro-trauma of vertebrae and inter-vertebral discs Although in shearing particularly during sheep struggle/ slip spinal injury may result from a single exposure event, over a period of time it is thought that multiple micro lesions occur in muscles, tendons, ligaments, or cartilage, eventually resulting in symptoms and/or impairment [83].

In a sample of 161 institutional aide workers, Kumar [13] investigated whether cumulative stress lead to LBP by calculating cumulative loads and comparing this load with the prevalence of LBP. Cumulative loads in workers with LBP were found to be higher than in a matched (age, weight and height) sample of workers without a current episode of LBP ($p<0.05$). The point prevalence of LBP in this study was 62%, where 101 of the 161 participating institutional aides were currently suffering from LBP.

Kumar [83] further postulated four main theories of musculoskeletal injury; multivariate interaction, differential fatigue, cumulative load and overexertion. The resulting injuries were analysed and it was noted that the path to the injury was either single or combinations of the four theories postulated by Kumar [83]:

Multivariate interaction theory: Multivariate interaction leading to musculoskeletal injury occurs as a result of interaction between various factors such as genetic, morphological, psychosocial and biomechanical factors. Each of these factors is considered to have several subdivisions that interact and are linked to musculoskeletal injury. Although there are likely to be numerous mechanisms for such interaction the type of injury depends on the relative weightings of these factors and the extent they have been stressed in any given individual [83]. Although the genetic, morphological and psychosocial profile of the individual makes him vulnerable to injury the biomechanical factors will substantially stress the musculoskeletal system of the individual [83]. This will lead to musculoskeletal strain that could either be structural or biochemical/ physiological in nature yet regardless of the type of strain, each one is interrelated to the other and is also a precursor of the other. Once there is a strain, the probability of injury precipitation is increased and any continued strain leads to a decrease in the threshold of injury occurrences. However once an individual sustains an injury it leads to pain and the individual then exhibits a pain behaviour [83].

Differential fatigue: It is hypothesized that occupational tasks or activities are often designed to meet the productivity demands (time, cost, efficiency) and are not necessarily linked to optimal biological compatibility. This theory is the basis of injuries resulting from differential fatigue where work demands such as repetitive industrial and agricultural tasks often require asymmetric, repetitive and yet differential loading on musculoskeletal structures, which may not be proportional to a given individual's psycho-physical capabilities. This may lead to disproportionate stress or exertion levels and higher rates of fatigue in the short-term, ultimately leading to altered muscle kinetics, joint kinematics and loading patterns that sub-optimum [83]. Differential fatigue can also affect two aspects of a joint; connective tissue and muscle tissue [83]. With a high, prolonged and repeated loading on the connective tissue, the tissues will tend to work either at a higher rate or for a longer time causing disproportionate deformation of the structures (kinematic imbalance). With repeated loading in a muscle tissue, fatigue sets in and the muscle will generate lesser force leading to kinetic imbalance. The combined effects of kinetic and kinematic imbalance may lead to sudden and abnormal motion at a joint that may lead to an injury. It is based on this theory that back rotation seems to be the dominant factor in the occurrence of lower back injury [16, 19, 84-86].

Overexertion theory: Here injuries are thought to occur where overexertion or excessive loading exceeds the tolerance limit of the musculoskeletal system [82]. Injury will thus occur when the applied load exceeds the failure tolerance level or the strength of the tissue [10]. In this model overexertion can be considered as a function of force, duration, posture and motion. Unexpected loads that commonly occur in occupational settings can lead to high forces on the spine and may cause LBP [83].

Large muscle forces required to stabilise unexpected loads are believed to be responsible for the majority of compressive and shear loading on the spine and consequently are responsible for resulting back injuries when external loads become excessive. When a sudden unexpected load is imposed on the body, the trunk muscles will respond rapidly to stabilize the body in an attempt to maintain balance and a stable posture. As the extensor muscle moment arm of the trunk is relatively short (in males and females in standing is 5.1cm and 5.2cm while in supine in males is 5.0cm and in females is 4.7cm) [87] the resultant muscle force must be large to achieve equilibrium in response to the external load [83]. In addition, sudden load includes a dynamic component (eg inertia, acceleration) of the external force which will add to the internal load.

Previous studies [13, 25, 88] have documented the magnitude of mechanical loads on LBP. Data from a US study shows that > 60% of LBP is caused by overexertion [89]. Evans and Lissner [90] and Sonoda [91] also report that the mean compressive loads on the spine are also age dependent; 3400N for individuals >60yrs and 6700N for individuals <40yrs. Static postural loads demand constant muscular exertion which is contrary to industrial jobs which are dynamic in nature. Similarly, Ayoub et al. [92] and Chaffin et al. [93] report that as the isometric strength required in a job increases, the incidence of injury also increases. The duration of exertion also plays an important role in the overexertion theory of injury causation which depends on the type of contraction, magnitude of contraction, the recovery period and the repetitiveness of the task [83]. However the duration of submaximal contraction and the corresponding time durations at which no significant adverse physiological and metabolic changes take place is still unclear [83]. It is being argued that at the end range of motions, joints are at the greatest mechanical and physiological disadvantage and that the mid range of motion seems to be the one requiring lowest effort for performance. In a work scenario, the biomechanical hazards (such as force, effective exposure and postural load) when combined creates a job-mediated injury risk. It is hypothesized that if this risk is high then an injury is most likely to occur [83]. Therefore this type of injury (overexertion) can occur even in a single forceful exertion either by exceeding the strength component of the joint or by exceeding the strain rate. Based on this Kumar [83] calculated the margin of safety (MOS) as well as the job-mediated injury risk (JMR) to be equal to a sum of one (MOS + JMR = 1). This differentiates the overexertion theory from the cumulative load theory as overexertion injuries results from the interaction of force, exposure time and the posture/ motion [13].

C**umulative load theory** is a model of spine injury driving considerable research in the biomechanics literature. [10, 11, 13, 82, 83, 94] From a cumulative loading perspective biological tissues are considered to be viscoelastic in nature [13] with a finite life cycle subject to wear and tear [83]. They are considered to be capable of self repair but will undergo irreversible mechanical degradation with repeated and prolonged loading [13].

Repeated load application may also result in cumulative fatigue thereby reducing the stress-bearing capacity and the threshold at which the tissues fail [83]. There is a strong association ($p< 0.01$) between biomechanical loading and exposure time (over an entire working life) with LBP or injury [13]. The cumulative compression and shear forces are calculated by first calculating for each task the compression and shear load at the joint for a fixed time intervals. The load time product is now summed up for the entire task and finally the load time product is then multiplied by the number of cycles in a days' work to calculate the cumulative and shear forces for the day. The units for the cumulative compression and shear forces are N.s [83].

A normal healthy spine maintains its stability as a result of interaction between intrinsic and extrinsic factors [95]. Prolonged symmetrical loading particularly in flexion will alter this balance by decreasing disc height [96] and resulting in reduced ligament tensions [13] while prolonged asymmetric and repeated loading is likely to bring about an asymmetric reduction in this ligament tension. [13] Such loading on the spine is thought to increase intradiscal pressure, reduce water content and subsequently decrease oxygen tension and nutrition[97] [98]. Such changes are argued to lead to structural degradation causing the individual to be more susceptible to back injuries and pain [13]. This gradual process is progressive as age progresses with advancement in age [99] but can also be linked to lifestyle [13].

Although studies have documented injury occurring in both acute and chronic conditions [83] most research has focused on the peak forces in activities with known high stresses [74-76, 92] however Brinckmann et al. [100] and Hansson et al. [79] investigated the fatigue failure of the lumbar spine and found that injuries occurred at either lower loads and higher repetition of task or at higher loads and lower repetition of tasks. As excessive cumulative loading has been considered a plausible mechanism for low back injury a number of researchers have attempted to calculate load exposure and estimate the threshold level for injury precipitation in various occupational groups [83]. This is the obvious focus of this research study where the study aims to document the cumulative loads on the spine in shearers and wool handlers.

2.5.1 Research supporting cumulative loading

Brinckmann et al. [100] and Hansson et al. [79] comparatively investigated the in-vitro fatigue failure of the human lumbar spine under low loads with high repetitions as well as higher loads with low repetitions. Both load magnitude and the number of cycles affected spinal structural failure. At 50% and 60% of their ultimate compressive strength, 92% suffered fatigue failures after 5000 cycles. A 10% load increase to 70% resulted in 91% fatigue failures after only 500 cycles, while loading at 75% of ultimate compressive strength resulted in fatigue failure onset within 10 repetitive cycles.

Santaguida et al. [65] compared the cumulative loads on the lower backs of caregivers when transferring patients using overhead and floor mechanical lifting devices. The threshold anterior shear and compressive values at 45° of flexion (relative to the vertical) were ≥ 275N and ≥ 750N. These values increased to ≥375N and ≥1700N with 75° of flexion. The extensor moment for these two forward leaning postures (45° and 75 ° of flexion) averaged ≥40Nm and ≥ 85Nm respectively. The above researchers also found no differences in the time required to complete a bed to chair transfer between floor and overhead devices and concluded that overhead manual lifting devices imparted lower median and cumulative spinal loads than floor devices during the transport phases of the bed to wheelchair transfer.

Norman et al. [94] compared the peak and cumulative physical work exposure risk factors for LBP in an automobile industry. The results of this study showed statistically significant and strong correlations within peak spinal forces and within cumulative forces although correlations between peak and cumulative forces were low. This study also identified that biomechanical work-exposure variables were strongly associated with the risk of reporting LBP. In addition, cumulative spinal load per shift appeared to provide more valuable information than peak forces to help distinguish workers with and without LBP. The peak and cumulative compressive spinal values for workers with LBP were 3423N (SD±1421N) and 21.0 MNs (±4.7MNs) and for the workers without was 2733N (±1073N) and 19.5MNs (3.8MNs) respectively. Besides cumulative loads the other variables that distinguished workers with and without LBP were peak spinal load, kinematic variables related to pelvic-torso motion involved in the physical demands of the job and the external forces on the hand. These combined variables (peak shear, integrated lumbar moment over the duration of shift, peak torso flexion velocity and hand force) also helped predict a 6 times greater risk of LBP when exposed to high loads.

In order to best quantify cumulative loading exposures that will enable correlations with a risk index for LBP a clear methodology needs to be determined and accepted. Fischer et al. [101] examined the influence of different joint models to determine cumulative spinal compression and explored the importance of time standardization in the calculation of daily cumulative loading dose. Time standardization refers to taking in account of the time (working time with or without rest periods) used in calculating cumulative loads. Kumar's [13] did not take into consideration the time that workers were on rest/ break while Norman et al. [94] included the planned rest period during calculating cumulative loads. The joint models that were examined were: single muscle equivalent [102], an electromyography-based third order polynomial [103], a modified version of the polynomial, and a hybrid approach. Kumar [13] estimated cumulative loads based on static postures from subjects drawings while Norman et al.[94] used a video-based posture analysis system.

The cumulative compression value calculated by the polynomial model was 43-53% higher than the single muscle equivalent model and the hybrid approach [104]. The value of cumulative compression predicted by the single muscle equivalent model was 18% higher than the load predicted by modified polynomial approach [104]. As all these modelling approaches appear to have their own unique properties caution should be taken when selecting a particular model to determine cumulative spine compression loading as there is a significant variability in the results. This study showed the importance of time standardization for calculating cumulative compression as the cumulative compressive values derived from time standardised frames were 28.3% greater than non-standardised estimates for a standard working day.

Unlike the relative ease of calculating peak loads, calculating cumulative spinal loads requires a time consuming mode of documenting the entire task for a whole working day [64]. Recently, a relatively easy to use tool (3D Match, Callaghan et al.2003) was developed that uses a posture based approach to calculate the cumulative loads at the L4/L5 spinal segment. This tool is based on a 3D rigid link model that uses a single muscle equivalent to calculate joint shear [104] and a third order polynomial to calculate joint compression [103]. Jackson et al. [105] conducted the reliability study of 3D Match and results shows excellent matching for identical postures during different testing sessions [105]. Compared to previously used 2D biomechanical model this new posture based assessment tool reliably calculates spine compression, anterior/ posterior shear and flexion/ extension moment for specific tasks. Other added advantage of this newer tool is that the data collection process involves a simple video camera that can be placed in industrial setup with ease however the obtaining the optimal position (sagittal view) could be an issue with industrial setups.

Sutherland et al. [106] assessed the effects of camera viewing angle on posture assessment repeatability and cumulative spinal loading. Four video cameras were placed at viewing angles of 0^o, 45^o, 60^o and 90^o to the frontal planes. Eleven examiners were trained to analyse 16 video files (four different lifting tasks at four different camera view angles) in a randomly assigned manner using the 3DMatch software. Four of the 11 participants were also asked to participate in an intra-observer repeatability trial. The results of the repeatability of posture matching across camera view angles showed that the agreement across all tasks and all participants ranged from 71.9% to 85.7% with a mean value of 80.0%. The best posture matching agreement occurred for the symmetrical lift from the floor to the waist height however the difference was only 5% between all four tasks. Smaller range of motion had higher repeatability than large range of motions. The reliability analysis showed no significant effect of examiners on any combinations of the forces and camera angles. The influence of task*observer revealed a significant interaction for joint posterior shear with task 4 and camera angle of 60^o ($P = 0.037$). The reliability of posture matching across days shows excellent reliability with ICC values of 0.863, 0.811 and 0.829 for compression, reaction anterior shear and extensor moment respectively. However the reliability of posture matching across was fair to good for joint anterior shear and joint posterior shear with ICC values of 0.697 and 0.590. This study concluded that the impact of the camera-viewing angle on the observer's ability to match the working postures was negligible, but there was a significant task effect.

Sutherland et al. [107] also validated a posture matching approach for determining 3D cumulative back loads. This study investigated the amount of error in calculating cumulative spinal kinetics using a newer posture matching approach to a previously available 3D coordinate electromagnetic tracking approach. The newer software, 3DMatch was compared to FASTRAK™. Six subjects performed five trials of two symmetric and two asymmetric lifts recorded simultaneously from four camera viewing angles of 0^o, 45^o, 60^o and 90^o. To facilitate direct comparison between 3DMatch and FASTRAK™, video cameras used to capture working postures were synchronised. This study found that there was no significant difference in the relative errors for any of the cumulative load variables (compression, anterior shear, posterior shear, reaction shear and extension moment) between the two methods used and the relative errors for all these variables were below 12%. This study suggests that by using trained users, relatively accurate 3D data can be determined for cumulative load calculations with a biomechanical model.

Sullivan et al. [59] determined the inter- and intra observer reliability of calculating cumulative spinal loads using the 3DMatch software. Three typical manual material handling tasks were recorded each of 5 to 6 seconds in duration was used for this study. Each examiner analysed one video file consisting of the three tasks with each task repeating over 5 times for a total of 15 files at each session. The inter-observer reliability was determined by using mixed model ANOVA with gender, day, and trial considered as fixed effects. Intra-observer reliability was determined to be excellent with the intra class correlation values (ICC) values of >0.75 linked to cumulative compression and extensor moment demonstrating the highest reliability. The inter-observer reliability showed that the average values of joint moment, joint compression, joint shear and reaction shear across all observers shows little variability across days. The results also indicate that there was also little variability between the observers within each test day.

Callaghan et al. [64] documented the errors in estimating the cumulative spinal loading by using the various approaches available and found that the results from previous different methodologies limits the ability to document the threshold limit value for cumulative loading, limits developing a standard for assessing risk of injury from the exposure to cumulative loads as well as compare the results from different studies. Three male subjects performed three sagittal lifting tasks for five repetitions. The cumulative loads (compression, moment, reaction and joint shear) were estimated using six approaches; a) rectangular integration of all frames collected at 30Hz (gold standard), b) rectangular integration with a reduced sample rate of 5Hz [13], c) spinal loading at the initiation of the lift multiplied by the duration of the task (used by Norman et al. [14]), d) cycle divided into work and rest, the work phase of the cycle and e) lastly cycle divided into four components (get load, lift load, place load and return). The errors in estimating the cumulative spinal forces for the task cycle on using the above methodologies are 1.8%, 70%, 35%, 27% and 39% respectively. However when the data was extrapolated to an hour of task, the rest phase was also included which resulted in a decrease in the errors for all approaches and tasks. There was a difference in the one-cycle analysis and one-hour analysis for the cumulative compressive loads; where having a lesser rest time had a lesser reduction in the estimated error. The use of rectangular integration with a reduced sample rate of 5Hz had the minimum error across all task and subjects suggesting significant time saving without compromising the accuracy in estimating the cumulative loads.

Andrews and Callaghan [12] determined the minimum sampling rate needed to accurately quantify cumulative spine loading from digitized video clips. Video clips have the advantage of having a permanent visual record of the tapes with the time duration of the task is also being maintained as well as the ability of tracking the shear forces and joint moments however it is quite labour intensive especially if documenting the load for a shift or day's work Andrews and Callaghan [12]. This study analysed the errors in cumulative load estimates using different sampling rates ranging of 30, 20, 15, 12, 10, 6, 5, 3, 4, 2 and 1Hz and compared it with the Gold Standard of 60Hz. Ten males performed three sagittal lift tasks with each task performed at three lift speeds and each three hand loads were observed for each speed. The results of this study shows that the video analyses with a sampling rate of 2 or 3Hz are suitable for cumulative load estimates during simple laboratory two-dimensional sagittal task. Errors in estimation cumulative load increases as the asymmetry of task increases. Rotational movement greater than 30^o has shown significant error in the peak and mean L5/S1 torques [108] however cumulative force calculated at a sampling rate of 3Hz were statistically different at 60Hz in some conditions although the relative error was under 3% for all variables at a rate of 2Hz [12].

It was therefore rationalised that a video based analysis at a sampling rate of 3Hz would be ideal for this current study where data was to be collected in a field study unlike the laboratory based setup of Andrews and Callaghan [12].

2.5.2 Summary

Although, back injury has been traditionally postulated to occur as a result of excessive peak loading there is an increased awareness of the effect and role of cumulative loads over a prolonged period of time which also result in back injuries. In-vitro studies have shown that repeated loading over a period of time results in irreversible damage to the spinal structures and can lead to fracture of vertebral endplates. Cumulative loading now seems to be a key factor for

LBP reporting in workers engaged in heavy physical work. A number of studies have calculated cumulative loads in workers with results showing that high cumulative loads imply a high risk for LBP and cumulative loads are best able to discriminate workers with and without LBP. Studies have also explored the various methodology used to calculate cumulative loads. Currently 3D Match seems to be the most promising tool in determining cumulative and peak loads for various reasons; relative ease of use in industrial set-ups, using a representative sample of the task to determine the day's cumulative loads instead of analysing the entire day's task, moderate to excellent intra-class reliability

2.6 Cumulative loads in shearers

Recent literature shows the significantly positive benefits for a commercially available trunk harness; Warrie back harness^{TM} (WBA^{TM}) in reducing cumulative compressive forces by 13% at the thoraco-lumbar joint and 20% at the lumbo-sacral joint and also reducing anterior shear forces by 40% at the thoraco-lumbar and 30% at the lumbo-sacral joint. Although the mean, peak and cumulative spinal loads in shearing [34] were observed to significantly reduce the authors argue that yet the spinal cumulative forces are still considerable with little or no change in the incidence of LBP[33]. It is argued that the substantial cumulative effect of these forces over the working day and life of a shearer[34] and the creep response of the lumbar spine following prolonged flexion[109, 110] are likely to be the precursors of occupational LBP.

McGill and Brown [109] documented the creep response as well as the recovery rate at T_{12} to L_1 level in 47 (males = 27, females = 20) undergraduate students. These subjects were exposed to 20 mins of prolonged flexion with a 30 min of recovery period. The results of this study showed that the creep response in both males and females was very similar where both groups showed a 5.5^o increase in flexion. It was noted that one-half of the creep elongation was regained within the first 2 mins and also that females recovered faster than males. They noted the creep response to be a first-order response with the recovery phase needing more time to return to normal as the residual stretch in the posterior tissues remained for a longer time. It is therefore assumed that individuals who spend more time in prolonged flexion should not perform a demanding lift immediately as there is increased chance of hyperflexion injuries to the disc and ligaments. This result implies that shearers and wool handlers are at an increased risk of lower back injuries as they job entails prolonged duration of stooped flexion and frequent requirements of lifting heavy loads (588.4 to 784.5N of sheep/ 55.0N of wool from 2-3 fleeces).

Although the work ethic, productivity and camaraderie of the predominantly male shearing workforce is legendary [111-113], it is now considered evident that these sustained working postures and spinal loads will place the shearer at risk of low back injury. Research for this high-risk wool harvesting occupation has been limited with only two studies investigating cumulative loads; on the shoulder[53] and the spine [33] of shearers. Interestingly no research to date has been conducted on the other occupations in the wool harvesting industry (wool handling and pressing).

Gregory et al. [33] analysed the peak and cumulative loads in shearers of two different skill-levels and also examined the effect of a commercially available trunk harness on these loads. The use of trunk harness significantly ($p<0.001$) decreased the magnitude of the maximum joint compression, peak extensor moment, joint shear in anterior direction and reaction shear in the anterior direction. Conversely the use of trunk harness increased the peak medio-lateral reaction shear ($p = 0.01$), lateral bend moment ($p = 0.01$) and axial twist moment ($p = 0.04$). Shearers with the higher skill level (open shearers) showed a significantly ($p = 0.004$) lowered peak axial twist moment in the right direction compared to a lower skill level (senior) shearers as well as a significantly lowered cumulative axial twist moment in the right direction ($p = 0.02$). Additionally a significantly ($p = 0.02$) higher cumulative flexor moment was observed in shearers in the open skill level versus the senior skill level. Gregory et al. [53] also examined the cumulative shoulder kinematics and kinetics when using a commercial trunk harness while sheep shearing on this same sample of sheep shearers. This study has been discussed in detail in section 2.2.1

2.6.1. Estimating cumulative loads in shearers

As cumulative loading seems to be one of the key factors for developing occupational LBP the mechanisms relating cumulative loading to LBP need to be identified, and a safe exposure limits developed for the wool harvesting industry. In-vitro experimental animal mechanical modelling may help to establish the link between measured spinal postures, loading (magnitude, frequency and duration) and changes in the structure and integrity of the spine [56]. Spinal radiographic analysis in conjunction with modelling may also be advantageous in order to relate the long-term structural changes in the lumbar spine of shearers with observed changes in experimental models and the mechanism of LBP. Relating cumulative loading and incidence of back injury across varying occupations may also indicate safe exposure limits and the risks associated with shearing.

2.6.2. Influence of skill on cumulative loads

Skill is assumed to be an important and integral element in the shearing industry. A higher skill level is assumed to be associated with improved productivity and lower risk of injury. Professional shearing instructors also emphasise the acquisition of skill for a number of issues including, animal control, shearer work postures and efficient fleece removal, as well as harvested wool quality and work throughput [114, 115]. Studies have shown a positive benefit for increased skill in reducing energy expenditure per sheep [36, 48], reducing the cumulative spinal load per sheep[33], and reducing thoraco-lumbar and lumbo-sacral asymmetrical rotation [34]. However Milosavljevic et al. [34] also found that skill had no effect on the peak or mean spinal compressive or anterior shear forces. As skill has a considerable effect on the energy expenditure of shearers [36] it is possible that skill level may also have some influence on the ability to cope physiologically in thermally challenged environments, such as working in shearing sheds in an Australian summer [49].

There is limited literature on the influence of skill-levels on injury risk in other manual workforces. Lett and McGill [23] identified that experienced fire-fighters were able to use their higher skill levels to reduce spinal compressive and shear forces during pushing and pulling activities. Goldenhar et al. [116] suggests that under-utilisation of skill by a manual workforce increases the risk of injury in construction labourers. Jarus and Tatzon [117] suggest that facilitating the learning of correct movement patterns is important for designing effective injury prevention programmes at work places. The influence of skill-levels on injury risk in sports has also been explored [118-124] with conflicting results. Although some report a decrease in the injury rate with increased skill level [120], others report the reverse effect with an increase in the injury rate [118, 119, 121]. While others have found no significant changes in the injury rates of sports people with different skill levels [123]. Professional shearing instructors, linked to the formal shearer training programmes in New Zealand and Australia, have shown interest in determining the role of skill acquisition in reducing the risk of injury while shearing. As the sheep shearing and wool handling tasks have clearly identified workplace skill categories (such as open, senior, intermediate and junior shearers) and skills-based training programs, there is a need for research to determine the influence of skill on the cumulative loads on the spine, and on the prevalence of occupational LBP.

2.7 Future research directions

Areas that require future research in the wool harvesting industry include:

2.7.1 Sheep catching, tipping and dragging

Shearers handle sheep that regularly weigh between 60 to 80kg (588.4 to 784.5N) and with an average daily "tally" of approximately 250 sheep, implies that the mean total daily catch and drag forces amounts to approximately 15 to 20 tonnes of live animal. This is a considerable repetitive daily workload and energy demand on the shearer and most likely to be without parallel in other industries. This daily load exposure exceeds the ISO 11228-1 [125] recommendations of the maximum cumulative load in an entire day of 10,000kg (10 tonnes). Despite the high-energy expenditure associated with catching, tipping and dragging the sheep in preparation for removal of the fleece there is limited research on the forces and postures involved in these tasks. Based on observation, personal communication, and results from a previous study focusing on dragging [35], but not the catching and tipping tasks, indicated that these tasks may also present high risk of back injuries [35].

2.7.2 Wool handling, wool sorting and wool pressing

Workplace observation reveals that in the predominantly female wool handling workforce the job involves a repetitive fully, or partially, stooped working posture - picking up in excess of 250 fleeces per day each weighing between 5 to 10 kg (49 to 98.1N) and "throwing" these onto wool sorting tables. Wool handling also involves using specialised sweeping implements to clean the shearing workstations, sorting the various quality oddments of wool and filling the wool bale with fleece. In the predominantly male wool presser workforce the job involves occasional herding of sheep into holding pens, gathering of wool from the sorting tables, filling and pressing of each bale with up to 200kg (1961.3N) of wool and moving these wool bales. Although modern powered pressing equipment has reduced the energy demand and physical loading of the pressing task, observation would suggest the workload is still substantial. Despite the importance of these tasks to the wool harvesting industry no published research was found on the injury risk or biomechanical loading, ergonomic or physiological demands of these occupations.

2.8 Summary of literature

Research to date has established that sheep shearing is a physically demanding occupation with high energy expenditure and a high risk of back injury. The catch and drag component of shearing subjects the spine to higher loads and is an important risk factor for the development of LBP. The shearing task consists of asymmetrical flexion, which over time has also lead to postural adaptations in the spine with loss of extension.

Previous research has established that the forces (cumulative and peak) acting on the spine of shearers are considerable. Sometimes peak loads do exceed the occupational safety limits yet majority of these forces are still below the safety limits. NIOSH has developed limits for maximal disk compression for infrequent MMH activities where 3400N is the recommended maximum compression force limit and 6500N is the upper limit in the revised NIOSH lifting equation [74, 126]. Although cumulative spinal load limits have yet to be determined [30] Callaghan [127] reports that in Germany a cumulative shift dose of 19.8MN.s is recommended.

Till date no safety limits have been established for the cumulative forces acting on the lower back. Research has also established that the use mechanical interventions such as back harness, manipulators and change in shearing shed design does reduce these loads substantially. Despite this evidence not all shearers use the harness and manipulator and therefore the injury prevalence of LBP in shearers remains high. There is growing evidence for cumulative loading and time varying response or fatigue failure as a mechanism for LBP in occupations such as shearing.

The New Zealand and Australian wool industries strongly advocate the need to improve productivity, reduce costs, and decrease the episodes and severity of back and other musculoskeletal injuries. In particular, there is a recent and ongoing focus on preventive measures (such as the use of ergonomic and assistive devices, exercise and/or activities, rest and work patterns) that can reduce injury risk in shearers. Research has shown that skill has shown beneficial in reducing cumulative loads and energy expenditure per sheep. The shearing and wool handling occupations have clearly identified workplace skill categories (such as Open, Senior, Intermediate and Junior) and skills based training programmes that impact on productivity and quality of wool harvest. There is pressing need for research to determine the influence of increased skill on the cumulative loads on the spine, and on the prevalence of occupational LBP.

2.9 Statement of the problem

The above summary clearly indicates that there is a need to reduce the high incidence of LBP in the wool harvesting industry. As previous studies [13] have found cumulative forces are significantly higher in workers who report LBP it will be desirable to evaluate if the cumulative compressive forces in those who report LBP in the wool harvesting workforce is also greater than those who do not. In addition a relationship between cumulative spine loading and the development of lower back injuries [128, 129] has also been established, further supporting the need to address cumulative loading as an independent risk factor in the generation of work related LBP.

The catch and drag component of shearing and cumulative loads have been identified as key areas in the development of LBP. Previous research supports the use of mechanical device to reduce these loads that probably has a role to play in the reduction of incidence of LBP in shearers.

Since skill has shown some positive effect on reducing these cumulative loads and energy expenditure per sheep it now desirable to determine whether improving skill levels is beneficial to reduce the incidence of LBP, decrease the cumulative and peak loads on the spine and explore if skill is related to LBP. This research is desirable because if skill does influence cumulative loads and therefore LBP then increasing the skill level is beneficial not only in terms of production and efficiency but for reducing this incidence of LBP and the cost associated with it.

2.10 Aims of study

The aims of this study are to;

1. quantify the spinal cumulative and peak compressive and anterior shear forces experienced by workers (sheep shearers and wool handlers) in the wool harvesting industry over an 8-hour workday.
2. determine the influence of skill on the magnitude of cumulative and peak spinal loads in these workers.
3. determine the influence of previous episode of occupational low back pain on cumulative and peak loads in these workers.
4. determine how skill and a previous history of LBP interact in the generation of these forces.

2.11 Purpose of study

To identify the prevalence of LBP in the various skill levels within the shearing and wool handling occupations and to investigate how skill and LBP interact in the generation of cumulative and peak spinal compressive and shear forces. Identifying such relationships will advise industry as to the merits of skill based training that may help to reduce the prevalence of LBP.

CHAPTER 3

METHODOLOGY

3. Methodology

3.1 Study design

This is a cross-sectional investigation of cumulative and peak spinal forces, skill and prevalence of LBP of shearers and wool handlers, with the results presented both descriptively and statistically.

3.2 Ethical approval and funding

Ethical approval for this study was obtained from the University of Otago Human Ethics Committee and the Ethics Committee of the Health Research Council (HRC) of New Zealand, Dunedin, New Zealand. (Refer to Appendix 1 for copy of ethical approvals).
This project was funded by the Vernon Willey Trust Fellowship 2005, HRC research grants 2005 and the School of Physiotherapy, University of Otago, Dunedin, New Zealand.

3.3 Variables of interest

3.3.1 ***Independent variables:*** The independent group measures for this study are 1) the task (shearing, wool handling) 2) occupational skill levels (Junior, Intermediate, Senior and Open classes); and 3) working lifetime history (Yes/No) of occupational LBP requiring clinical intervention (LBP-Clin). The rationale for using this 'definition' of LBP was based on personal communication with workers as well as with industry experts, who reveal that most workers will continue to work despite LBP and it is only the most severe form of this disorder that forces them to seek clinical intervention. Anecdotal information also reveals that many shearers develop LBP and yet do not seek intervention – unless it hinders their ability to work. Thus it was considered that LBP–Clin) was a more accurate indicator of disabling LBP that would hinder the workers ability to remain at work and likely influence their productivity. As most shearers describe having had LBP (> 90%) at sometime during their working lifetime it was considered that little comparative information would be gained from LBP prevalence alone.

LBP-Clin was therefore considered to be a more sensitive discriminator of the effects of LBP on postural and loading variables.

3.3.2 ***Dependent variables**:* The dependent measures are lumbar compressive and anterior shear forces and moments (peak and cumulative) measured at the L4/ L5 spinal segment.

3.4 Inclusion and exclusion criteria

All participants were fulltime shearers and wool handlers or trainees in industry Tectra ™ sponsored courses (Tectra is a quality assured company delivering education and training to people in New Zealand's farming industries). The exclusion criterion for this study was participants with a history of previous spinal surgery.

3.5 Wool harvesting

The occupational groups within the wool harvesting industry being investigated are shearers and wool handlers employed within the workforce at the time of investigation.

3.5.1 Work place set-up

A typical shearing shed in New Zealand involves 2 to 6 shearers working at individual shearing work stations (or "stands"); supported by 2 to 6 wool handlers who gather, sort, and prepare the removed fleeces; who are in turn supported by 1 to 2 wool pressers who fill the bales with wool – preparing them with labelling and stacking them ready to be transported to auction. The shearers, wool handlers and pressers work together in a simultaneous and complimentary manner in order to remove wool from the sheep and ultimately package the harvested wool in a "bale", thus preparing the product ready for marketing. FIGURE 3.1 shows the layout of a typical shearing shed arrangement.

Although it is now common for many modern wool harvesting worksites to provide shearers with raised working platforms ("raised boards"), non-raised or traditional "flat board" worksites are still observed. The wool handlers' usually sort fleeces that are harvested annually on raised sorting tables while shorter length wool (often harvested at ~ 8 monthly intervals) is typically sorted on the floor. The wool handlers also use sweeping "brooms" to strategically push wool around the worksite for sorting.

There are various types of wool presses available depending on affordability and farmer preference. Industry recommended wool presses range from the basic electric and hydraulic devices that require manual tramping and preparation of the wool within the bale; to more sophisticated electrical and hydraulic "no-tramp" presses that prepare and electronically weigh the bale and only require the presser to lift wool into the bale. Industry advice from Tectra ™, indicated that the Vangard FM1 two-box hydraulic, electric tip-over press, was still the predominant press used by sheep farmers in New Zealand, as such this was the device used for standardising the work tasks for the wool pressers who participated in this study.

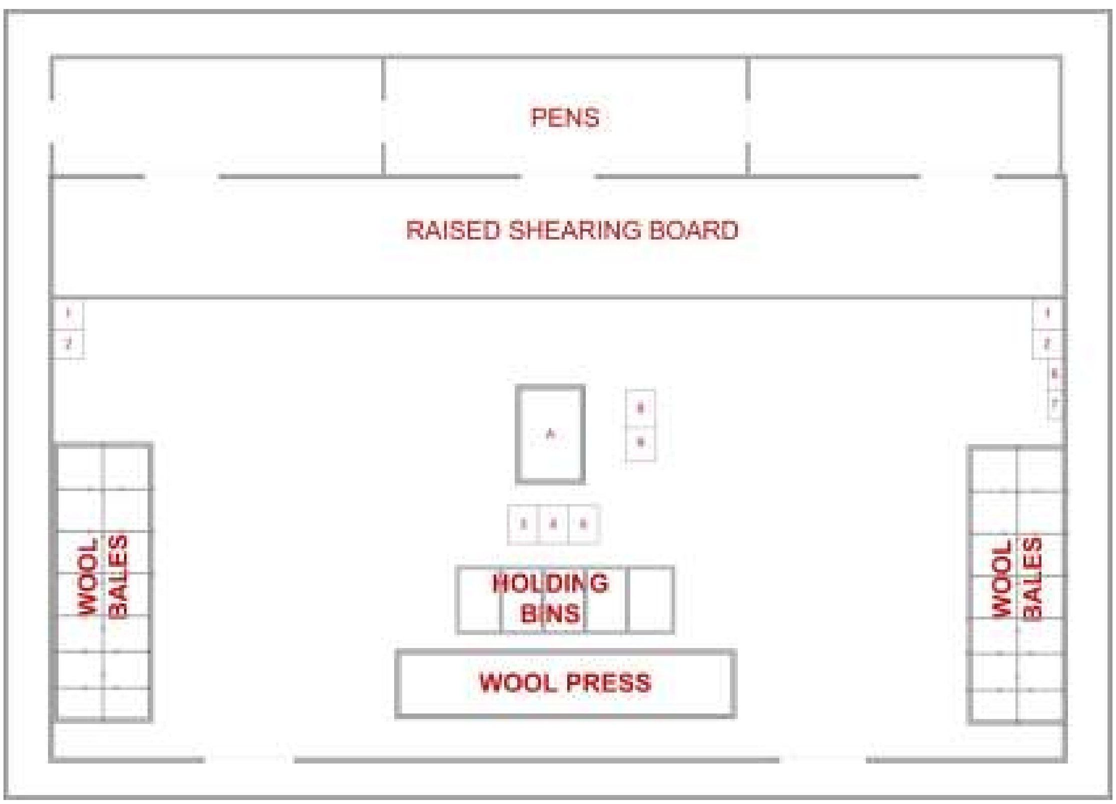

FIGURE 3.1: Schematic representation of a shearing shed. Adapted from Tectra, Wool Handling Handbook. Key: 1-9 Bins for wool oddments and inferior quality sortings, A - wool sorting table; Holding bins - for sorted fleeces prior to pressing; Wool Press – for preparation of wool bales.

3.5.2 Skill levels

The shearers and wool handlers are formally categorised based on skill levels, set by the guidelines from wool harvesting industries in Australia and New Zealand. The skill levels are assessed during both professional training as well as competitions in Australia and New Zealand. [130] This skill ranking system is based on both speed and the quality of fleece removal and fleece preparation respectively. Shearers are categorized into four ranked skill levels: from the highest or 'open class', to 'senior class', to 'intermediate class' and finally the beginner or 'junior class'. Wool handlers are similarly categorized into three skill levels: 'open class', 'senior class' and 'junior class'. There is no approved/ formal skill categorization for the wool pressers.

The 'open' classes represent workers who have the highest levels of experience, productivity, speed and skill, formally judged by harvested wool quality, the senior class represents subjects that are ranked at a lesser level than open class. Similarly the intermediate class represents subjects with a lesser ability than the senior class while the junior class represents shearers/or wool handlers who are in their initial stages of training.

3.5.3 Work and rest periods

Workers in the wool harvesting industry usually work an 8-hour workday excluding a one-hour lunch break together with two 30 minute breaks – one mid morning and one mid-afternoon. These three formal breaks are usually taken following a continuous two-hour harvesting session. The shearers also take occasional (< 5 minutes) short breaks or pauses to service their shearing devices (or hand pieces), have a drink, use a towel to wipe away excess sweat, or take a short respite from their work tasks.

3.5.4 Work cycle and time

For the purpose of data capture and analysis a complete cycle for each working group was identified. It was determined that the process of catching the sheep, dragging it to the work station, removing the wool (fleece) and releasing the animal represented one complete cycle of shearing, while for the wool handlers the process of gathering, throwing, skirting, sorting the fleece, and sweeping from one sheep represents a complete cycle. Depending on skill level a shearer will take about 1-3 mins to shear a sheep while a wool handler takes 2-4 minutes to sort the wool from one sheep.

3.6 Sample size

Data from a total of 150 subjects were collected; of which 80 were shearers (sub-categorised by 4 skill levels) and 60 were wool handlers (sub-categorised by 3 skill levels). This allowed a minimum number of 20 subjects for each identified skill level in shearing and wool handling providing sufficient statistical strength to provide reasonable estimates of variance and to determine whether skill category had any significant between group effect for cumulative or peak loading or for prevalence of LBP. Two open class shearers were also videotaped in a separate visit to the shearing sheds to collect data on the catch and drag phase of sheep shearing. The video clips are matched to posture bins (ranges of motion of a body segments in separate bins) of a posture analysing software (3D Match). The software consists of posture bins for trunk flexion (6), trunk lateral bend (3), trunk rotation (3), neck flexion/ extension (4), neck lateral bend (2), neck rotation (3), shoulder flexion/ extension (6), shoulder abduction/ adduction (6) and elbow flexion/ extension (5).

3.7 Data collection

The shearers and wool handlers were recruited during the peak summer shearing season in the southern South Island. At this time there are considerable numbers of resident and itinerant workers and seasonal shearing competitions are a predominant feature for the work force, for both social reasons and for formal testing of skill by recognized industry experts. The gathering of the profession at shearing competitions and workforce availability makes it the optimal time to recruit the participants and where competing shearers and wool handlers will be those most likely involved in mentoring and skill upgrading programmes offered by the industry. For these reasons the shearing and wool handling participants recruited for this study can be accepted as a valid representation of the shearing workforce in New Zealand. During these competitions each shearer's competitive score is formally judged based on both the time taken to shear the sheep as well as the quality of the removed fleece. Wool handlers are judged by the quality of the fleece preparation, by the time taken to prepare the wool fleece and clean the sorting area.

3.7.1 Video Capture

Videotapes were collected during industry recognised annual shearing and wool handling competitions held in the rural areas of Otago/Southland during the summers of 2006 and 2007. Each subject was video-taped while executing 3-5 consecutive trials/ repetitions of their normal task cycle. Although the practical restraints of capturing video footage in an actual working environment (shearing competition) meant only relatively front on views of the participants was captured, recent research investigating the effect of camera viewing angle on posture assessment repeatability and spinal loading has shown high levels of reliability regardless of camera viewing angle [106]. Video camera placement and field of view enabled capture of competing shearers/wool handlers for each heat of the event yet at the same time provided video footage that would clearly identify body segments for analysis.

3.7.2 Demographic data

Following video capture, each participant was approached with the information sheet (Refer to Appendix 2 for copy of information sheet) and the study explained. Following written informed consent (Appendix 3), each subject was asked to complete a questionnaire, (Appendix 4) that gathered the following information; name, age, estimated body weight and height, years of working experience, average daily tally (total number of sheep shorn in a day) and any previous history of low back pain requiring the participant to take time off work and seek medical intervention. This information was then entered in a Microsoft® Excel 2003 spreadsheet for further analysis and is presented in the results chapter of this thesis.

3.7.3 Pull/ Push forces

The loads/weights in the hands of the participants while performing the task (shearing or wool handling) are required for the software based calculation of cumulative and peak lumbar forces (3D Match). Forces acting in an X-axis can be described as push/pull forces; forces acting in the Y-axis are either vertical lift or a downward pressing force; forces acting in a Z-axis are orientated in a medial to lateral directions.

3.7.3 a) Hand forces in shearers

Shearing being a dynamic process (ranging from catching the sheep in the pen, dragging it out from the pen to the shearing platform, shearing and finally guiding the shorn sheep out though an exit chute) involves constant changes in the hand forces of shearers.

i) *During shearing*: The load in the hand holding the shearing clippers was considered to be a constant load of 1 kilogram (kg) (9.8N) (mass of shearing clippers) based on the previous studies by Milosavljevic et al. [34] and Gregory et al. [33]. A force of zero was chosen for the hand without the shearing piece based on the work of Milosavljevic et al. [34], who describe that the intermittent forces generated with this hand never exceeded 3kg while removing the wool and were considered to be minor in the overall calculation of L4/L5 loading.

ii) *During catching and dragging task*: The hand forces used during the catch and drag of sheep from the holding pen was calculated by using a strain gauge load cell (Celtron STC-250kg S-type load cell) (FIGURE 3.2) attached to a sheep via a harness (FIGURE 3.3). In order to calculate the hand forces during this task two open class shearers volunteered to catch and drag sheep. The average value of the forces from these two shearers over ten trials was used for the analysis in the following manner. A metal handle was attached to one end of the load cell for the shearer to grasp, while the other end was clipped to the harness that had been placed on the sheep. (FIGURE 3.4) The handle was adjusted so as to measure the dominant and non-dominant hand forces of the two shearers while catching and dragging the sheep and thus generate the force profiles while using each hand in this occupational task. (Refer to Appendix 5) These hand force profiles were then used in the calculation of lumbar forces during the catch and drag sequence.

FIGURE 3.2.: S-shaped load cell used to calculate hand forces during catch and drag phase of sheep shearing.

FIGURE 3.3: Harness that was attached to the sheep.

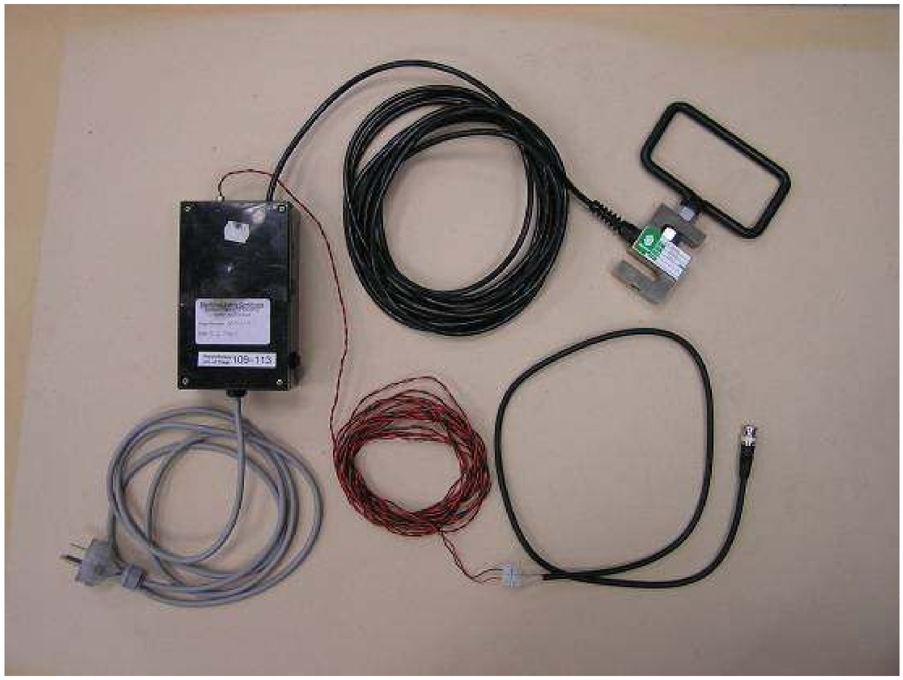

FIGURE 3.4: S- shaped load cell with attached handle and required cables data gathering during catch and drag sequence.

3.7.3 b) Hand forces in wool handlers

This also involved various loads of wool lifted by the hands during different phases of the wool handling task. In order to differentiate these forces a number of wool handlers were weighed with representative samples of wool on domestic bathroom scales (SALTER model 9982 Digital Bathroom Scale) both with and without the loads. Thus a full fleece of wool was accepted as weighing 55N while smaller samples were subjectively judged when viewing the video clip and a representative weight chosen depending on the estimated size. In addition to the loads from handling the wool, wool handlers also use a small flat piece of wood to sweep the wool from the shearing station towards them, a process that marks the start of the wool-handling task. The wool handler also uses a standard long handle broom to sweep the wool from the floor and finally heaps this wool in designated bins; this process usually marks the end of the wool handling cycle. The weight of the stick, broom and wool fleece was measured by a weighing scale to be 1.0 N, 2.0 N and 55.0N respectively.

3.8 Data Analysis

The PAL (Phase Alteration Lines) video tape cassette format clips obtained were converted into AVI digital format for compatibility with the software used for calculating cumulative and peak loads. The software used for converting the PAL videotape cassettes to digital format was Adobe Premiere ™ (Version 6.5). The videotape was played in a videocassette recorder, connected to a PC computer and the appropriate video clips were re-captured in real time and saved in digital format.

All AVI video clips resulting from the above digital conversion as well as those recorded from two additional digital cameras were transferred onto a personal computer for further processing in the following manner. The frequency of the digital video files (25Hz) was reduced by using Adobe Premiere ™ (Version 6.5) to the sampling frequency of 3Hz previously described by Andrews & Callaghan [12] as the minimum sampling frequency required for calculation of spinal cumulative loading. Each complete cycle of the task (shearing/wool handling) per person was stored as a separate file. These files were then analysed by using 3DMatch biomechanical software.

3.9 3DMatch

3DMatch (Callaghan 2003, University of Waterloo) is specialised software capable of determining three dimensional (3D) peak and cumulative loads developed at the L4/L5 inter-vertebral level (FIGURE 3.6). 3DMatch spinal load calculation is based on a worker's 3D kinematics and uses a binned posture approach with the incorporation of external forces and anthropometric data of each subject. It provides an interface that allows the user to scroll through digital video files frame by frame inputting X, Y and Z bilateral hand forces and selecting appropriate postures from a series of representative posture bins for the elbow, shoulder, neck and trunk. (FIGURE 3.6) A static 3D rigid link model is thus generated from the subject's anthropometric and postural data. Using the above model joint compression forces are calculated using the third order polynomial spinal optimisation loading described by McGill et al. [103] with joint anterior/posterior shear calculated using a single spinal extensor muscle equivalent with a 5.3° angle of pull [102]. The hand pull/ push forces during all of the tasks (catching, shearing or wool handing) were calculated as previously described in section 3.7.3.

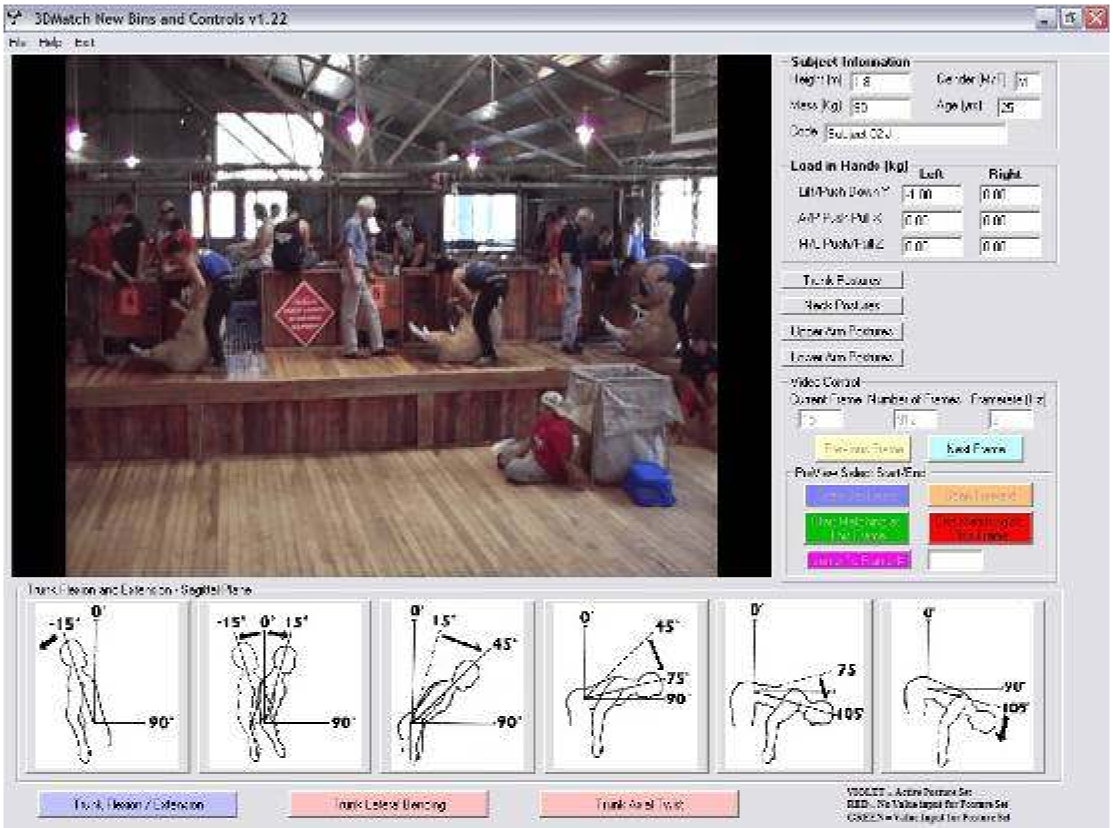

FIGURE 3.5: A screen capture of 3D Match software during shearer analysis.

3.9.1 Posture Bins:

Segment posture bins in 3DMatch were previously determined by the degree of LBP risk found in the existing literature [15, 68]. Trunk flexion and extension postures consist of 6 bins based on the range of trunk motion in the sagittal plane: with extension >-15^{o}, -15^{o} to 15^{o} (through a neutral stance of 0^{o}), 15^{o} (of flexion) to 45^{o}, 45^{o} to 75^{o}, 75^{o} to 105^{o} and flexion >105^{o} (FIGURE 3.6). The trunk lateral bend posture consists of 3 bins based on the range of trunk motion in the frontal plane: 0^{o} to 15^{o}, 15^{o} to 30^{o} and >30^{o} in either right or left lateral bend (FIGURE 3.7). The trunk rotation posture consists of 3 bins based on the range of trunk motion in the transverse plane: <15^{o}, 15^{o} to 25^{o} and >25^{o} in either right or left rotation (FIGURE 3.8).

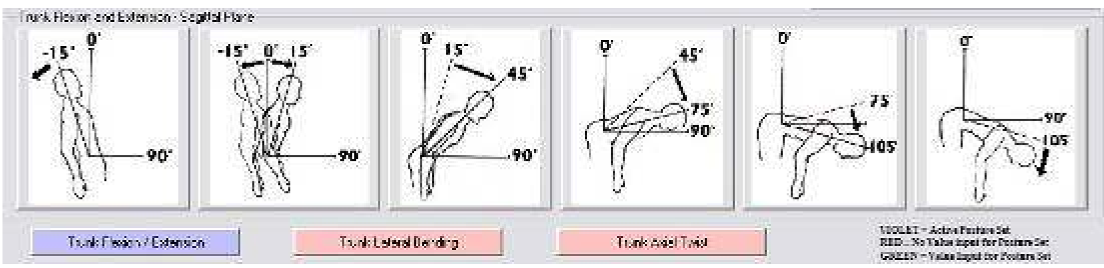

FIGURE 3.6: Trunk flexion/ extension posture bins in 3D Match

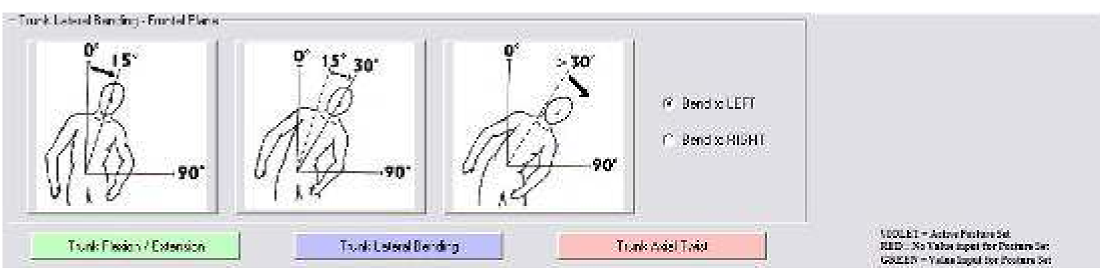

FIGURE 3.7: Trunk lateral bend posture bins in 3D Match

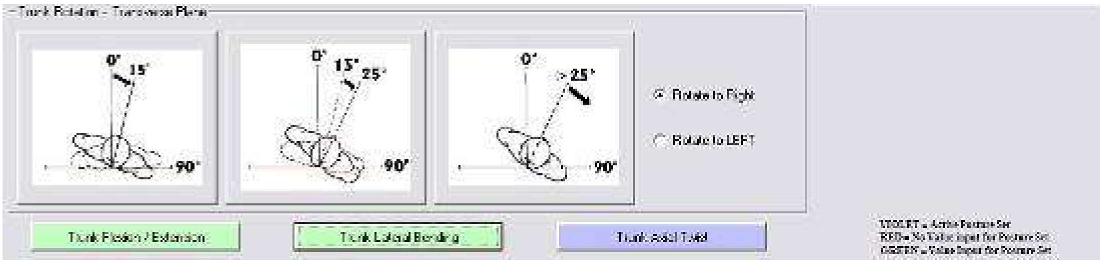

FIGURE 3.8: Trunk rotation posture bins in 3D Match

Neck flexion extension posture consists of 4 bins based on the range of neck movement in the sagittal plane: with extension <-10^o, -10^o to 10^o (through neutral stance), 10^o of flexion to 30^o and >30^o of flexion. (FIGURE 3.9) The neck lateral bending consists of 2 bins based on the range of neck movement in the frontal plane: 0 to 20^o and >20^o in either left or right lateral bend. (FIGURE 3.10) Similarly neck axial twist consists of 3 bins based on the range of neck movement in the transverse plane: <10^o, 10^o to 40^o and ≥40^o in either right or left rotation. (FIGURE 3.11)

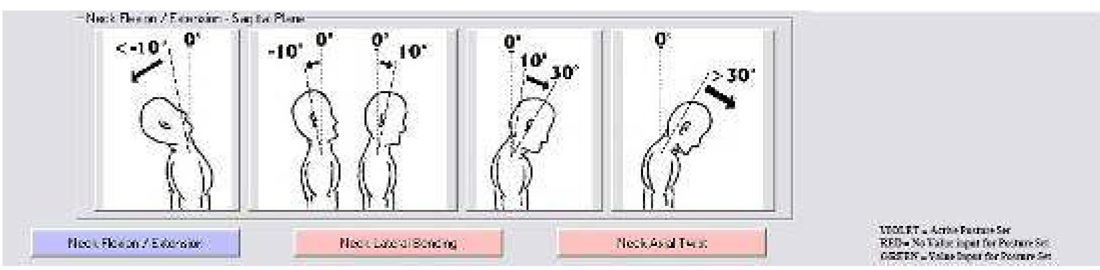

FIGURE 3.9: Neck flexion/ extension posture bins in 3D Match

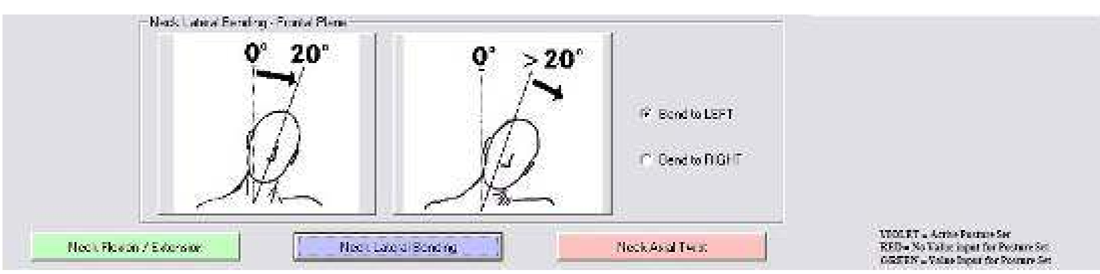

FIGURE 3.10: Neck lateral bend posture bins in 3D Match

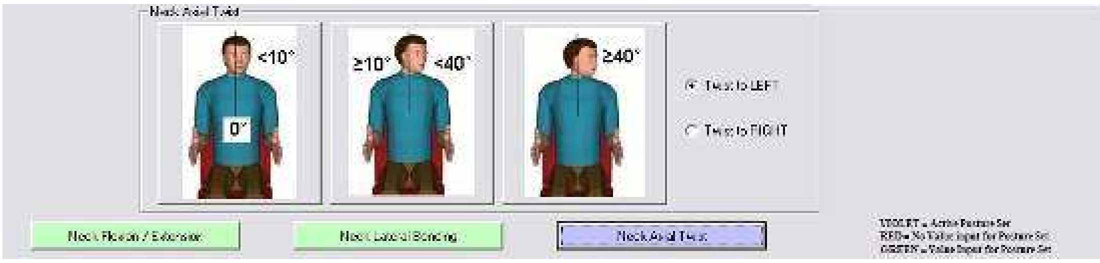

FIGURE 3.11: Neck axial twist posture bins in 3D Match

The shoulder flexion and extension postures consist of 6 bins based on the range of shoulder movement in the sagittal plane: with extension <-20°, -20° to 20°, 20° to 45°, 45° to 90°, 90° to 135° and >135° flexion. (FIGURE 3.12) The shoulder abduction and adduction postures consist of 6 bins based on the range of shoulder movement in the sagittal plane: 0 to 10°, 10 to 10°, 10° to 45°, 45° to 90°, 90° to 135° and >135°. (FIGURE 3.13)

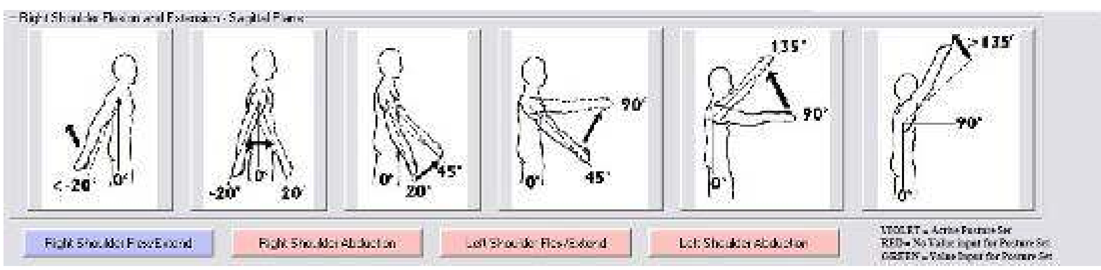

FIGURE 3.12: Shoulder flexion/ extension posture bins in 3D Match

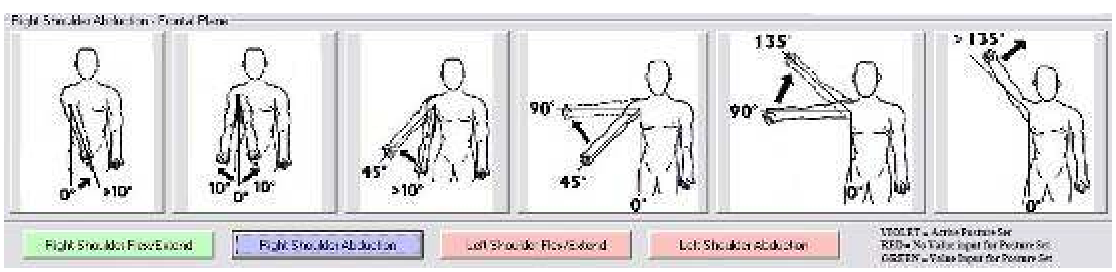

FIGURE 3.13: Shoulder abduction/ adduction posture bins in 3D Match

The elbow flexion and extension postures consist of 5 bins based on the range of elbow movement in the sagittal direction: 0^o, 0^o to 40^o, 40^o to 80^o, 80^o to 120^o and $>120^o$. (FIGURE 3.14)

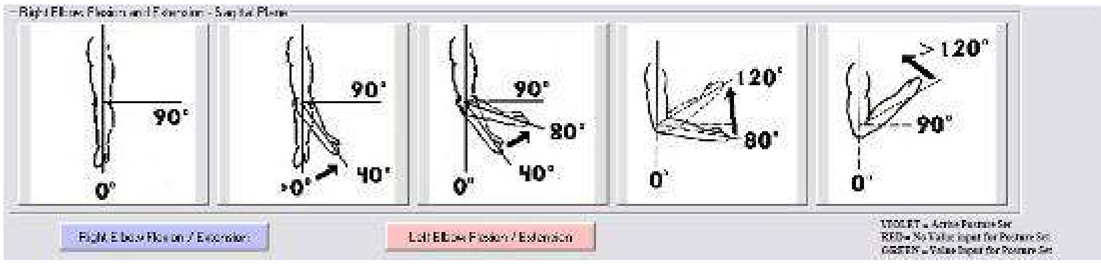

FIGURE 3.14: Elbow flexion/ extension posture bins in 3D Match

For the postural analysis the analyst chooses the posture bin that best represents the position of the trunk, shoulder, elbow and neck. A bin represents a range of postures and the 3D Match software uses the middle of this range in calculating the position of the trunk, shoulder, elbow and neck. Refer to TABLE 3.1 for the range of postures and the middle value of the angles. For example if the trunk is in about 90^o of flexion the best posture bin will be the 75^o to 105^o.

TABLE 3.1: Postural bin values of 3D Match (v5.05)

Body segment	**Plane of motion**	**Type of movement**	**Range in the posture bin (°)†**	**Angle used for calculation (°)†**
Trunk	Sagittal	Extension	> -15	>-15
		Neutral	-15 to 15	0
		Flexion	15 to 45	30
		Flexion	45 to 75	60
		Flexion	75 to 105	90
		Flexion	> 105	>105
	Frontal	Neutral lateral flexion	0 to 15	7.5
		Lateral flexion	15 to 30	22.5
		Lateral flexion	> 30	>30
	Transverse	Neutral rotation	0 to 15	7.5
		Rotation	15 to 25	20
		Rotation	>25	>25
Neck	Sagittal	Extension	< -10	<-10
		Neutral	-10 to10	0
		Flexion	10 to 30	20
		Flexion	> 30	>30
	Frontal	Neutral lateral flexion	0 to 20	10
		Lateral flexion	> 20	>20
	Transverse	Neutral rotation	< -10	<-10
		Rotation	≥ 10 to <40	25
		Rotation	≥ 40	≥ 40
Shoulder	Sagittal	Extension	< -20	<-20
		Neutral	-20 to20	0
		Flexion	20 to 45	32.5
		Flexion	45 to 90	67.5
		Flexion	90 to 135	112.5
		Flexion	> 135	>135
	Frontal	Adduction	0 to >-10	-5
		Neutral	-10 to 10	0
		Abduction	> 10 to 45	27.5
		Abduction	45 to 90	67.5
		Abduction	90 to 135	112.5
		Abduction	>135	
Elbow	Sagittal	Extension	0	0
		Neutral	> 0 to 40	20
		Flexion	40 to80	60
		Flexion	80 to 120	100
		Flexion	> 120	>120

† **A** negative value indicates segment extension and positive that the segment is in flexion.

3.9.2 Reliability of 3DMatch

Both inter- and intra-rater reliability for using manual video-digitising to calculate cumulative spinal loads has been previously explored by Sullivan et al. [59] with cumulative compression, cumulative joint shear, cumulative reaction shear, and cumulative moment used to assess reliability. Inter-rater reliability showed no significant differences for rater, gender, day or trial. Intra-rater reliability for measurement of these variables was calculated by intraclass correlation (ICC) coefficients within each task demonstrating ICC values >0.75 (accepted as excellent). Cumulative compression and cumulative extensor moment demonstrated the highest reliability of the four parameters studied. Thus a manual video digitisation tool appears to be reliable for the quantification of cumulative spinal loads both within a given observer, as well as across days, trials and observers.

Jackson et al. [105] has also examined the inter-rater reliability of using 3DMatch and found that observers were excellent at matching identical postures during different testing sessions. They also found that 3DMatch reliably calculates spine compression, anterior/posterior shear and flexion/extension moments for specific tasks when compared to a 2D model. However this study was conducted in a laboratory with a single sagittal view and caution should be exercised when applying the above results to studies conducted in an industrial setting.

For the purpose of estimating the reliability of 3DMatch used in this current study where the data were collected in the actual working environment inter-rater reliability of determining cumulative loading was investigated. Video footage from 20 shearers was used for this calculation of reliability. A second rater with a degree in Physical Education was employed to independently evaluate the videotapes. This analysis was performed on 20 randomly selected sheep shearers over a period 3 months. Intra-class correlation coefficients and Bland Altman plots were used to evaluate the inter-rater reliability for this study. The inter-rater reliability was carried out for the four variables of cumulative compression, cumulative joint shear, peak compression and peak joint anterior shear similar to the research of Sullivan et al. [59]. The result for this reliability study is presented in the results section 4.2 of this thesis.

3.10 Posture analysis and cumulative load calculation

Each shearing and wool handling trial was analysed to determine the cumulative compression and shear loads using *3DMatch* (Callaghan 2003, University of Waterloo). Each trial was extrapolated to a full workday defined as the number of task cycles in one day. This was calculated by dividing 8 hours (or 28,800seconds) by the average time to perform one task cycle. This whole working day extrapolation was carried out for all of the shearers and wool handlers. For the wool handlers this was directly possible from their video footage as this recording showed a complete cycle of their task. However for shearers there were practical limitations to video camera placement in a working shearing shed due to movement of shearers, sheep, handlers and judges (with the video camera placed in front of the shearer and shearing platform capturing the frontal or the sagittal shearing views) leading to the catch and drag segment being videoed and analysed separately.

In order to video capture the catch and drag sequence of the shearing task and make it applicable to each shearer the following methodology was used. Two shearing sheds were visited subsequent to the shearing competitions where 6 shearers were videotaped. Specific catch and drag video clips were recorded and then observed. One video clip that appeared to best represent the catch and drag sequence was used as a proxy (single representative participant) for the catch and drag section of all shearers. This video clip was then used to obtain the postures of the catch and drag section of the shearing cycle for all shearers. However, the anthropometric data of each individual shearer was then incorporated into the posture-matching analysis for this (3Hz sampled) video clip to generate the posture and model files of each individual shearer and respective spinal forces. The posture file that were generated from this catch and drag analysis were then added to the respective shearing posture file to obtain the full cycle for each shearer. Norman et al. [14] also used the above method with a proxy method used in place of an actual worker based on the results of previous study by Punnett et al. (22). In the study by Norman et al.out of the 104 subjects analysed, twenty were used as proxy and this use of proxy did not affect the results of the study.

Spinal posture analysis during the resting postures (walking, upright standing, out of camera view etc.) of all workers was estimated assuming the person was in the neutral upright trunk posture where the neck was in 0^o of flexion and extension with no lateral bends and axial twists, the shoulder in 0^o of flexion and extension, with no abduction or adduction, the elbow in 0^o of flexion and extension and the trunk in 0^o of flexion and extension with no lateral bends and axial twists.

The posture matching analysis using *3DMatch* generates both *posture* and *model* files. This posture file contains the details regarding the origin of the trial file, participants' information, loads in hands, total frames, frame rate and examiners' posture selection for each category for all frames of the complete participants trial. The model file that is created from the posture file consists of 36 calculated cumulative loading variables and peak spinal loading variables at the L4/L5 spinal level. For the purposes of this study the following variables were analysed: cumulative compression, cumulative force weighted compression, cumulative joint anterior shear, cumulative reaction anterior shear, cumulative extensor moment, peak compression, peak extensor moment, peak anterior trunk shear and peak anterior trunk reaction shear. These data were exported into a Microsoft ® Excel 2003 spreadsheet.

3.11 Load Magnitude Weighting Factor

Although cumulative exposure has been primarily calculated by simple summation of exposures over time, Jager et al. [131] have also examined the influence of force weighting (square or tectra (4^{th}) power) on cumulative exposure. This was based on the theory that magnitude of force contributes non-linearly to injury. This theory has been confirmed by Parkinson & Callaghan [132, 133] on *in-vitro* vertebral specimens and force weighting factor relationship has also recently been proposed and incorporated into 3D Match analysis. Since a non-linear relationship was found between cumulative load tolerance at failure and loading magnitude, this relationship is used to develop weighting factors to adjust loading magnitudes for their impact on injury development when assessing cumulative loading. Thus data for the cumulative compressive load at L4/L5 calculated for each frame for each participant were multiplied by this load magnitude-weighting factor proposed by Parkinson and Callaghan [132, 133]. They determined that all loading magnitudes lesser than 37.5% of the maximum compressive strength (leading to failure) are assigned a weighting factor of 1 [133].

3.12 Statistical Analysis

All statistical analyses were performed using SPSS® for Windows™ Version.16.0. (SPSS Inc., Chicago, IL).

Descriptive statistics and tables were used to describe each groups' (shearers and wool handlers) anthropometric characteristics (age, weight, height, body mass index -BMI), tally (shearers: number of sheep shorn in a day, wool handlers: number of fleeces sorted in a day), prevalence of LBP-Clin and years of work experience. Graphical representation, descriptive statistics and tables were also used to describe skill based anthropometric characteristics, tally, prevalence of LBP-Clin and years of work experience in each occupational group. The means, standard deviations (SD) and 95% confidence interval (95% CI) were reported for these data in the tables.

The mean (SD), 95% CI and range for cumulative and peak loads in shearers and wool handlers are also presented in a tabular form. The mean (SD), 95% CI and range for cumulative and peak loads within each skill level for shearers and wool handlers is presented in a tabular form as well as graphically. The cumulative forces for the catch and drag phase of shearing were added to the shearing task to describe one cycle and therefore the cumulative forces for the catch and drag phase is not presented separately.

The anthropometric, work experience and tally was recorded as continuous data while skill and LBP-Clin recorded as categorical variables. For skill the data was labelled as follows; 0 = Junior; 1 = Intermediate; 2 = Senior; 3 = Open and LBP-Clin was labelled as; 0 = No; 1 = Yes.

Correlation analysis between independent variables was carried out in order to determine the likelihood of collinearity existing between variables. Univariate linear regression analyses were used to determine the influence of age, BMI, tally, skill and LBP-Clin on cumulative and peak loads. The mean differences, p-values, 95% confidence intervals, and R^2 values are presented in the tables

The influences of both skill and LBP-Clin on cumulative and peak loads were explored by a multivariate stepwise linear regression model by combining skill and LBP-Clin. In order to determine this interaction between LBP-Clin and skill, new variables were created where data for levels of skill (0 to 3 for shearers; 0 to 2 for wool handlers) and LBP-Clin (0 and 1) were multiplied by each other in order to determine interactions. Preparatory univariate analyses against cumulative posture and load allowed LBP-Clin or skill into the multivariate model if $p < 0.10$.

CHAPTER 4

RESULTS

4. RESULTS

Although 154 participants were recruited data were only analysed from 140 participants (80 shearers and 60 wool handlers. The data from the excluded 14 participants could not be analysed either because they had not completed the demographic questionnaire or the video footage was incomplete.

4.1 Shearers

4.1.1 Anthropometric data and work characteristics of shearers

The shearers had a mean (±SD) age of 25.4 years, mean weight of 84.9 kgs, mean height of 1.80 m, and mean body mass index (BMI) of 26.2 kg/m^2 (TABLE 4.1). They had an average of 6.3 years of work experience and a mean daily tally of 274 sheep shorn per day. Forty four percent of the shearers described at least one episode of work related LBP-Clin. (TABLE 4.1)

TABLE 4.1: Summary of personal, anthropometric and work characteristics of shearers (n=80)

	Age (yrs)	Weight (kg)	Height (m)	BMI (kg/ m^2)	Tally (sheep/day)	LBP (%)	Experience (yrs)
Mean (±SD)	25.4 (8.2)	84.9 (11.9)	1.80 (0.07)	26.2 (2.8)	274 (76)	44	6.3 (6.9)
Range	15.0 to 52.0	61.0 to 125.0	1.60 to 1.90	21.6 to 35.4	100 to 400	-	0.2 to 33.0
95% CI	23.6 to 27.2	82.3 to 87.5	1.78 to 1.82	25.5 to 26.8	257 to 291	-	4.8 to 7.8

4.1.2 a Influence of skill on anthropometric and work characteristics of shearers

The influence of skill on independent variables such as age, BMI, work experience, tally and LBP-Clin was explored using linear and logistic regression (LBP-Clin is a categorical variable (0, 1)). Although skill level was significantly associated with age, work experience, tally and LBP-Clin there were no significant differences in BMI amongst these four skill levels (TABLE 4.2).

T able 4.2: Influence of skill on independent variables (n = 80)

	Age	BMI	Tally	LBP	Experience
B	-4.62	0.07	-62.18	-0.23	-4.21
R^2 value	0.409	0.001	0.869	0.287	0.479
P value	<0.000	0.806	<0.000	<0.000	<0.000
95% CI	-5.87 to (-3.38)	-0.49 to 0.63	-67.59 to (-56.76)	-0.15 to 0.32	-5.19 to (-3.23)

4.1.2 b Skill-level based group anthropometric and work characteristics:

The anthropometric and work characteristics of the junior, intermediate, senior and open skilled categories of shearers are summarized in TABLE 4.3. The working lifetime prevalence of LBP-Clin occurring in New Zealand shearers was 10% (n=2) for the junior shearers, 26% (n=5) for the intermediate shearers, 60% (n=12) for the senior shearers and 77% (n=17) for the open class shearers (FIGURE 4.1). The mean daily tallies was 170, 260, 302 and 355 sheep/day (FIGURE 4.2) and mean work experience was 1.4, 2.3, 6.8 and 13.8 years (FIGURE 4.3) for the junior, intermediate, senior and open class shearers respectively.

When comparing a combined junior and intermediate shearer category (0) to a combined senior and open class shearing category (1) the senior and open class group had a prevalence odd ratio (OR) for LBP-Clin that was 9.85 greater with a 95% CI ranging from 3.45 to 28.12 (P<0.0001).

TABLE 4.3: Summary of personal, anthropometric and work characteristics of each skill-level shearers

	Anthropometric data based on skill levels of shearers			
	Juniors (20)	**Intermediate (19)**	**Senior (20)**	**Open (22)**
Mean Age (±SD) (yrs)	19.2 (4.0)	21.7 (3.3)	27.2 (8.8)	32.7 (7.5)
Range	15.0 to 33.0	18.0 to 28.0	18.0 to 50.0	22.0 to 52.0
Mean Height (±SD) (m)	1.76 (0.07)	1.83 (0.05)	1.80 (0.08)	1.79 (0.08)
Range	1.60 to 1.88	1.73 to 1.92	1.68 to 1.96	1.60 to 1.93
Mean Weight (± SD) (Kg)	83.5 (10.7)	86.6 (13.7)	85.6 (11.6)	84.1 (12.1)
Range	70.0 to 108.0	65.0 to 125.0	68.0 to 113.0	61.0 to 108.0
BMI (± SD) (Kg/m^2)	26.5 (2.8)	25.7 (3.6)	26.4 (2.5)	26.0 (2.5)
Range	21.6 to 32.6	21.7 to 35.4	22.7 to 32.2	22.9 to 31.8
Years of experience (± SD) (yrs)	1.4 (0.9)	2.3 (1.6)	6.8 (5.7)	13.8 (7.3)
Range	0.2 to 3.0	1.0 to 8.0	2.0 to 25.0	4.0 to 33.0
Tally (± SD) (sheep per day)	170 (30)	260 (36)	302 (26)	355 (40)
Range	100 to 210	165 to 300	250 to 350	300 to 400
Prevalence of LBP-Clin %	10%	26%	60%	77%

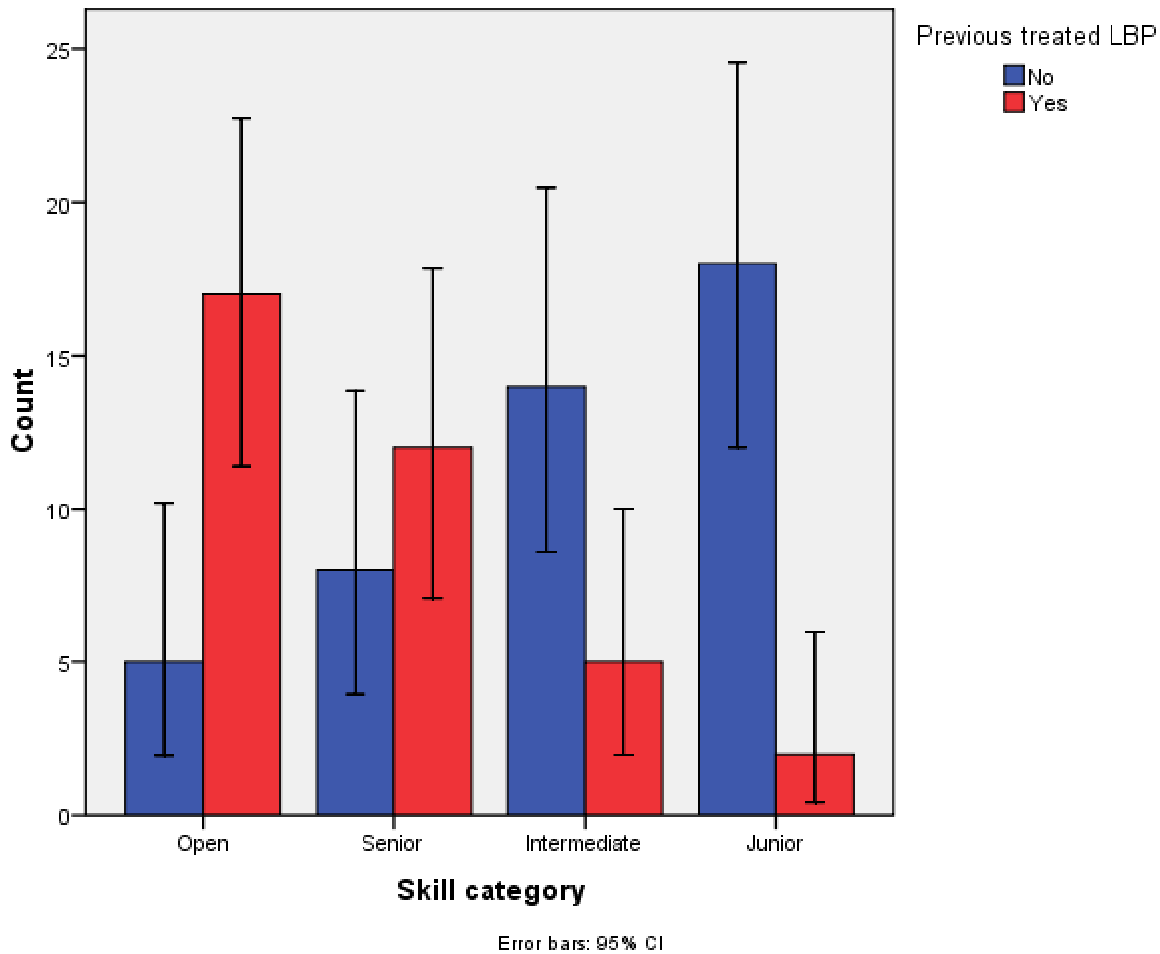

FIGURE 4.1: Previous episode of LBP-Clin within each skill level of shearers

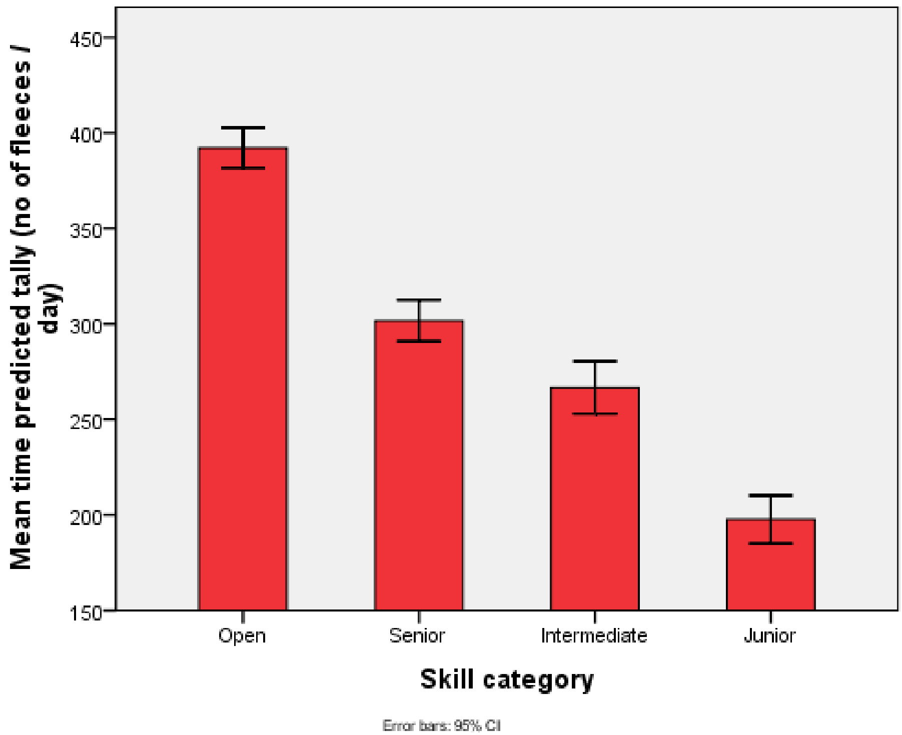

FIGURE 4.2: Daily predicted tally and 95%CI within each skill level of shearers

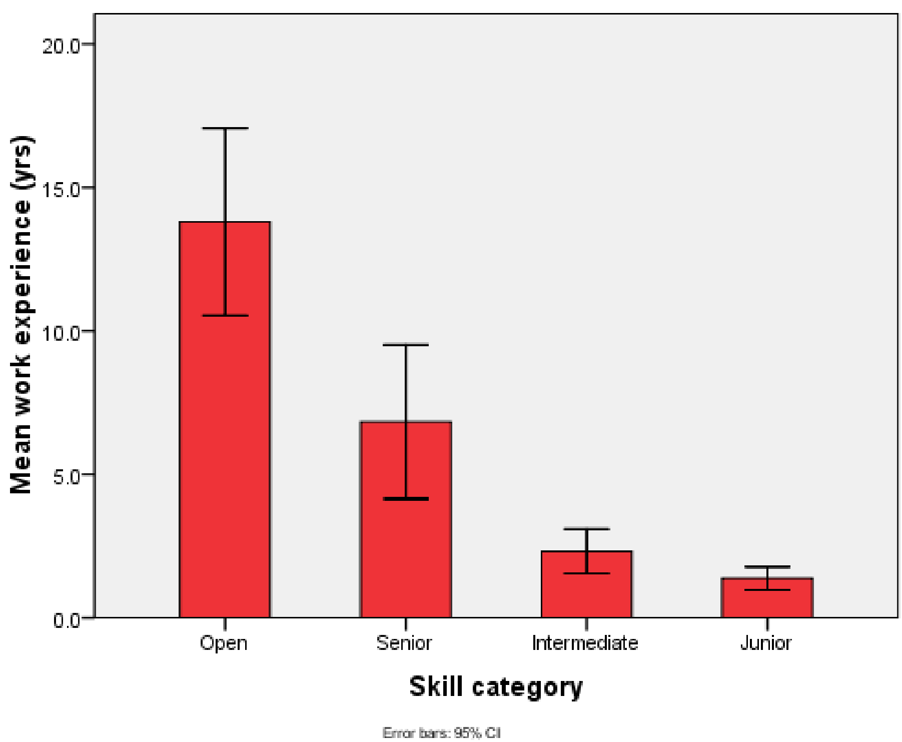

FIGURE 4.3: Years of work experience and 95%CI within each skill level of shearers.

4.2.1 Cumulative and peak forces in shearers

The cumulative lumbo-sacral forces of interest in this study are: cumulative compression (CC), cumulative force weighted compression (CFWC), cumulative joint anterior shear (CJAS), cumulative joint anterior reaction shear (CJARS) and cumulative extensor moment (CEM). The peak forces of interest for this study are: peak compression (PC), peak joint anterior shear (PJAS), peak joint anterior reaction shear (PJARS) and peak extensor moment (PEM). The group mean (±SD), range and 95% confidence interval (CI) values for the shearers is summarised in TABLE 4.4.

As previously mentioned in section 3.10 of the methodology, data analysis for shearers was carried out in two parts due to the catch and drag phase not being captured with the shearing phase during the competition. For the cumulative force calculation, cumulative forces during catch and drag and during shearing were simply added. However for peak forces, the results are presented in two segments: peak forces during shearing and peak forces during catch and drag phase.

TABLE 4.4: Summary of cumulative and peak forces in sheep shearers

	Mean (±SD)	Range	95% CI
Cumulative Forces			
Cumulative compression (MN.s)	82.6 (16.0)	58.7 to 141.3	79.1 to 86.1
Cumulative force weighted compression (MN.s)	84.8 (17.9)	59.2 to 162.1	80.9 to 88.7
Cumulative joint anterior shear (MN.s)	5.4 (0.8)	4.0 to 7.5	5.2 to 5.5
Cumulative joint anterior reaction shear (MN.s)	11.8 (1.9)	8.4 to 18.0	11.4 to 12.2
Cumulative extensor moment (MNm.s)	4.2 (0.8)	2.8 to 6.8	4.0 to 4.4
Peak Forces			
Peak compression (N)	3828.7 (764.2)	2710.1 to 6865.9	3662.3 to 3995.1
Peak joint anterior shear (N)	230.0 (27.3)	185.1 to 314.9	224.1 to 234.0
Peak joint anterior reaction shear (N)	458.3 (61.2)	351.6 to 667.1	444.9 to 471.6
Peak extensor moment (Nm)	185.1 (28.8)	137.0 to 227.8	178.8 to 191.3
Peak Catch and Drag Forces			
Peak compression (N)	4265.3 (755.6)	2830.4 to 5833.9	4100.8 to 4429.4
Peak joint anterior shear (N)	694.6 (37.5)	551.4 to 842.9	686.4 to 702.8
Peak joint anterior reaction shear (N)	698.2 (34.2)	634.4 to 842.9	690.8 to 705.7
Peak extensor moment (Nm)	189.2 (24.6)	133.6 to 278.5	183.8 to 194.5

4.2.2 a Cumulative and peak forces in sheep shearers based on skill level

The mean (±SD), range and 95% CI for CC, CFWC, CJAS, CJARS, CEM, PC, PJAS, PJARS and PEM forces for each skill level of shearers are summarised in TABLE 4.5.

TABLE 4.5: Cumulative and peak forces during shearing within each skill level of shearers

		Open	Senior	Intermediate	Junior
Cumulative Forces					
Compression (MN.s)	Mean (±SD)	79.2 (15.9)	79.7 (13.9)	86.6 (18.0)	85.5 (15.9)
	Range	58.7 to 121.5	62.1 to 111.6	62.7 to 141.3	61.6 to 113.9
	95% CI	72.1 to 86.3	73.2 to 86.2	77.9 to 95.2	78.2 to 93.0
Force weighted compression (MN.s)	Mean (±SD)	82.9 (17.3)	81.3 (14.8)	89.0 (22.1)	86.5 (17)
	Range	59.2 to 128.9	62.4 to 115.7	63.2 to 162.1	61.6 to 114
	95% CI	75.2 to 90.6	74.3 to 88.2	78.4 to 99.7	78.6 to 94.5
Joint anterior shear (MN.s)	Mean (±SD)	5.3 (0.8)	5.4 (0.7)	5.2 (0.9)	5.5 (0.8)
	Range	4.0 to 7.0	4.3 to 6.9	5.0 to 7.5	4.4 to 7.4
	95% CI	5.0 to 5.7	5.1 to 5.7	4.8 to 5.6	5.1 to 5.9
Joint anterior reaction shear (MN.s)	Mean (±SD)	11.4 (2.0)	11.7(1.7)	12.0 (2.1)	12.3 (2.0)
	Range	8.4 to 16.5	9.3 to 15.5	9.3 to 18.0	9.8 to 16.4
	95% CI	10.5 to 12.3	10.9 to 12.5	11.0 to 13.0	11.3 to 13.2
Extensor moment (Nm)	Mean (±SD)	4.0 (0.8)	4.1 (0.7)	4.4 (0.8)	4.4 (0.8)
	Range	2.8 to 6.1	3.1 to 5.6	3.1 to 6.8	3.2 to 5.9
	95% CI	3.6 to 4.3	3.8 to 4.4	4.0 to 4.8	4.0 to 4.8
Peak shearing forces					
Compression (N)	Mean (SD)	3721.0 (680.1)	3656.2 (705.5)	4076.4 (915.0)	3884.2(739.7)
	Range	2746.5to5246.9	2710.1 to 5343.7	2778.4 to6869.5	2789.2 to 5350.4
	95% CI	3419.5to4022.5	3326.0 to 3986.4	3635.4 to4517.5	3538.0 to 4230.4
Joint anterior shear (N)	Mean (±SD)	233.2 (25.9)	232.4 (25.9)	225.8 (33.3)	228.2 (25.2)
	Range	196.1 to 286.9	189.2 to 293.1	185.1 to 314.9	188.0 to 286.8
	95% CI	221.7 to 244.7	220.3 to 244.6	209.8 to 241.9	216.4 to 239.9
Joint anterior reaction shear (N)	Mean (±SD)	456.8 (57.8)	459.9 (60.8)	465.3 (72.1)	451.5 (58.0)
	Range	377.9 to 577.7	367.4 to 604.0	351.6 to 667.1	377.9 to 577.7
	95% CI	431.1 to 482.4	431.5 to 488.4	430.6 to 500.1	424.3 to 478.7
Extensor moment (Nm)	Mean (±SD)	184.3 (28.3)	187.4 (29.8)	191.3 (31.3)	180.4 (26.7)
	Range	140.1 to243.8	142.8 to 253.1	137.5 to 277.8	137.0 to 233.2
	95% CI	171.7 to 196.8	170.8 to 198.7	176.2 to 206.4	167.9 to 192.9

i. Cumulative forces during sheep shearing:

The mean (95% CI) CC, CFWC, CJAS, CJARS and CEM forces in open, senior, intermediate and junior shearers are presented graphically in figures 4.4 to 4.8.

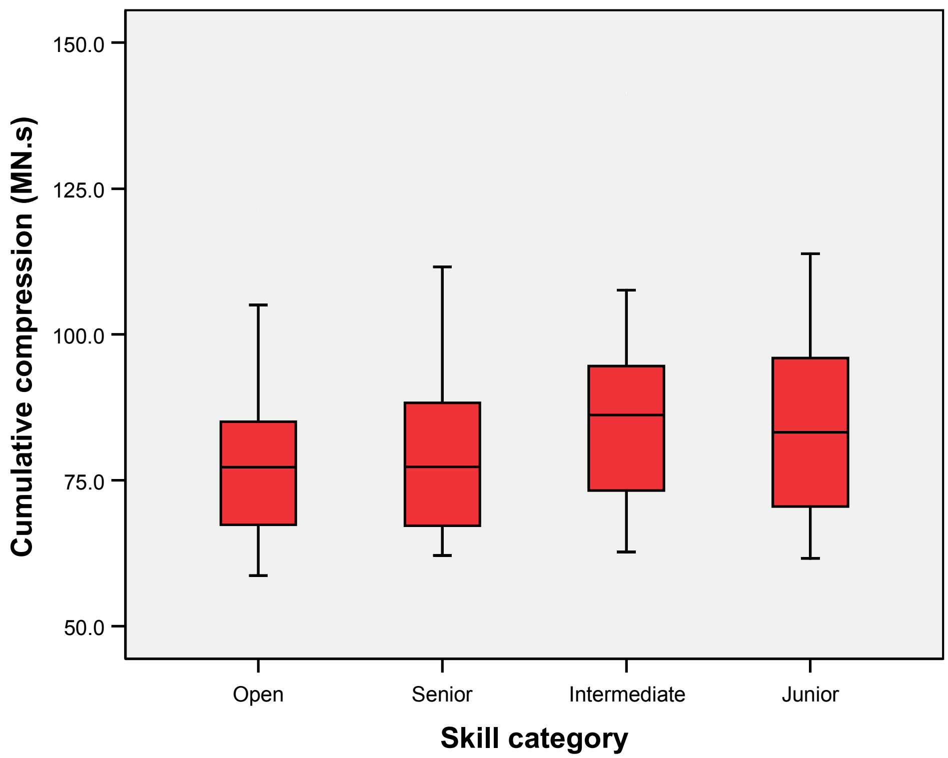

FIGURE 4.4: Comparative cumulative compression of shearers within each skill level.

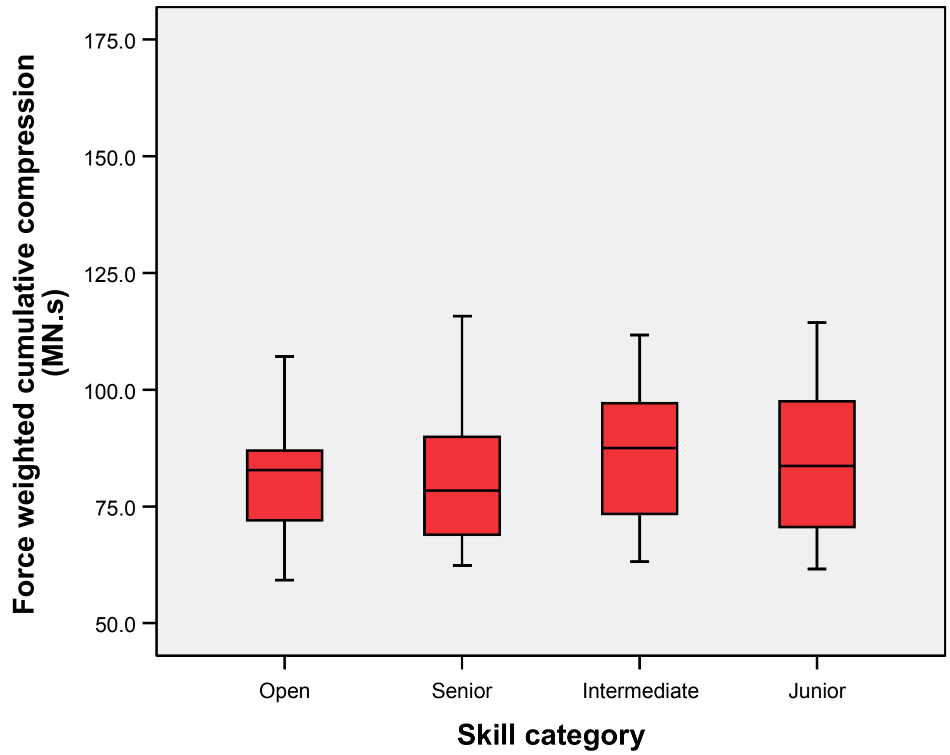

FIGURE 4.5: Comparative force weighted cumulative compression in shearers within each skill level.

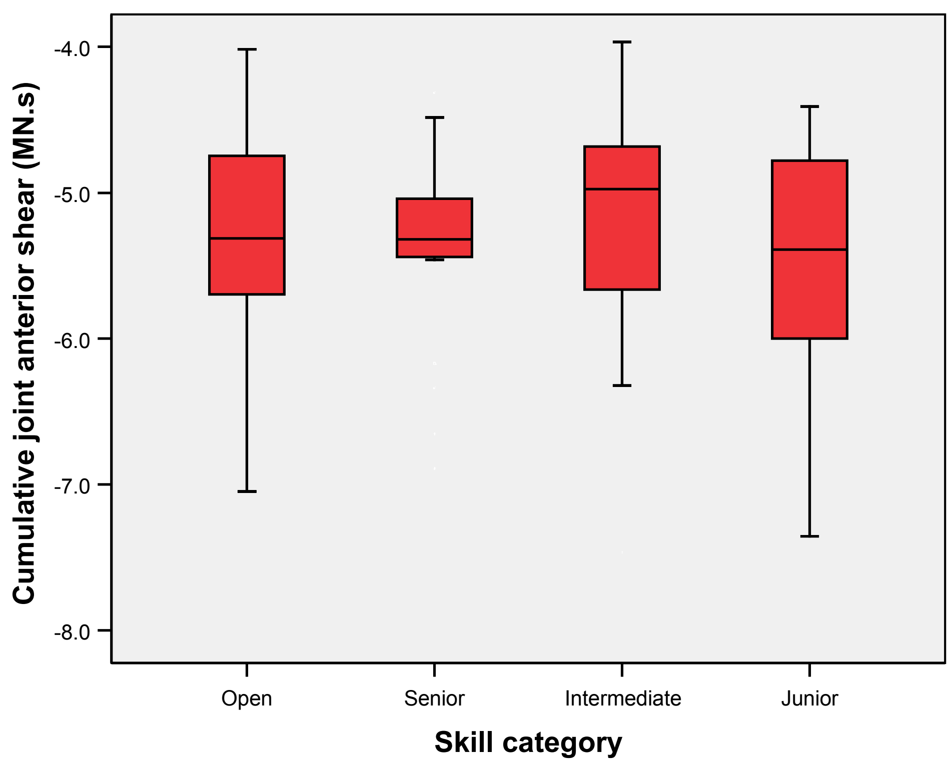

FIGURE 4.6: Comparative cumulative joint anterior shear in shearers within each skill level.

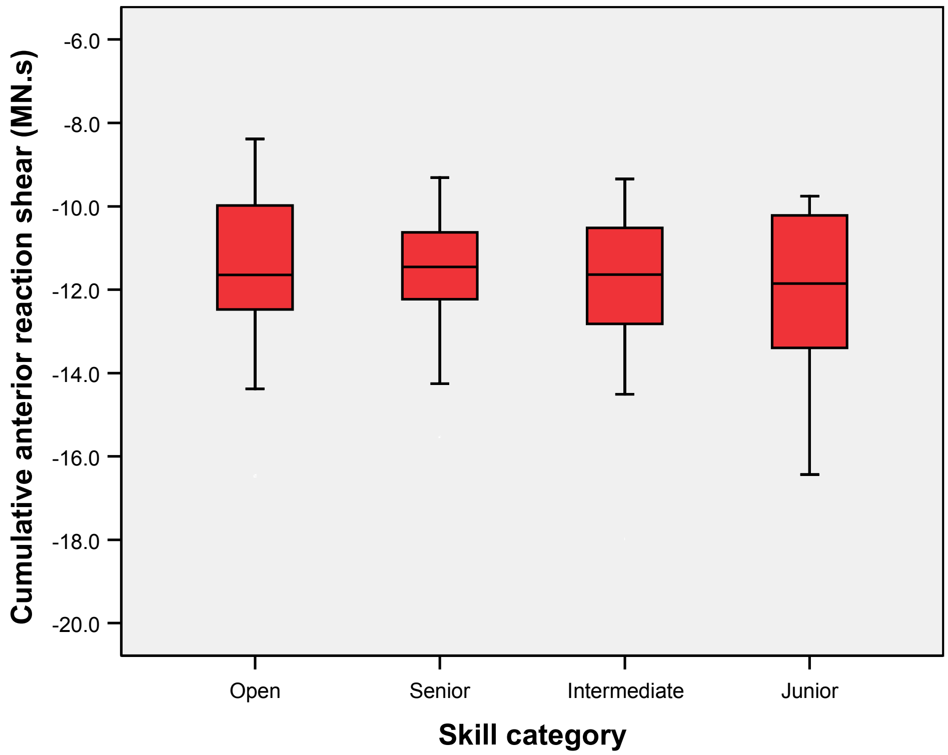

FIGURE 4.7: Comparative cumulative anterior reaction shear in shearers within each skill level.

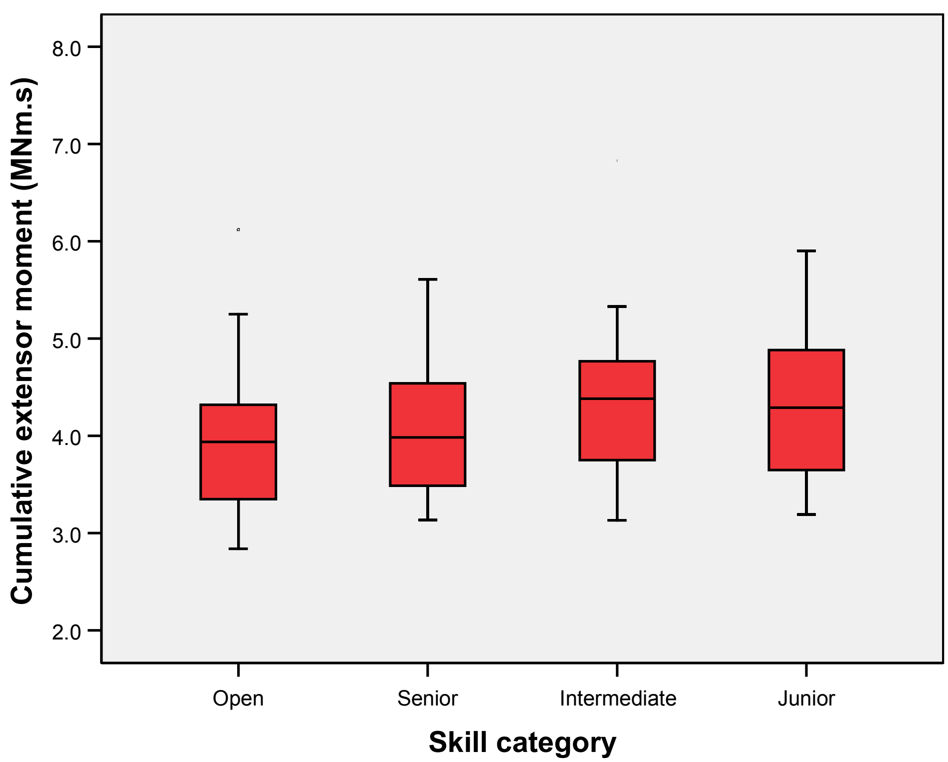

FIGURE 4.8: Comparative cumulative extensor moment in shearers within each skill level.

ii. Peak forces during sheep shearing:

The mean (95% CI) PC, PJAS, PJARS, PEM force generated during shearing in open, senior, intermediate and junior shearers is also presented graphically in figures 4.9 to 4.12.

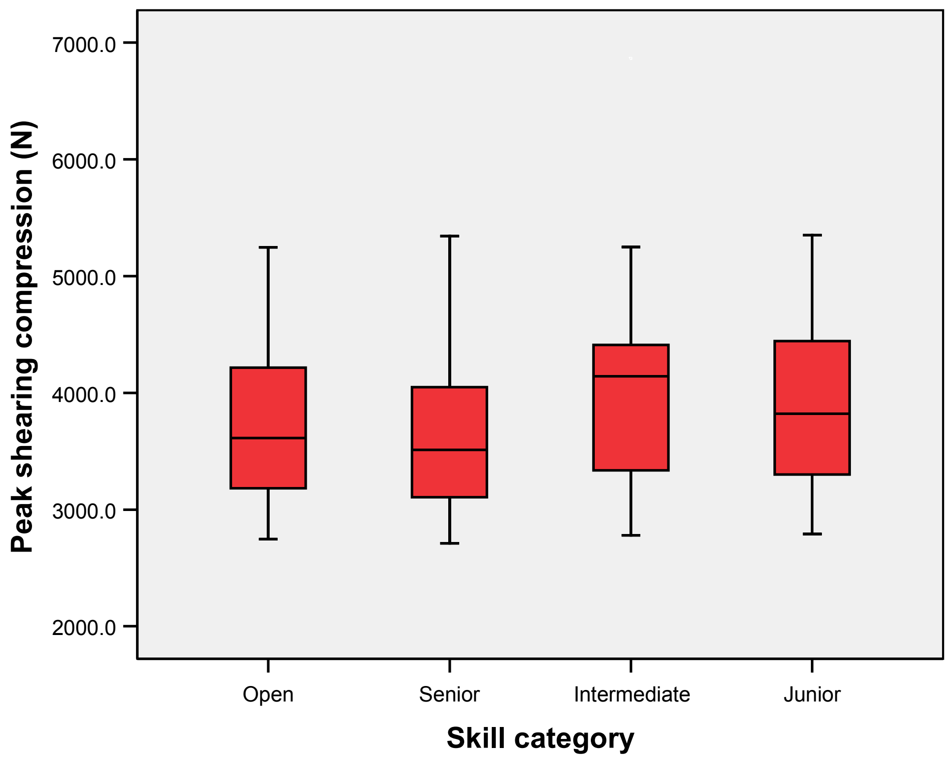

FIGURE 4.9: Comparative peak shearing compression in shearers within each skill level.

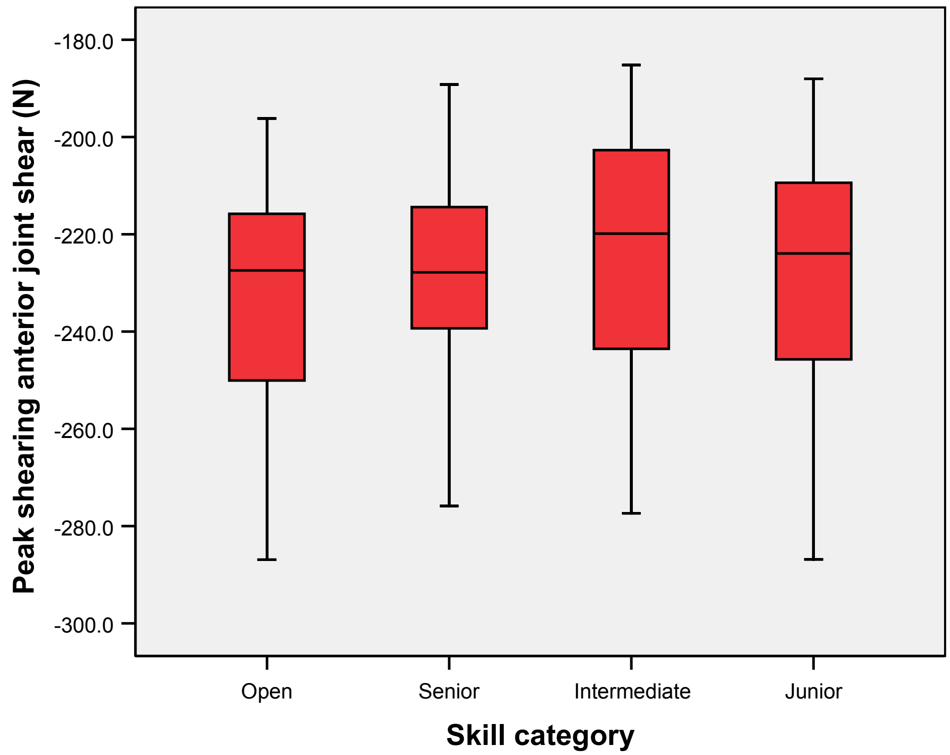

FIGURE 4.10: Comparative peak shearing anterior joint shear in shearers within each skill level.

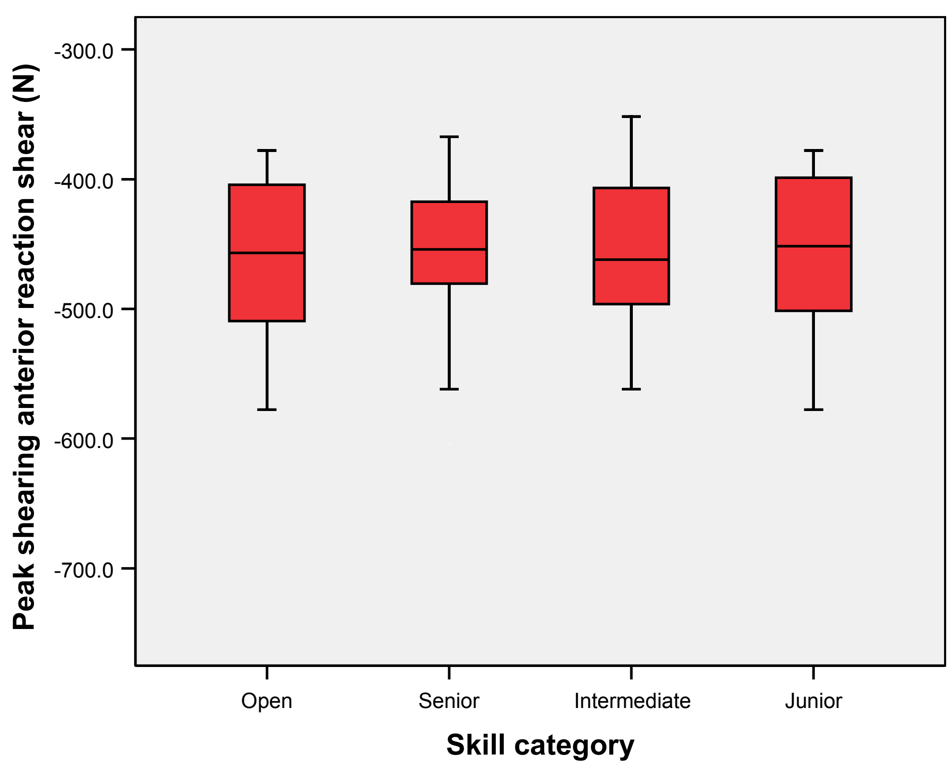

FIGURE 4.11: Comparative peak shearing anterior reaction shear in shearers within each skill level.

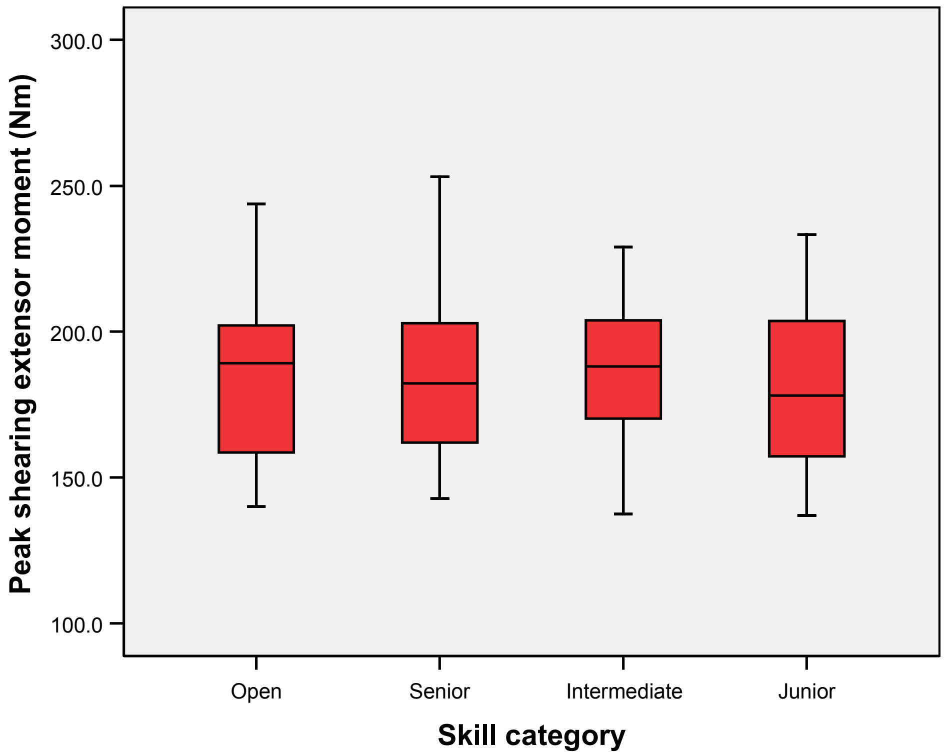

FIGURE 4.12: Comparative peak shearing extensor moment in shearers within each skill level.

iii. Peak catch and drag forces

Similarly the mean (95% CI) PC, PJAS, PJARS, PEM forces during the catch and drag forces for the open, senior, intermediate and junior shearers was is presented through from figures 4.13 to 4.16.

TABLE 4.6: Peak catch and drag forces (N) within each skill level of shearers

Peak Catch and Drag Forces					
		Open	**Senior**	**Intermediate**	**Junior**
Compression (N)	Mean (±SD)	4096.2 (687.2)	4581.6 (737.7)	4591.3 (759.3)	3825.6(585.9)
	Range	2830.4 to 5746.0	3316.2 to5706.1	3422.6 to 5833.9	3089.6 to5111.2
	95% CI	3791.5 to 4400.9	4236.4 to 4926.9	4225.3 to 4957.3	3551.4 to4099.9
Joint anterior shear (N)	Mean (±SD)	684.2 (42.1)	697.9 (34.0)	704.1 (43.0)	693.7 (28.8)
	Range	551.4 to 765.5	652.8 to 788.3	645.0 to 842.9	658.1 to 765.5
	95% CI	665.5 to 702.9	682.0 to 713.8	683.4 to 724.8	680.2 to 707.2
Joint anterior reaction shear (N)	Mean (±SD)	695.3 (32.6)	700.0 (32.8)	704.2 (43.0)	694.0 (29.2)
	Range	634.4 to 765.5	652.8 to 788.3	645.0 to 842.9	658.1 to 765.5
	95% CI	680.9 to 709.8	684.7 to 715.4	683.5 to 724.9	680.3 to 707.6
Extensor moment (Nm)	Mean (±SD)	188.3 (20.4)	197.9 (25.9)	194.2 (25.9)	176.6 (22.6)
	Range	152.3 to 226.9	168.0 to 278.5	140.4 to 251.1	133.6 to 215.1
	95% CI	179.2 to 197.3	185.8 to 210	181.7 to 206.7	166.0 to 187.2

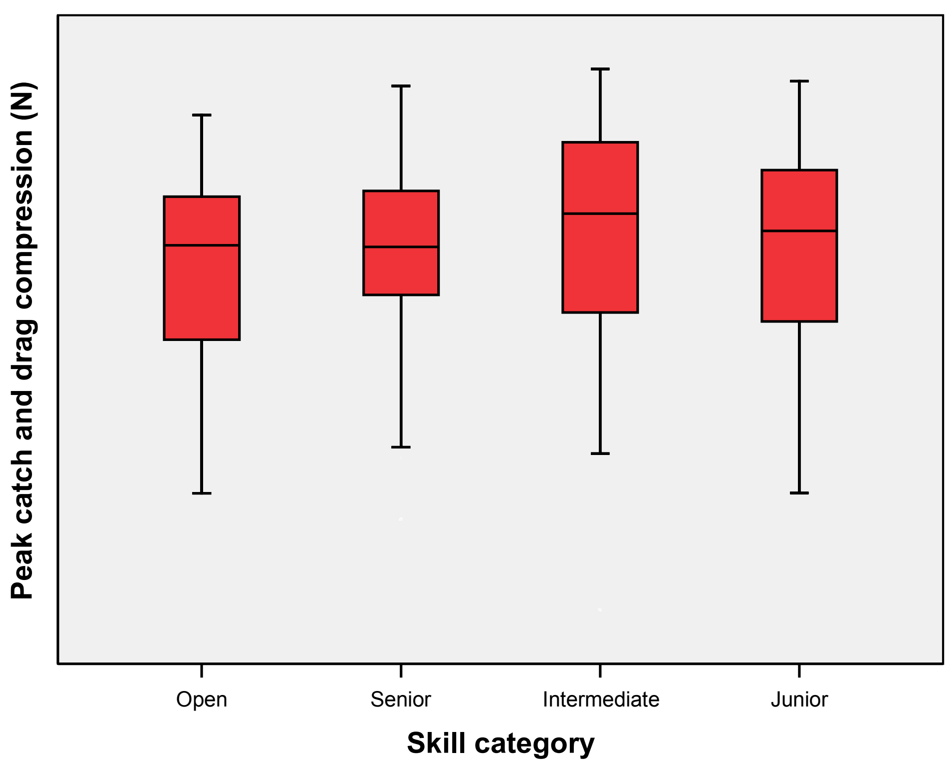

FIGURE 4.13: Comparative peak catch and drag compression in shearers within each skill levels.

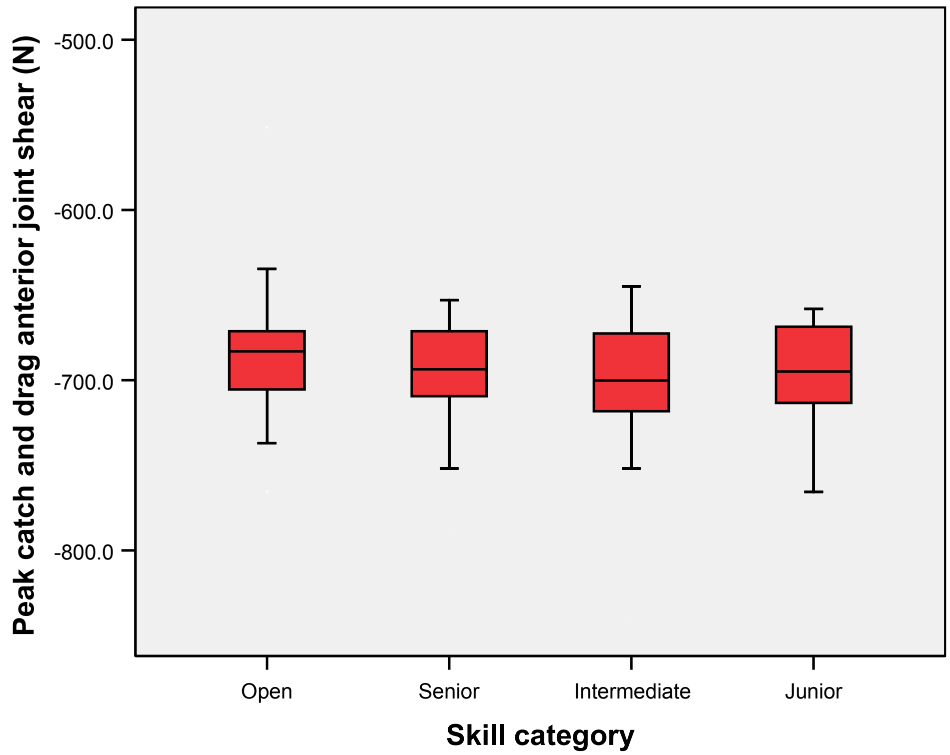

FIGURE 4.14: Comparative peak catch and drag joint anterior shear within each skill level.

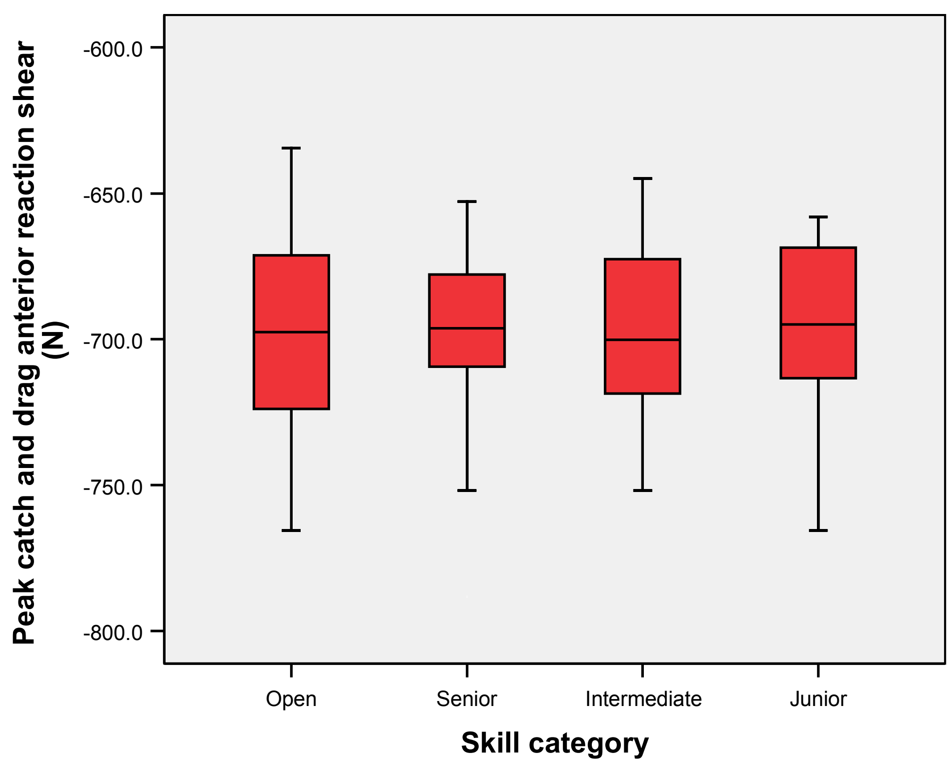

FIGURE 4.15: Comparative peak catch and drag reaction anterior shear within each skill level.

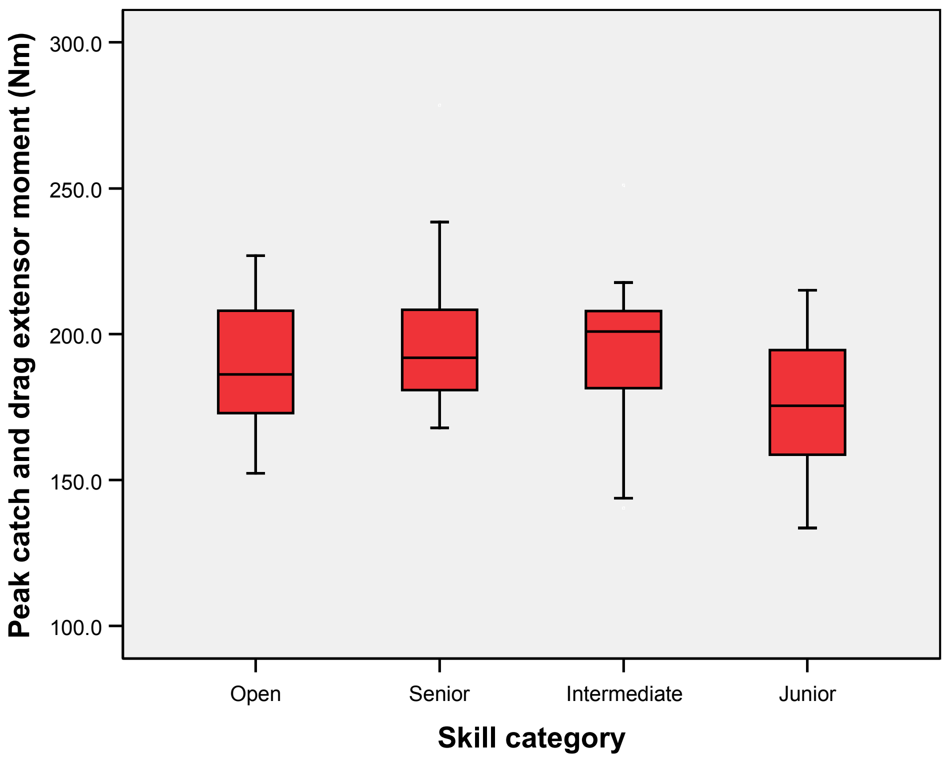

FIGURE 4.16: Comparative peak catch and drag extensor moment within each skill level.

4.2.2b Influence of skill on cumulative and peak forces in sheep shearers

The result of this analysis is presented in TABLE 4.7 and results show that in majority skill does not influence CC, CFWC, CJAS, CJARS, PC, PJAS, PJARS, PEM as well as peak catch and drag JAS and JARS. TABLE 4.7 shows the actual difference (β), p-value, 95% CI of the actual difference and the correlation co-efficient (R^2). Peak catch and drag compression is only influenced by senior, intermediate and junior skill level shearers.

TABLE 4.7: Univariate linear regression analysis of cumulative and peak forces in shearers

		β	P value	95% CI	R^2 value
Cumulative forces					
Compression (MN.s)	Juniors	3.8	0.353	-4.36 to 12.70	0.011
	Intermediate	5.17	0.220	-3.16 to 13.50	0.019
	Senior	-3.90	0.347	-12.12 to 4.31	0.011
	Open	-4.65	0.247	-12.59 to 3.29	0.017
Force weighted compression (MN.s)	Junior	2.26	0.627	-6.94 to 11.46	0.003
	Intermediate	5.47	0.245	-3.82 to 14.77	0.017
	Senior	-4.68	0.312	-13.84 to 4.47	0.013
	Open	-2.69	0.550	-11.60 to 6.22	0.005
Joint anterior shear (MN.s)	Junior	-0.20	0.322	-0.59 to 0.20	0.012
	Intermediate	0.19	0.339	-0.21 to 0.60	0.012
	Senior	-0.05	0.796	-0.45 to 0.35	0.001
	Open	0.06	0.764	-0.33 to 0.44	0.001
Joint anterior reaction shear (MN.s)	Junior	-0.58	0.251	-1.57 to 0.42	0.017
	Intermediate	-0.21	0.690	-1.22 to 0.84	0.002
	Senior	0.18	0.729	-0.83 to 1.18	0.002
	Open	0.56	0.248	-0.40 to 1.53	0.017
Extensor moment (MNm.s)	Junior	-0.25	0.235	-0.16 to 0.66	0.018
	Intermediate	0.26	0.220	-0.16 to 0.68	0.019
	Senior	-0.15	0.479	-0.56 to 0.27	0.006
	Open	-0.33	0.101	-0.72 to 0.07	0.034
Peak forces					
Compression (N)	Juniors	73.77	0.710	-320.27 to 467.81	0.002
	Intermediate	323.68	0.107	-71.08 to 718.44	0.033
	Senior	-229.0	0.247	-620.03 to 162.04	0.017
	Open	-147.85	0.442	-528.77 to 233.07	0.007
Joint anterior shear (N)	Junior	2.48	0.727	-11.60 to 16.67	0.002
	Intermediate	5.49	0.447	-8.80 to 19.78	0.007
	Senior	3.20	0.652	-17.28 to 10.88	0.003
	Open	-4.31	0.531	17.94 to 9.32	0.005
Joint anterior reaction shear (N)	Juniors	8.97	0.573	-22.57 to 40.49	0.004
	Intermediate	-9.26	0.567	-41.34 to 22.83	0.004
	Senior	-2.21	0.890	-33.80 to 29.38	0.000
	Open	2.05	0.894	-28.58 to 32.68	0.000
Extensor moment (Nm)	Juniors	-6.19	0.407	-20.96 to 8.59	0.009
	Intermediate	8.14	0.283	-6.86 to 23.13	0.015
	Senior	-0.48	0.949	-15.32 to 14.36	0.000
	Open	-1.11	0.878	-15.50 to 13.27	0.000
Peak forces - Catch & drag					
Compression (N)	*Juniors	583.9	0.000	216.5 to 951.3	0.112
	*Intermediate	425.8	0.030	40.5 to 811.0	0.058
	*Senior	420.0	0.030	41.5 to 798.4	0.058
	Open	-232.30	0.220	-606.76 to 142.17	0.019

Joint anterior shear (N)	Juniors	1.22	0.901	-18.13 to 20.57	0.00
	Intermediate	-7.74	0.208	-25.61 to 10.12	0.020
	Senior	-4.41	0.651	-23.73 to 14.92	0.003
	Open	14.28	0.128	-4.21 to 32.76	0.029
Joint anterior reaction shear (N)	Juniors	5.68	0.522	-11.91 to 23.27	0.005
	Intermediate	-7.74	0.391	-25.61 to 10.12	0.009
	Senior	-2.41	0.787	-20.04 to 15.23	0.001
	Open	3.95	0.647	-13.13 to 21-.03	0.003
Extensor moment (Nm)	Juniors	16.7	0.086	4.5 to 28.8	0.086
	Intermediate	6.61	0.309	- 6.24 to 19.47	0.013
	Senior	11.57	0.068	-0.87 to 24.02	0.042
	Open	-1.20	0.847	-13.52 to 11.13	0.00

P-value is considered to be significant at 0.05 level

4.3 Correlation analysis of independent variables for shearers

Prior to carrying out a multivariate linear or logistic regression analysis to determine the co-variate (combined models) effects on dependent variables it was considered necessary to carry out a correlation analysis between independent variables in order to determine the likelihood of collinearity existing between variables. Demonstration of significant levels of collinearity would confound any intended multivariate regression analysis and likely invalidate such an analysis.

Correlation analysis was carried out to determine relationships between age, BMI, prevalence of LBP-Clin, work experience, tally and skill in shearers. TABLE 4.8 shows the Pearson's correlation coefficient (r) and p-values for all the variables analysed.

The results show that BMI had no statistically significant association with age ($r = 0.058$, $p = 0.609$), prevalence of LBP-Clin ($r = 0.087$, $p = 0.439$), work experience ($r = 0.093$, $p = 0.411$), tally ($r = 0.003$, $p = 0.978$) and skill ($r = 0.028$, $p = 0.806$). Age demonstrated a statistically significant correlation with LBP-Clin ($r = 0.429$, $p < 0.001$), work experience($r = 0.902$, $p < 0.001$), tally ($r = 0.600$, $p < 0.001$) and skill ($r = 0.639$, $p < 0.001$). Prevalence of LBP-Clin also had a statistically significant association with age ($r = 0.429$, $p < 0.001$), work experience ($r = 0.487$, $p < 0.001$) and tally ($r = 0.526$, $p < 0.001$). Work experience had a statistically significant association with age ($r = 0.902$, $p < 0.001$), prevalence of LBP-Clin ($r = 0.487$, $p < 0.001$), tally ($r = 0.669$, $p < 0.001$) and skill ($r = 0.69$, $p < 0.001$). Skill has statistically significant associations with age (r = 0.64, p < 0.001), work experience (r = 0.692, p < 0.001) and tally(r = 0.932, p < 0.001).

TABLE 4.8: Correlations analysis of independent variables in shearers

		Age (yrs)	BMI (kg/m²)	Prevalence of LBP (%)	experience (yrs)	Tally (sheep/ day)	Skill
Age (yrs)	r p value	1	0.058 0.609	0.429* <0.001	0.902* <0.001	0.600* <0.001	0.639* <0.001
BMI (kg/m²)	r p value	0.058 0.609	1	0.087 0.439	0.093 0.411	0.003 0.978	0.028 0.806
Prevalence of LBP (%)	r p value	0.429* <0.001	0.087 0.439	1	0.487* <0.001	0.526* 0.000	0.536* <0.001
Experience (yrs)	r p value	0.902* <0.001	0.093 0.411	0.487* 0.00	1	0.669* <0.001	0.692* <0.001
Tally (sheep/ day)	r p value	0.600* <0.001	0.003 0.978	0.526* <0.001	0.669* <0.001	1	0.932* <0.001
Skill	r p value	0.639* <0.001	0.028 0.806	0.536* <0.001	0.692* <0.001	0.932* <0.001	1

*** = Correlation is significant at the 0.01 levels**

The results showed that BMI had no significant associations with age, LBP-Clin, work experience, tally and skill. Age had a highly statistically significant association with work experience however had a moderate association with tally and skill. Age had a low yet statistically significant association with LBP-Clin. These statistically significant correlations negated the use of these variables as co-variates in the models and therefore multi-variate regression analysis was not undertaken.

Therefore in order to determine the influence of age, work experience, tally and skill on cumulative and peak forces were thus carried out by using univariate linear regression analysis.

4.4 Univariate linear regression analysis

Univariate linear regression was carried out for shearers where age, LBP-Clin, work experience, tally and skill were each singularly explored for a relationship with the dependent cumulative and peak loads variables. The significance (p-value) level was kept at 0.05. The results for this analysis are presented in tables below where a cross (X) represents no statistically significant result and a tick (✓) represents a statistically significant result.

4.4.1 Influence of dependent variables on cumulative and peak loads

The results for univariate linear regression determining the influence of age, LBP-Clin, work experience and tally on cumulative and peak loads in shearers is presented in TABLE 4.9. TABLE 4.10 shows the actual difference (β), p-value, 95% CI of the actual difference and the correlation co-efficient (R^2).

Peak catch and drag extensor moment is influenced by age and tally with R^2 values of 0.053 and 0.038. The mean difference for age and tally are 0.69Nm and 0.06Nm.

TABLE 4.9: Univariate linear regression analysis of cumulative and peak forces in shearers

	Age (yrs)	**LBP-**Clin **(%)**	**Experience (yrs)**	**Tally (sheep/day)**
Cumulative forces				
Compression (N)	X	X	X	X
Force weighted compression (MN.s)	X	X	X	X
Joint anterior shear (MN.s)	X	X	X	X
Joint anterior reaction shear (MN.s)	X	X	X	X
Extensor moment (Nm)	X	X	X	X
Peak forces				
Compression (N)	X	X	X	X
Joint anterior shear (MN.s)	X	X	X	X
Joint anterior reaction shear (MN.s)	X	X	X	X
Extensor moment (Nm)	X	X	X	X
Peak forces – catch and drag				
Compression (N)	X	X	X	X
Joint anterior shear (MN.s)	X	X	X	X
Joint anterior reaction shear (MN.s)	X	X	X	X
Extensor moment (Nm)	✓	✓	X	X

P-value was considered to be significant at 0.05 level, X = not significant, ✓ =significant

TABLE 4.10: Results of statistically significant univariate linear regression analysis of cumulative forces with independent variables in shearers

		β	P value	95% CI	R^2 value
Cumulative extensor moment (Nm)					
	Age	0.69	0.038	0.04 to 1.34	0.053
	LBP-Clin	10.9	0.048	0.09 to 21.6	0.048

P-value is considered to be significant at 0.05 level

4.5 Influence of LBP-Clin and skill on cumulative and peak forces

In order to determine the influence of the interaction between LBP-Clin and skill on cumulative and peak loads, four new combined variables were created where data for the four levels of skill (0 to 3) and LBP-Clin (0 and 1) were multiplied by each other in order to determine interactions. A multivariate stepwise linear regression was then carried out to determine the effect of these combined variables on cumulative and peak loads. As skill and LBP-Clin demonstrated a statistically significant correlation with each other (R^2 = 0.54; p < 0.001) collinearity diagnostics were used to ensure results were within acceptable statistical thresholds. [134, 135]

The results showed no statistically significant interaction of cumulative and peak loads with skill, LBP-Clin and the combination of skill and LBP-Clin (TABLE 4.11).The influence of skill and LBP-Clin on peak catch and drag forces also showed no statistically significant interaction of cumulative and peak loads with skill, LBP-Clin and the combination of skill and LBP-Clin. (TABLE 4.11)

4.11: Results of multivariate linear regression determining the combined influence of LBP-clin and skill on cumulative and peak loads in shearers

		β	P value	95% CI	R^2 value
Cumulative forces					
Compression (MN.s)					0.118
	Intermediate	9.33	0.089	-1.46 to 20.12	
	Senior	6.08	0.413	-8.63 to 20.80	
	Skill	5.46	0.043	0.17 to 10.74	
	LBP-Clin	17.56	0.139	-5.82 to 40.93	
	Intermediate*LBP-Clin	-21.61	0.135	-50.13 to 6.91	
	Senior*LBP-Clin	-16.31	0.239	-43.72 to 11.10	
	Open*LBP-Clin	-2.23	0.875	30.54 to 26.07	
Force weighted compression (MN.s)					0.106
	Intermediate	11.12	0.072	-1.00 to	
	Senior	5.94	0.476	-10.58 to 22.46	
	Skill	5.01	0.097	-0.92 to 10.95	
	LBP-Clin	19.20	0.149	-7.05 to 45.45	
	Intermediate*LBP-Clin	-25.63	0.115	-57.66 to 6.40	
	Senior*LBP-Clin	17.90	0.250	-48.68 to 12.88	
	Open*LBP-Clin	-1.98	0.901	-33.77 to 29.80	
Joint anterior shear (MN.s)					0.101
	Intermediate	0.04	0.889	-0.49 to 0.56	
	Senior	-0.35	0.338	-1.06 to 0.37	
	Skill	-0.22	0.100	-0.47 to 0.04	
	LBP-Clin	-0.98	0.091	-2.11 to 0.16	
	Intermediate*LBP-Clin	0.78	0.265	-0.60 to2.17	
	Senior*LBP-Clin	0.86	0.204	-0.48 to 2.19	
	Open*LBP-Clin	0.26	0.704	-1.11 to 1.64	
Joint anterior reaction shear (MN.s)					0.107
	Intermediate	-0.65	0.327	-1.97 to 0.67	
	Senior	-0.94	0.300	-2.74 to 0.86	
	Skill	-0.70	0.035	-1.34 to -0.05	
	LBP-Clin	-2.31	0.111	-5.16 to 0.55	
	Intermediate*LBP-Clin	2.31	0.189	-1.17 to5.79	
	Senior*LBP-Clin	2.11	0.213	-1.23 to5.46	
	Open*LBP-Clin	0.40	0.820	-3.06 to 3.85	
Extensor moment (MNm.s)					0.131
	Intermediate	0.45	0.101	-0.09 to 0.98	
	Senior	0.39	0.296	-0.35 to 1.12	
	Skill	0.31	0.020	0.05 to 0.58	
	LBP-Clin	0.87	0.142	-0.30 to 2.03	
	Intermediate*LBP-Clin	-1.00	0.166	-2.41 to 0.42	
	Senior*LBP-Clin	-0.81	0.237	-2.18 to 0.55	
	Open*LBP-Clin	-0.09	0.903	-1.49 to 1.32	
Peak forces					
Compression (N)					0.061
	Intermediate	399.78	0.138	-131.96 to 931.25	
	Senior	-79.11	0.828	-803.85 to 645.63	
	Skill	83.25	0.526	-177.08 to 343.58	
	LBP-Clin	337.53	0.561	-813.99 to 1489.05	
	Intermediate*LBP-Clin	-681.72	0.337	-2086.65 to 723.22	
	Senior*LBP-Clin	-251.95	0.711	-1602.22 to 1098.33	
	Open*LBP-Clin	-181.90	0.796	-1576.09 to 1212.28	

Joint anterior shear (N)					0.023
	Intermediate	5.15	0.598	-14.22 to 24.52	
	Senior	3.97	0.765	-22.44to 30.39	
	Skill	1.28	0.790	-8.21 to 10.76	
	LBP-Clin	-2.36	0.911	-44.33 to 39.61	
	Intermediate*LBP-Clin	-4.39	0.865	-55.60 to 46.82	
	Senior*LBP-Clin	-7.54	0.761	-56.76 to 41.68	
	Open*LBP-Clin	0.52	0.984	-50.29 to 51.34	
Joint anterior reaction shear (N)					0.019
	Intermediate	-19.76	0.368	-63.28 to 23.75	
	Senior	-4.42	0.882	-63.75 to 54.92	
	Skill	-2.03	0.850	-23.34 to 19.29	
	LBP-Clin	-23.37	0.623	-117.65 to 70.91	
	Intermediate*LBP-Clin	29.30	0.613	-85.72 to 144.33	
	Senior*LBP-Clin	6.06	0.913	-104.49 to 116.61	
	Open*LBP-Clin	5.68	0.921	-108.47 to 119.83	
Extensor moment (Nm)					0.034
	Intermediate	14.79	0.150	-5.49 to 35.07	
	Senior	4.59	0.742	-23.06 to 32.25	
	Skill	1.09	0.827	-8.84 to 11.03	
	LBP-Clin	14.02	0.527	-29.92 to 57.96	
	Intermediate*LBP-Clin	-19.39	0.473	-73.00 to 34.22	
	Senior*LBP-Clin	-8.54	0.742	-60.07 to 42.99	
	Open*LBP-Clin	-2.99	0.911	-56.19 to 50.21	
Peak forces - Catch & drag					
Compression (N)					0.220
	Intermediate	794.33	0.001	315.26 to 1273.40	
	Senior	879.44	0.009	226.16 to 1532.72	
	Skill	-49.48	0.676	-284.15 to 185.18	
	LBP-Clin	-232.92	0.656	-1270.91 to 805.07	
	Intermediate*LBP-Clin	-152.59	0.811	-1419.01 to 1113.83	
	Senior*LBP-Clin	-176.57	0.773	-1393.72 to 1040.58	
	Open*LBP-Clin	360.79	0.569	-895.94 to 1617.52	
Joint anterior shear (N)					0.071
	Intermediate	-16.36	0.213	-42.29 to 9.58	
	Senior	-4.67	0.793	-40.04 to 30.69	
	Skill	-0.13	0.984	-12.83 to 12.58	
	LBP-Clin	-42.02	0.140	-98.22 to 14.17	
	Intermediate*LBP-Clin	48.12	0.166	-20.44 to 116.67	
	Senior*LBP-Clin	35.33	0.289	-30.56 to 101.22	
	Open*LBP-Clin	48.37	0.161	-19.67 to 116.40	
Joint anterior reaction shear (N)					0.056
	Intermediate	-13.40	0.266	-37.23 to 10.43	
	Senior	-4.57	0.780	-37.07 to 27.92	
	Skill	-0.22	0.970	-11.90 to 11.45	
	LBP-Clin	-41.72	0.112	-93.36 to 9.91	
	Intermediate*LBP-Clin	37.17	0.243	-25.83 to 100.17	
	Senior*LBP-Clin	31.50	0.303	-29.05 to 92.05	
	Open*LBP-Clin	33.64	0.287	-28.87 to 96.16	
Extensor moment (Nm)					0.139
	Intermediate	17.29	0.039	0.88 to 33.70	
	Senior	14.65	0.196	-7.73 to 37.02	
	Skill	-0.03	0.994	-8.07 to 8.01	
	LBP-Clin	2.69	0.881	-32.86 to 38.24	
	Intermediate*LBP-Clin	-0.50	0.982	-43.87 to 42.87	
	Senior*LBP-Clin	8.72	0.678	-32.97 to 50.40	
	Open*LBP-Clin	12.68	0.559	-30.36 to 55.71	

4.6. Wool Handlers

4.6.1 Anthropometric data and work characteristics of wool handlers

Wool handlers in this study had a mean age of 27.6yrs, mean weight of 72.0kg, mean height of 1.65m and mean BMI of 26.3 kg/m^2. The wool handlers had a mean daily working tally (fleeces sorted / day) of 231 fleeces per day and a mean working experience of 9.4 yrs. The prevalence of LBP-Clin in wool handlers was 40% (TABLE 4.12).

TABLE 4.12: Summary of wool handler anthropometric and work characteristics (n=60)

	Age (yrs)	Weight (Kg)	Height (m)	BMI (Kg/m^2)	Tally (fleeces/day)	Prevalence of LBP %)	Experience (yrs)
Mean (± SD)	27.6 (8.7)	72.0 (16.3)	1.65(0.07)	26.3 (5.3)	231 (26)	40	9.4 (7.6)
Range	16 to 47	54 to 130	1.52to1.88	19.1 to 43.4	179 to 288	-	0.1to30.0
95% CI	25.4to29.8	67.9 to76.2	1.64to1.67	24.9to- 27.6	225 to 238	-	7.5 to 11.3

4.6.2a Skill-level based group anthropometric and work characteristics

The anthropometric and work characteristics of wool handlers within each skill category are summarised in TABLE 4.13. The prevalence of LBP-Clin occurring in this sample of wool handlers was 25% (n=5) for the junior, 50% (n=10) for the senior and 45% (n=9) for the open class wool handlers (FIGURE 4.17). The estimated mean fleece handling tally was 218, 217 and 259 fleeces/day for the junior, senior and open wool handlers respectively (FIGURE 4.18). The mean years of work experience was 4.9, 9.3 and 14.2 years for the junior, senior and open wool handlers respectively (FIGURE 4.19).

When comparing a combined category of open and senior wool handlers (1) to the junior wool handlers (0) the OR for LBP-Clin in the more skilled group was 0.37 with a 95% CI of 0.11 to 1.21 and was non-significant ($P < 0.10$).

TABLE 4.13: Summary of the anthropometric and work characteristics within each skill level of wool handlers

	Anthropometric data based on skill levels of wool handlers		
	Junior (20)	**Senior (20)**	**Open (20)**
Mean Age (±SD) (yrs)	22.9 (5.7)	27.9 (7.6)	32.0 (10.0)
Range	17.0 to 40.0	17.0 to 42.0	16.0 to 47.0
Mean Height (± SD) (m)	1.62 (0.06)	1.66 (0.07)	1.68 (0.08)
Range	1.52 to 1.75	1.58 to 1.85	1.54 to 1.88
Mean Weight (± SD) (Kg)	69.8 (14.9)	73.3 (19.8)	73.1 (14.3)
Range	55.0 to 111.0	54.0 to 130	54.0 to 105.0
BMI (± SD) (Kg/m^2)	26.6 (5.6)	26.5 (5.9)	25.8 (4.6)
Range	21.2 to 43.4	20.2 to 43.4	19.1 to 38.5
Years of experience (± SD) (yrs)	4.9 (5.1)	9.3 (6.0)	14.2(8.4)
Range	0.1 to 20.0	2.0 to 20.0	2.0 to30.0
Tally (± SD) (fleece / day)	218 (23)	217 (14)	259 (14)
Range	179 to 265	187 to 252	233 to 288
Prevalence of LBP-Clin (%)	25	50	45

4.6.2b Influence of skill on anthropometric and work characteristics of wool handlers

The influence of skill on independent variables such as age, BMI, work experience, tally and LBP-Clin was explored using linear regression. The results of this analysis show that skill significantly influenced age, work experience and tally with the results presented in TABLE 4.14.

Table 4.14: Influence of skill on independent variables (n = 60)

	Age	BMI	Tally	LBP	Experience
Skill					
β	-0.04	0.01	-0.02	-0.28	-0.06
R^2value	0.184	0.004	0.405	0.028	0.255
P value	0.001	0.622	0.000	0.203	<0.000
95% CI	-0.06 to(-0.02)	-0.03 to 0.05	-0.03 to (-0.01)	-0.71 to 0.15	-0.08 to (-0.03)

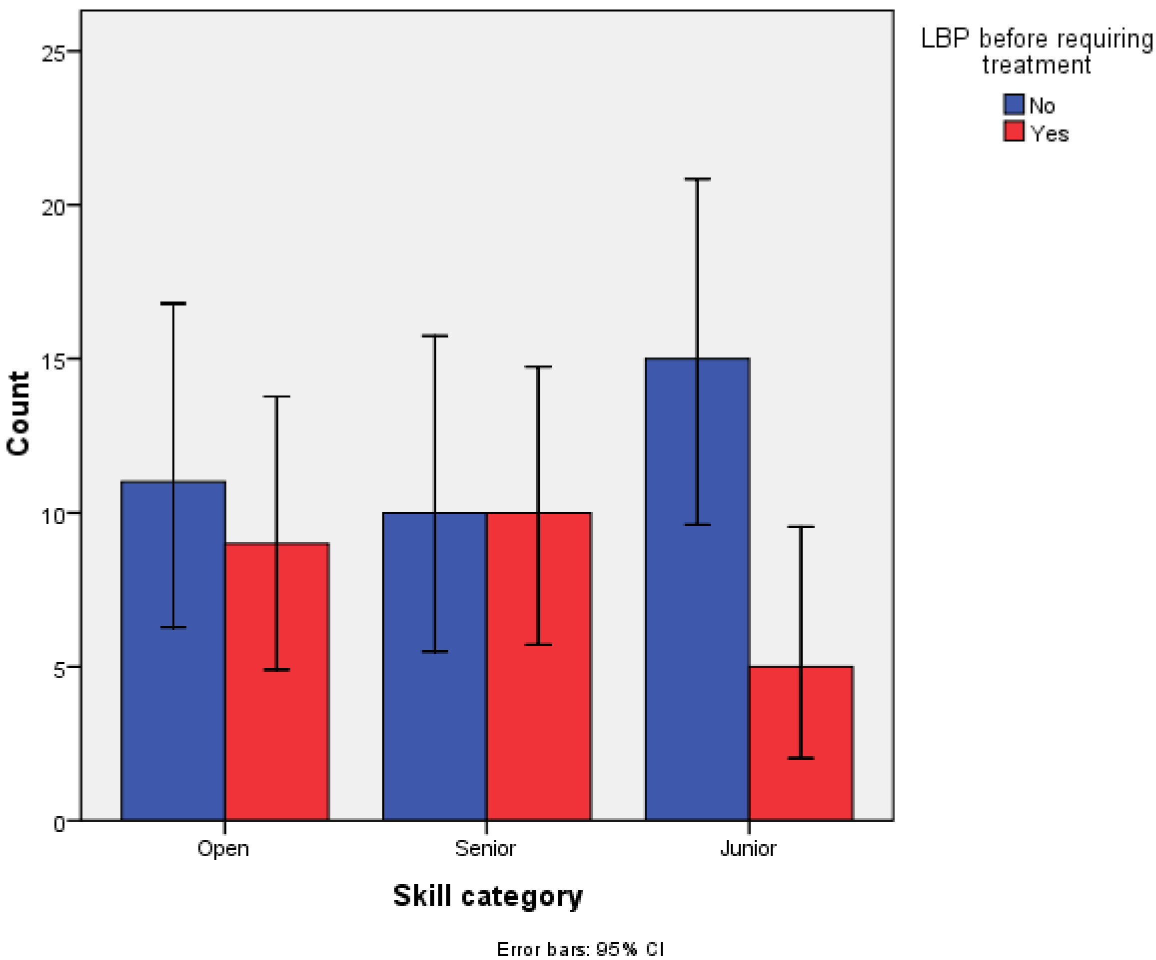

FIGURE 4.17: Previous episodes of LBP-Clin within each skill level of wool handlers

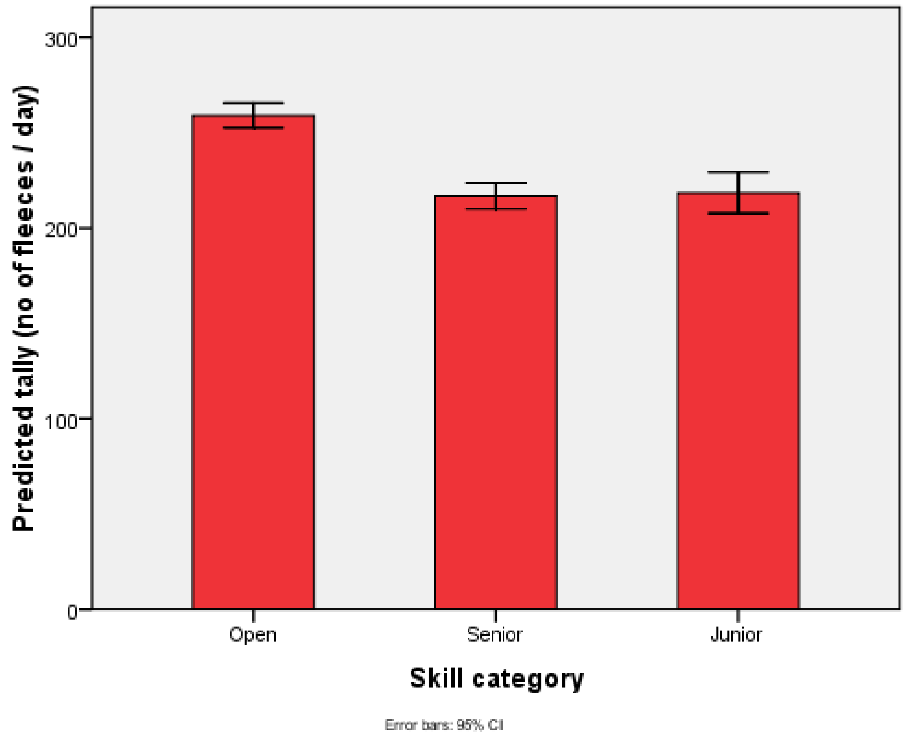

FIGURE 4.18: Daily predicted tally and 95% CI within each skill level of wool handlers

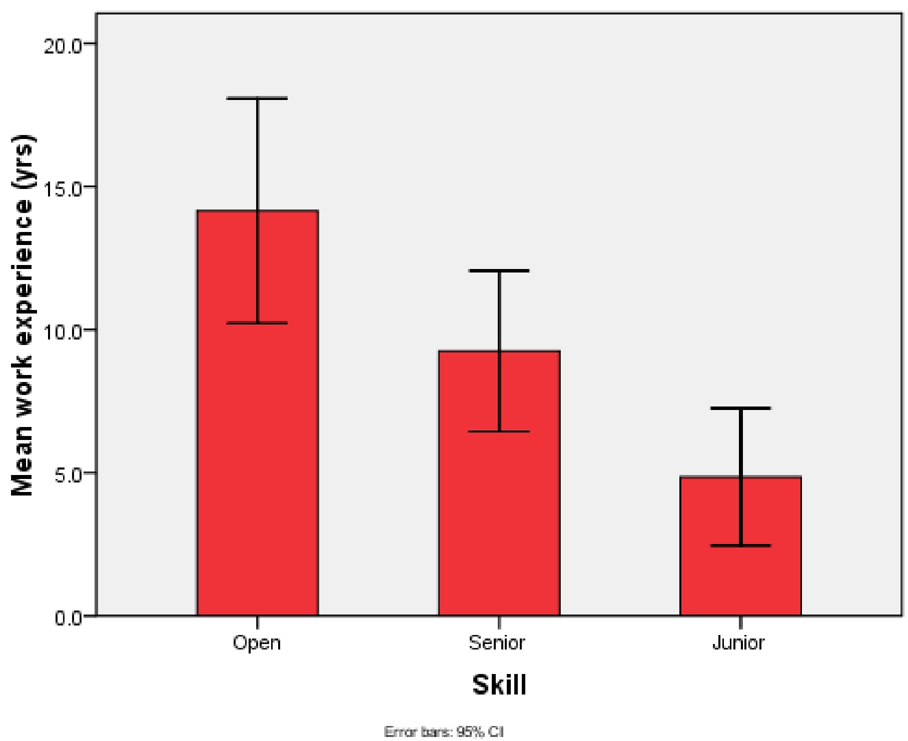

FIGURE 4.19: Years of work experience and 95% CI within each skill level of wool handlers.

4.7.1 Cumulative and peak forces in wool handlers

The cumulative and peak forces for the wool handlers are summarised in table 4.15 and for each skill category are summarised in table 4.16.

TABLE 4.15: Cumulative and peak forces during wool handling

	Mean (SD)	Range	95% CI
Cumulative Forces			
Cumulative compression (MN.s)	48.7 (8.9)	34.4 to 78.7	46.5 to 51.0
Cumulative force weighted compression (MN.s)	48.9 (9.4)	34.4 to 83.5	46.5 to 51.2
Cumulative joint anterior shear (MN.s)	2.53 (0.6)	1.7 to 4.1	2.4 to 2.7
Cumulative joint anterior reaction shear (MN.s)	5.7 (1.4)	3.6 to 9.6	5.3 to 6.0
Cumulative extensor moment (MNm.s)	0.023 (0.008)	0.012 to 0.047	0.021 to 0.25
Peak Forces			
Peak compression (N)	3194.2 (802.2)	2163.3 to6033.4	2991.2 to 3397.2
Peak joint anterior shear (N)	189.2 (42.2)	132.1 to 325.4	178.5 to 199.9
Peak joint anterior reaction shear (N)	391.4 (87.6)	278.8 to 697.7	369.2 to 413.6
Peak extensor moment (Nm)	165.1 (35.4)	106.7 to 292.4	156.1 to 174.0

4.7.2a Cumulative and peak forces in wool handlers based on skill level

The mean (95% CI) CC, CFWC, CJAS, CJARS, and CEM forces in open, senior and junior wool handlers are presented in figures 4.20 to 4.24.

TABLE 4.16: Cumulative and peak forces within each skill level of wool handlers

		Open	Senior	Junior
Cumulative Forces				
Compression (MN.s)	Mean (±SD)	50.2 (9.6)	50.1 (10.6)	45.9 (5.6)
	Range	39.7 to 78.7	38.4 to 76.3	34.4 to 59.3
	95% CI	45.7 to 54.7	45.1 to 55.0	43.3 to 48.5
Force weighted compression (MN.s)	Mean (±SD)	50.6 (10.5)	50.2 (10.9)	45.9 (5.7)
	Range	39.8 to 83.5	38.4 to 77.6	34.4 to 59.4
	95% CI	45.7 to 55.5	45.1 to 55.3	43.3 to 48.6
Joint anterior shear (MN.s)	Mean (±SD)	2.5 (0.6)	2.6 (0.7)	2.5 (0.4)
	Range	1.7 to 3.5	1.7 to 4.1	2.0 to 3.6
	95% CI	2.2 to 2.7	2.3 to 3.0	2.3 to 2.7
Joint anterior reaction shear (MN.s)	Mean (±SD)	5.7 (1.4)	5.9 (1.7)	5.4 (0.9)
	Range	4.0 to 8.7	3.6 to 9.6	4.1 to 7.7
	95% CI	5.0 to 6.4	5.1 to 6.7	5.0 to 5.9
Extensor moment (Nm)	Mean (±SD)	0.025 (0.007)	0.026 (0.01)	0.018 (0.003)
	Range	0.016 to 0.042	0.012 to 0.047	0.013 to 0.025
	95% CI	0.022 to 0.028	0.021 to 0.030	0.016 to 0.019
Peak Forces				
Compression (N)	Mean (±SD)	3474.3 (819.1)	3182.6 (912.4)	2925.8 (580.0)
	Range	2555.1 to 6033.4	2163.6 to 6021.1	2213.0 to 4231.8
	95% CI	3091.0 to 3857.7	2755.5 to 3609.6	2654.4 to 3197.3
Joint anterior shear (N)	Mean (±SD)	189.6 (36.4)	192.7 (48.3)	185.3 (43.2)
	Range	132.1 to 255.0	139.4 to 325.4	147.8 to 319.4
	95% CI	172.6 to 206.6	170.1 to 215.3	165.1 to 205.6
Joint anterior reaction shear (N)	Mean (±SD)	409.5 (76.4)	395.8 (102.2)	368.8 (81.4)
	Range	294.3 to 554.5	278.8 to 697.7	283.1 to 603.7
	95% CI	373.7 to 445.3	348.0 to 443.7	330.7 to 407.0
Extensor moment (Nm)	Mean (±SD)	175.2 (35.0)	164.8 (41.0)	155.3 (28.0)
	Range	132.8 to 268.7	106.7 to 292.4	118.6 to 217.6
	95% CI	158.8 to 191.6	145.6 to 184.0	142.1 to168.4

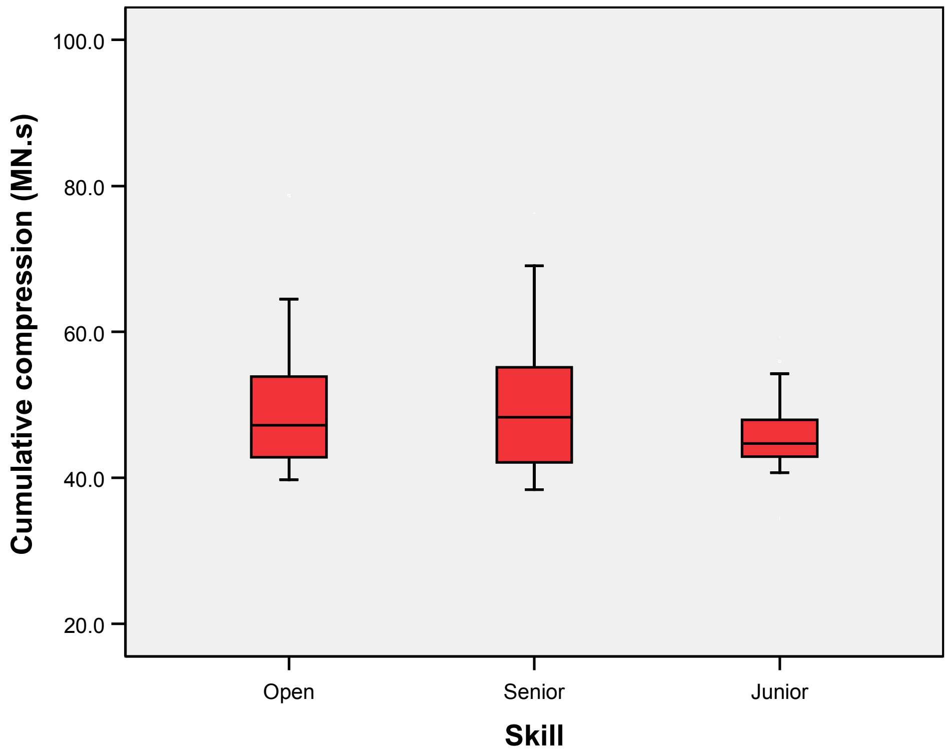

FIGURE 4.20: Comparative cumulative compression within each skill level of wool handlers.

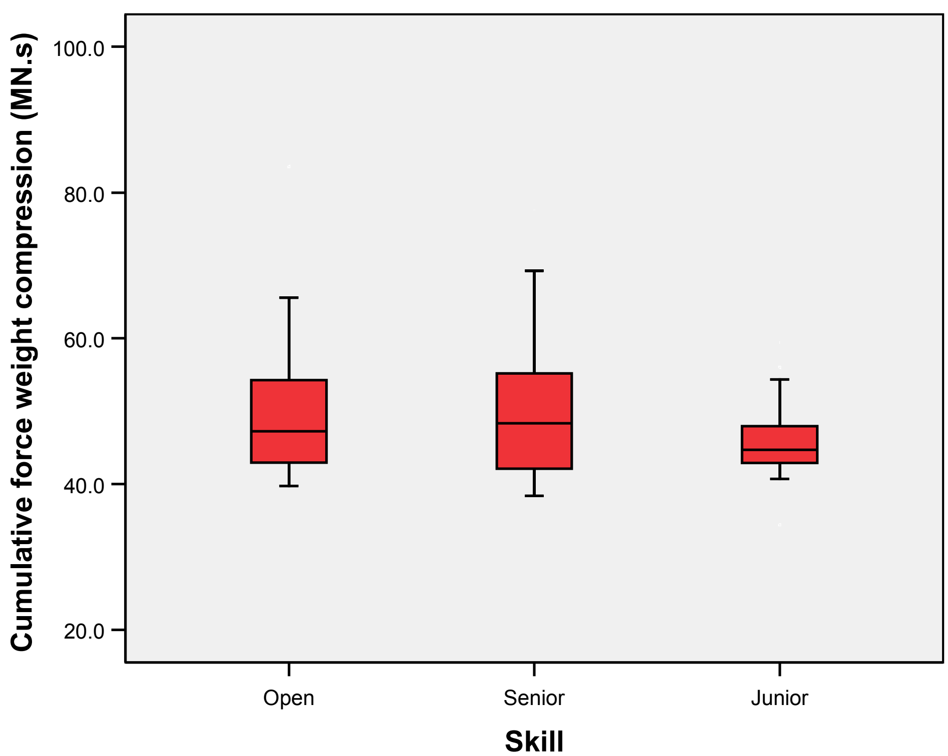

FIGURE 4.21: Comparative cumulative force weighted compression within each skill level of wool handlers

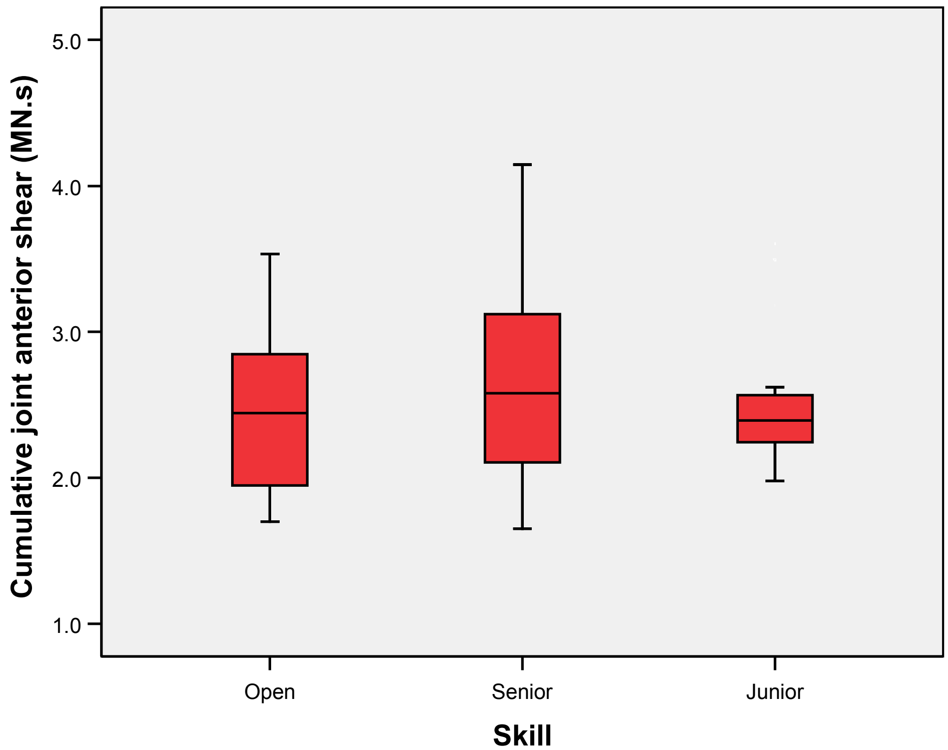

FIGURE 4.22: Comparative cumulative joint anterior shear within each skill level of wool handlers

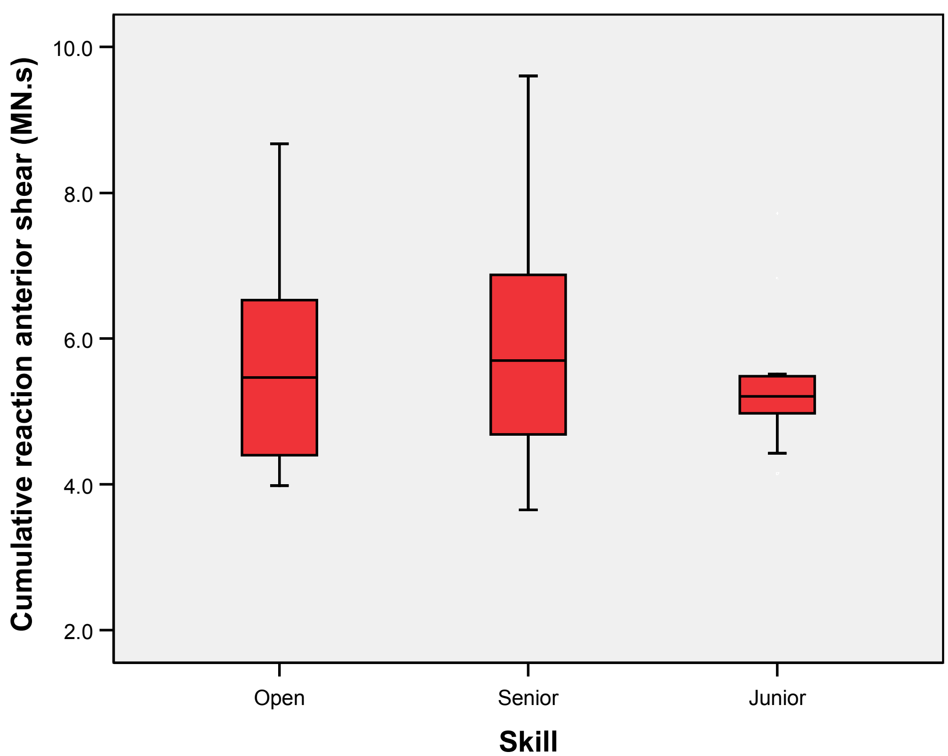

FIGURE 4.23: Comparative cumulative reaction anterior shear within each skill level of wool handlers

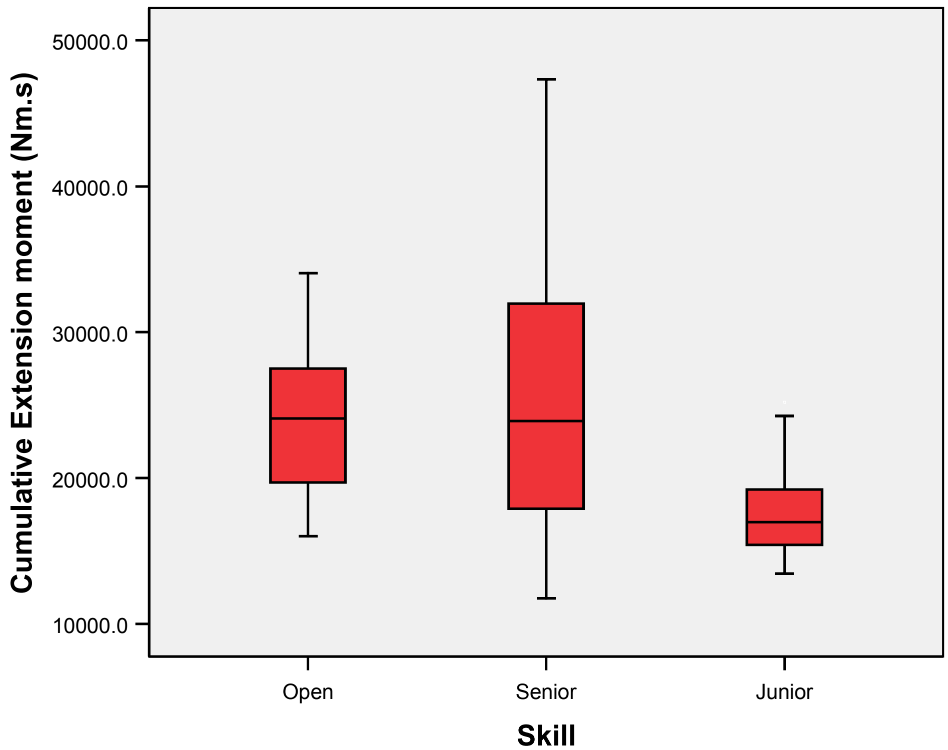

FIGURE 4.24: Comparative cumulative extensor moment within each skill level of wool handlers

The mean (95% CI) PC, PJAS, PJARS and PEM forces for the open, senior and junior wool handlers are presented from figures 4.25 to 4.28.

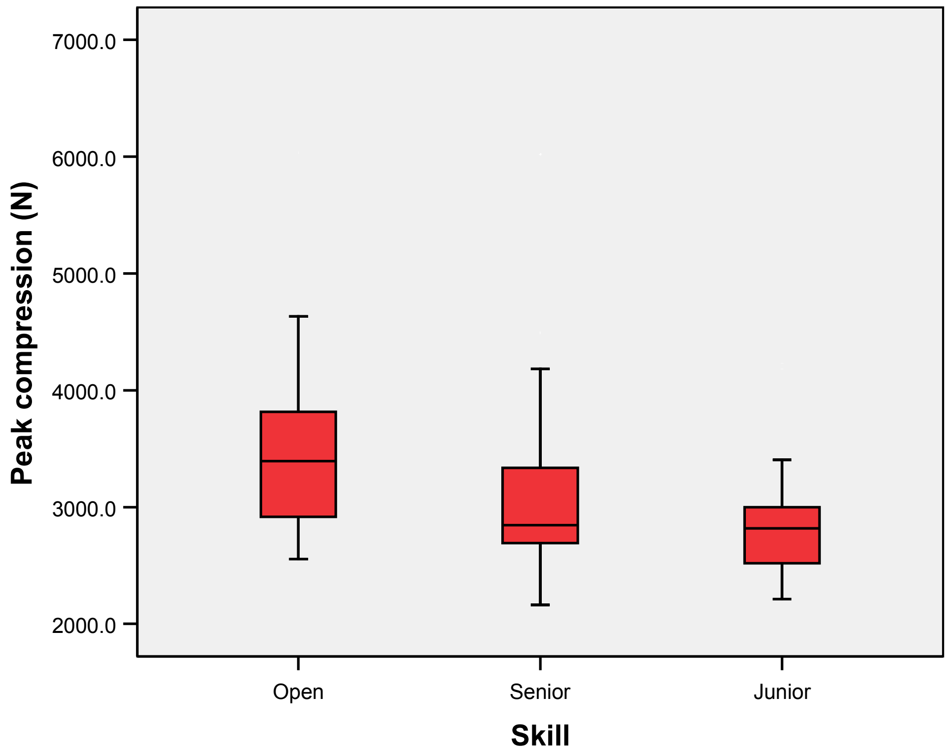

FIGURE 4.25: Comparative peak compression within each skill level of wool handlers

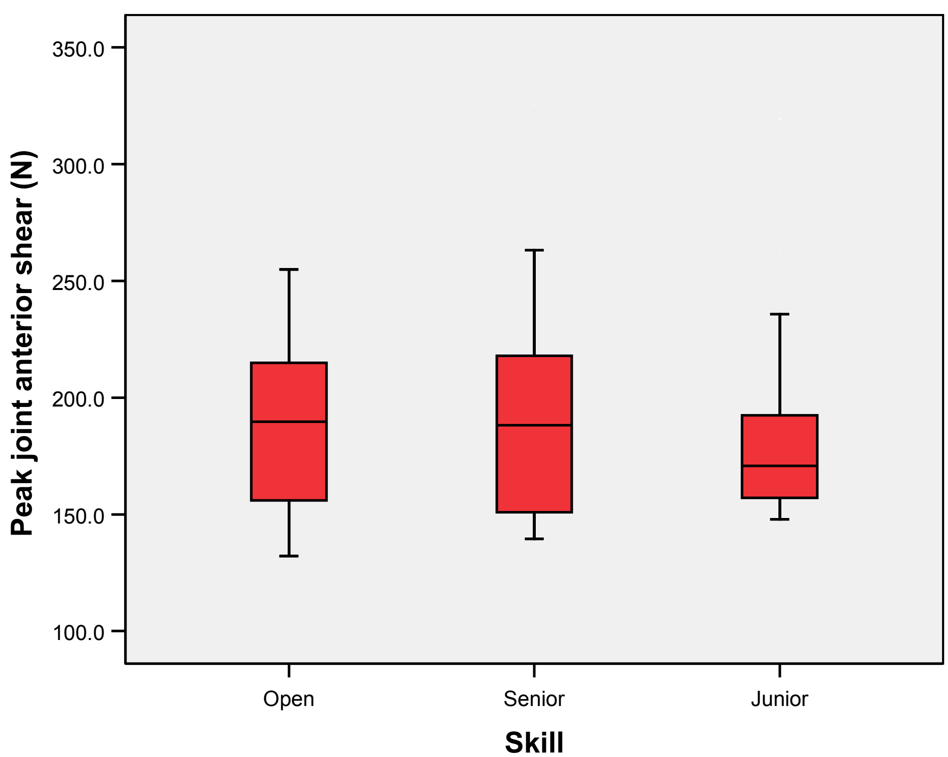

FIGURE 4.26: Comparative peak joint anterior shear within each skill level of wool handlers

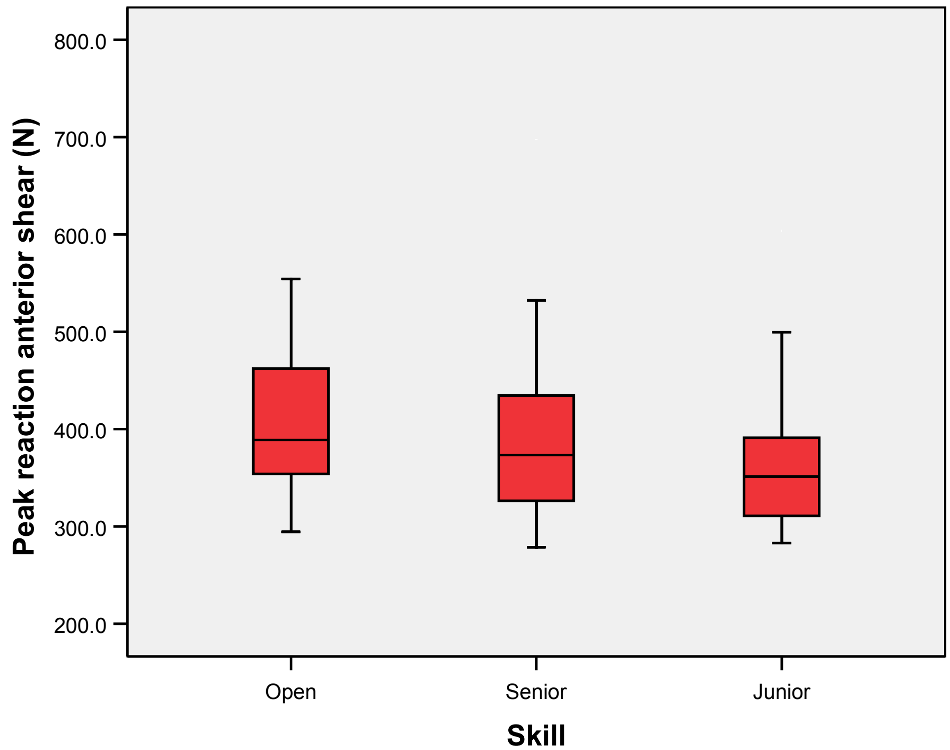

FIGURE 4.27: Comparative peak reaction anterior shear within each skill level of wool handlers

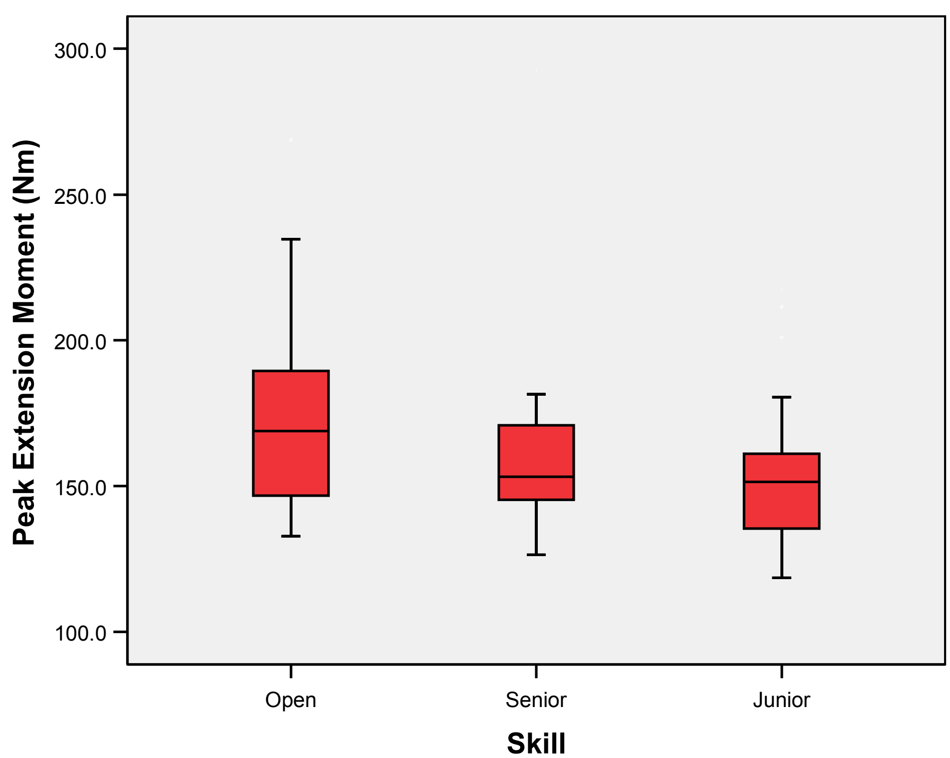

FIGURE 4.28: Comparative peak extension moment within each skill level of wool handlers

4.7.2b Influence of skill on cumulative and peak forces in wool handlers

The result of this analysis is presented in TABLE 4.17 and results show that in majority skill does not influence CC, CFWC, CJAS, CJARS, PC, PJAS, PJARS and PEM. TABLE 4.19 shows the actual difference (β), p-value, 95% CI of the actual difference and the correlation co-efficient (R^2). Cumulative extensor moment is influenced only by junior skill and senior level shearers.

TABLE 4.17: Univariate linear regression analysis of cumulative and peak forces with independent variables in wool handlers

		β	P value	95% CI	R^2 value
Cumulative forces					
Compression (MN.s)	Juniors	-4.24	0.084	-9.06 to 0.59	0.051
	Senior	2.04	0.410	-2.88 to 6.96	0.012
	Open	2.20	0.374	-2.72 to 7.11	0.014
Force weighted compression	Junior	-4.49	0.081	-9.55 to 0.57	0.052
	Senior	1.97	0.449	-3.20 to 7.14	0.010
	Open	2.52	0.331	-2.63 to 7.67	0.016
Joint anterior shear	Junior	-0.05	0.780	-0.36 to 0.27	0.001
	Senior	0.17	0.298	-0.15 to 0.48	0.019
	Open	-0.12	0.448	-0.44 to 0.20	0.010
Joint anterior reaction shear	Junior	-0.38	0.324	-1.14 to 0.38	0.017
	Senior	0.34	0.373	-0.42 to 1.10	0.014
	Open	0.04	0.926	-0.73to 0.80	0.000
Extensor moment	*Junior	-7518.62	0.000	-11429 to 3608.02	0.203
	*Senior	4339.95	0.045	109.48 to 8570.41	0.068
	Open	3178.68	0.144	-1122.49 to 7479.84	0.036
Peak forces					
Compression (N)	Juniors	-402.60	0.066	-833.34 to 28.13	0.057
	Senior	-17.52	0.937	-461.04 to 426.00	0.000
	Open	420.12	0.055	-9.45 to 849.70	0.062
Joint anterior shear	Junior	-5.81	0.620	-29.10 to 17.52	0.004
	Senior	5.23	0.655	-18.10 to 28.57	0.003
	Open	0.57	0.961	-22.80 to 23.95	0.000
Joint anterior reaction shear (N)	Juniors	-33.82	0.160	-81.42 to 13.79	0.034
	Senior	6.66	0.784	-41.73 to 55.06	0.001
	Open	27.15	0.261	-20.75 to 75.05	0.022
Extensor moment (Nm)	Juniors	-14.74	0.130	-33.95 to 4.47	0.039
	Senior	-0.46	0.963	-20.06 to 19.14	0.000
	Open	15.20	0.118	-4.00 to 34.38	0.042

P-value is considered to be significant at 0.05 level. * = statistically significant result.

4.8 Correlation analysis of independent variables for wool handlers

Correlation analysis was carried out for age, BMI, prevalence of LBP-Clin, work experience, tally and skill in wool handlers. TABLE 4.18 shows the Pearson's correlation coefficient (r) and p-values for all variables.

The results show that BMI had no statistically significant collinear relationships with age ($r = 0.115$, $p = 0.382$), prevalence of LBP-Clin ($r = 0.105$, $p = 0.425$), work experience($r = 0.101$, $p = 0.445$), tally ($r = 0.044$, $p = 0.736$) and skill($r = 0.065$, $p = 0.622$). Similarly, prevalence of LBP-Clin had no influence on age ($r = 0.152$, $p = 0.247$), BMI ($r = 0.105$, $p = 0.425$), work experience ($r = 0.167$, $p = 0.201$), tally ($r = 0.141$, $p = 0.283$) or skill($r = 0.167$, $p = 0.203$). Age had a statistically significant correlation with work experience($r = 0.779$, $p < 0.001$) and skill($r = 0.429$, $p < 0.001$) and work experience had a statistically significant relationship with age ($r = 0.779$, $p < 0.001$), tally ($r = 0.356$, $p = 0.005$) and skill($r = 0.505$, $p < 0.001$). Tally also had a significance correlation with work experience ($r = 0.356$, $p = 0.005$) and skill ($r = 0.636$, $p < 0.000$). Skill had a significant relationship with age ($r = 0.429$, $p < 0.001$), work experience ($r = 0.505$, $p < 0.001$) and tally($r = 0.636$, $p < 0.001$).

Similar to shearers these results show high levels of collinearity exist among age, work experience, tally and skill within this sample of wool handlers and therefore a multivariate regression analysis was not used with these variables in the equation. The influence of these variables on cumulative and peak forces was therefore undertaken with univariate linear regression analysis. The influence of LBP-Clin on age, BMI, work experience, tally, skill, cumulative and peak forces was completed by using univariate logistic regression.

TABLE 4.18: Correlations analysis of independent variables in wool handlers

		Age (yrs)	BMI (kg/m^2)	Experience (yrs)	Prevalence of LBP (%)	Tally (sheep/ day)	Skill
Age (yrs)	R p - value	1	0.115 0.382	0.779* <0.001	0.152 0.247	0.247 0.057	0.429* 0.001
BMI (kg/m^2)	R p - value	0.115 0.382	1	0.101 0.445	0.105 0.425	0.044 0.736	0.065 0.622
Experience (yrs)	R p – value	0.779* <0.001	0.101 0.445	1	0.167 0.201	0.356* 0.005	0.505* <0.001
Prevalence of LBP (%)	R p - value	0.152 0.247	0.105 0.425	0.167 0.201	1	0.141 0.283	0.167 0.203
Tally (no of sheep/ day)	R p - value	0.247 0.057	0.044 0.736	0.356* 0.005	0.141 0.283	1	0.636* <0.001
Skill	R p - value	0.429* 0.001	0.065 0.622	0.505* <0.001	0.167 0.203	0.636* <0.001	1

.* = Correlation is significant at 0.01 levels

4.9 Univariate linear regression analysis of wool handlers

Similar to shearers, univariate linear regression was carried out for wool handlers where age, LBP-Clin, work experience, tally and skill were each singularly explored for a relationship with the dependent cumulative and peak loads variables. The significance (p-value) level was also kept at 0.05. The results for univariate linear regression determining the influence of the independent variables such as age, prevalence of LBP-Clin, tally and skill on cumulative and peak loads for wool handlers is presented in TABLE 4.19. TABLE 4.20 shows the actual difference (β), p-value, 95% CI of the actual difference and the correlation co-efficient (R^2). The results show that BMI influences all cumulative and peak wool handling loads. Age influences peak forces: compression (R^2 = 0.087), joint anterior shear (R^2 = 0.046) and extensor moment (R^2 = 0.073). The mean difference (95% CI) for peak compression, peak joint anterior shear and peak extensor moment is 27.3N (4.1 to 50.5N), 2.2N (-0.43 to 4.8N) and 1.1Nm (0.07 to 2.13Nm). Tally influences peak compression and peak extensor moment with R^2 values of 0.062 and 0.052. The mean difference (95% CI) for peak compression and peak extensor moment is 7.6N (-0.2 to 15.4N) and 0.31Nm (-0.04 to 0.65Nm).

TABLE 4.19: Univariate linear regression analysis of cumulative and peak forces with independent variables in wool handlers

	Age (yrs)	LBP-Clin (%)	Experience (yrs)	Tally (sheep/day)
Cumulative forces				
Compression (N)	X	X	X	X
Force weighted compression (MN.s)	X	X	X	X
Joint anterior shear (MN.s)	X	X	X	X
Joint anterior reaction shear (MN.s)	X	X	X	X
Extensor moment (Nm)	X	X	X	X
Peak forces				
Compression (N)	✓	X	X	X
Joint anterior shear (MN.s)	X	X	X	X
Joint anterior reaction shear (MN.s)	X	X	X	X
Extensor moment (Nm)	✓	X	X	X

P-value is considered to be significant at 0.05 level. X = no statistically significant result, ✓= statistically significant result

TABLE 4.20: Results of statistically significant univariate linear regression analysis of peak forces with independent variables in wool handlers

		B	**P value (<0.1)**	**95% CI**	**R^2 value**
Peak forces					
Compression (N)	Age	27.3	0.022	4.1 to 50.5	0.087
	Tally	7.6	0.054	-0.2 to 15.4	0.062
Joint anterior reaction shear (N)					
	Age	2.2	0.100	-0.43 to 4.8	0.046
Extensor moment (Nm)					
	Age	1.10	0.037	0.07 to 2.13	0.073

P-value is considered to be significant at 0.05 level

4.10 Influence of LBP-Clin and skill on cumulative and peak forces in wool handlers

Although correlation analysis between skill and LBP-Clin showed no statistical significance the interaction between skill and LBP-Clin on cumulative and peak loads was also explored by a multivariate stepwise linear regression model by combining skill and a history of LBP-Clin. These results also showed no statistically significant interaction of cumulative and peak loads with skill, LBP-Clin and the combination of skill and LBP-Clin. (TABLE 4.21).

4.21: Results of multivariate linear regression determining the combined influence of LBP-Clin and skill on cumulative and peak loads in wool handlers

		β	P value	95% CI	R^2 value
Cumulative forces					
Compression (MN.s)					0.082
	Skill	-1.97	0.272	-5.54 to 1.59	
	LBP-Clin	-5.37	0.251	-14.65 to 3.91	
	Senior	0.00	0.999	-6.71 to 6.71	
	Senior*LBP-Clin	7.10	0.252	-5.18 to 19.37	
	Open*LBP-Clin	3.15	0.610	-9.16 to 15.45	
Force weighted compression (MN.s)					0.082
	Skill	-2.26	0.232	-6.00 to 1.48	
	LBP-Clin	-5.39	0.272	-15.13 to 4.35	
	Senior	-0.14	0.968	-7.18 to 6.90	
	Senior*LBP-Clin	7.08	0.275	-5.80 to 19.96	
	Open*LBP-Clin	2.75	0.671	-10.16 to 15.66	
Joint anterior shear (MN.s)					0.041
	Skill	0.06	0.619	-0.18 to 0.29	
	LBP-Clin	-0.29	0.340	-0.90 to 0.32	
	Senior	0.06	0.789	-0.38 to 0.50	
	Senior*LBP-Clin	0.42	0.296	-0.38 to 1.23	
	Open*LBP-Clin	0.28	0.495	-0.53 to 1.08	
Joint anterior reaction shear (MN.s)					0.046
	Skill	-0.07	0.796	-0.64 to 0.49	
	LBP-Clin	-0.73	0.319	-2.20 to 0.73	
	Senior	0.03	0.957	-1.03 to 1.09	
	Senior*LBP-Clin	1.12	0.251	-0.82 to 3.06	
	Open*LBP-Clin	0.61	0.528	-1.33 to 2.56	
Extensor moment (MNm.s)					0.221
	Skill	-3637.06	0.015	-6547.05 to -727.06	
	LBP-Clin	-2940.23	0.440	-10511.38 to 4630.93	
	Senior	2965.57	0.282	-2508.37 to 8439.50	
	Senior*LBP-Clin	4076.29	0.418	-5939.41 to 14091.98	
	Open*LBP-Clin	989.91	0.844	-9047.44 to11027.26	

Peak forces					
Compression (N)					0.099
	Skill	-254.77	0.113	-571.51 to 61.97	
	LBP-Clin	-399.44	0.335	-1223.52 to 424.64	
	Senior	-150.45	0.615	-746.26 to 445.36	
	Senior*LBP-Clin	504.52	0.358	-585.64 to 1594.68	
	Open*LBP-Clin	264.07	0.630	-828.44 to 1356.59	
Joint anterior shear (N)					0.330
	Skill	-2.27	0.793	-19.56 to 15.02	
	LBP-Clin	-22.16	0.328	-67.14 to 22.83	
	Senior	-4.23	0.795	-36.76 to 28.29	
	Senior*LBP-Clin	29.73	0.321	-29.77 to 89.24	
	Open*LBP-Clin	9.22	0.758	-50.41 to 68.85	
Joint anterior reaction shear (N)					0.053
	Skill	-20.95	0.241	-56.41 to 14.51	
	LBP-Clin	-32.46	0.484	-124.71 to 59.80	
	Senior	-7.68	0.818	-74.38 to 59.02	
	Senior*LBP-Clin	43.67	0.476	-78.38 to 165.71	
	Open*LBP-Clin	11.66	0.849	-110.65 to 133.97	
Extensor moment (Nm)					0.073
	Skill	-8.96	0.211	-23.16 to 5.23	
	LBP-Clin	-18.39	0.323	-55.31 to 18.54	
	Senior	-5.23	0.696	-31.93 to 21.47	
	Senior*LBP-Clin	20.77	0.398	-28.08 to 69.61	
	Open*LBP-Clin	12.68	0.606	-36.27 to 61.63	

4.11. Reliability Study

4.11.1. Intra class correlation analysis:

The inter-rater reliability was carried out on four variables; cumulative compression, cumulative joint anterior shear, peak compression and peak joint anterior shear. The result of this inter-rater reliability study; point estimates and 95% CI is summarised in TABLE 4.22. The individual values for these variable by the two raters shearing 3 sheep is summarised in TABLE 4.23. The point estimates obtained in this study was compared to the proposed guidelines by Portney and Watkins [136] which states that ICC values greater than 0.5 but less than 0.75 are considered moderate and values greater than 0.75 are considered as good to excellent. The result of this study shows that the inter-rater reliability for cumulative compression and cumulative joint anterior forces are excellent. However for the peak compression and peak joint anterior shear, the

ICC values show moderate correlation with the 95% CI showing moderate to excellent correlation.

TABLE 4.22: Reliability analysis of cumulative and peak forces in sheep shearers (n=20)

	Cumulative forces		Peak forces	
	Compression	**Joint anterior shear**	**Compression**	**Joint anterior shear**
ICC values	0.965	0.955	0.807	0.760
95% CI	0.913 to 0.986	0.886 to 0.982	0.512 to 0.923	0.394 to 0.905

TABLE 4.23: Summary of individual values of cumulative and peak forces by the two raters on shearing 3 sheep

Shearers	**Cumulative forces (N.s)**				**Peak forces (N)**			
	Compression		**Joint anterior shear**		**Compression**		**Joint Anterior Shear**	
	Rater 1	**Rater 2**	**Rater 1**	**Rater 2**	**Rater 1**	**Rater 2**	**Rater 1**	**Rater 2**
1	3476.4	2918.0	-230.8	-195.0	4323.0	3037.9	-275.1	-215.7
2	3234.5	3303.0	-220.1	-173.2	4082.0	3903.7	-249.8	-228.4
3	3324.9	2876.9	-207.8	-165.5	4092.3	3815.4	-244.0	-231.9
4	3022.1	2665.3	-179.9	-161.9	3852.8	4271.3	-212.7	-267.2
5	2427.3	2371.7	-183.7	-163.5	3040.5	2958.2	-215.1	-215.2
6	2658.4	2539.3	-182.5	-161.8	3233.4	3188.2	-217.0	-222.1
7	2849.9	2740.4	-186.7	-168.4	3497.0	3748.5	-225.5	-228.4
8	3299.6	3260.1	-191.8	-166.7	4170.5	4153.6	-228.7	-227.2
9	4212.8	3996.9	-242.2	-224.4	5312.9	5343.7	-287.1	-293.1
10	3462.9	3305.7	-238.4	-215.9	4209.5	4259.3	-277.7	-278.5
11	3126.5	3026.7	-182.3	-156.0	3853.4	3943.6	-228.5	-223.2
12	3201.5	3201.5	-191.2	-191.2	4169.7	4169.7	-255.4	-255.4
13	2685.7	2685.7	-155.4	-155.4	3331.4	3331.4	-220.5	-220.5
14	2319.3	2402.0	-143.7	-118.2	3292.3	3619.5	-195.1	-185.1
15	3821.8	3883.0	-233.9	-199.3	4924.1	5248.8	-270.5	-277.4
16	3493.0	3570.7	-225.9	-201.6	4238.1	4495.1	-261.1	-261.3
17	3301.4	3465.8	-206.6	-178.3	4109.7	3263.0	-242.7	-207.8
18	2393.5	2426.7	-169.6	-148.1	2807.2	4450.4	-203.7	-265.5
19	2437.1	2501.7	-156.0	-141.3	3101.9	2954.5	-193.1	-198.9
20	2384.5	2370.7	-178.4	-151.8	2778.3	3168.5	-207.6	-212.1

4.11.2 Bland Altman Plots

The inter-rater reliability between the two raters was also analysed descriptively by Bland Altman Plots (FIGURES 4.29 to 4.32). The X-axis represents the mean score of the variables from the two raters and the Y-axis represents the differences between these scores and the respective mean. Each graph has two horizontal lines representing mean difference of the variables from the two raters ± 1.96*sd.

For cumulative compression forces r = 0.12 and the inter-rater Coefficient of Variation (1.96*sd) was ± 369.2 Ns. For cumulative anterior shear forces r = 0.27 and the inter-rater Coefficient of Variation (1.96*sd) was ± 22.6 Ns. For peak compression force the inter-rater Coefficient of Variation (1.96*sd) was ± 1087.4 Ns while for peak joint anterior shear the inter-rater Coefficient of Variation (1.96*sd) was ±50.2Ns.

4.11.3 BIAS

For cumulative compression forces the mean inter-rater difference was 81.1Ns (±82.6, 95% CI) (p = 0.069) while for cumulative anterior shear forces the mean inter-rater difference was (-23.5) Ns (±5.0, 95% CI) (p = <0.001). For peak compression force the mean inter-rater difference was (-45.2) N (±243.1, 95% CI) while for peak anterior shear forces the mean inter-rater difference was 0.2N (±11.2, 95% CI). The average of the differences for each variable shows that the resulting values are close to zero indicating a lesser bias and better agreement between the two raters.

On analysing the Bland Altman plot for CC force shows that the difference between the two raters is evenly distributed across mean values of 2500 to 3500N.s. The plot for CJAS shows that the values were more clustered about the mean values of -225 to -150N.s. Plot for PC had a similar trend to the CC plot, where the difference between the two raters was evenly distributed between 3000 to 4500Ns. The plot for PJAS shows that the value was also distributed about 200 to 240 N.s. Although the values for the differences is spread across the mean values yet most of these values lie within the Mean ± 1.96sd with very few values outside this boundary for all the variables analysed. These plots are considered to project good agreement between the two raters for all variables analysed.

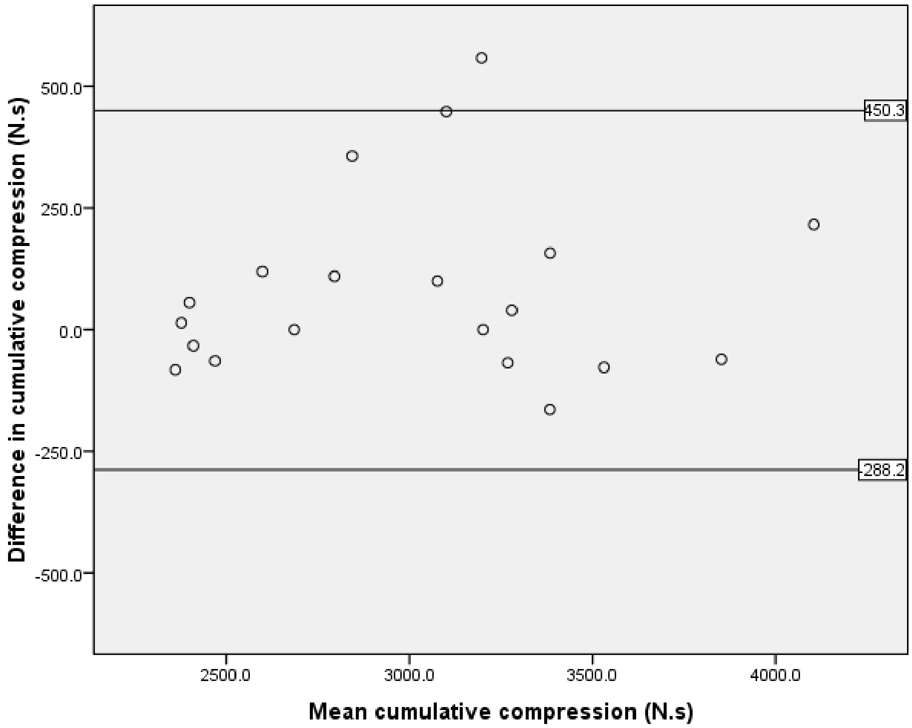

FIGURE 4.29: Bland Altman plot showing the inter-rater agreement for cumulative compression.

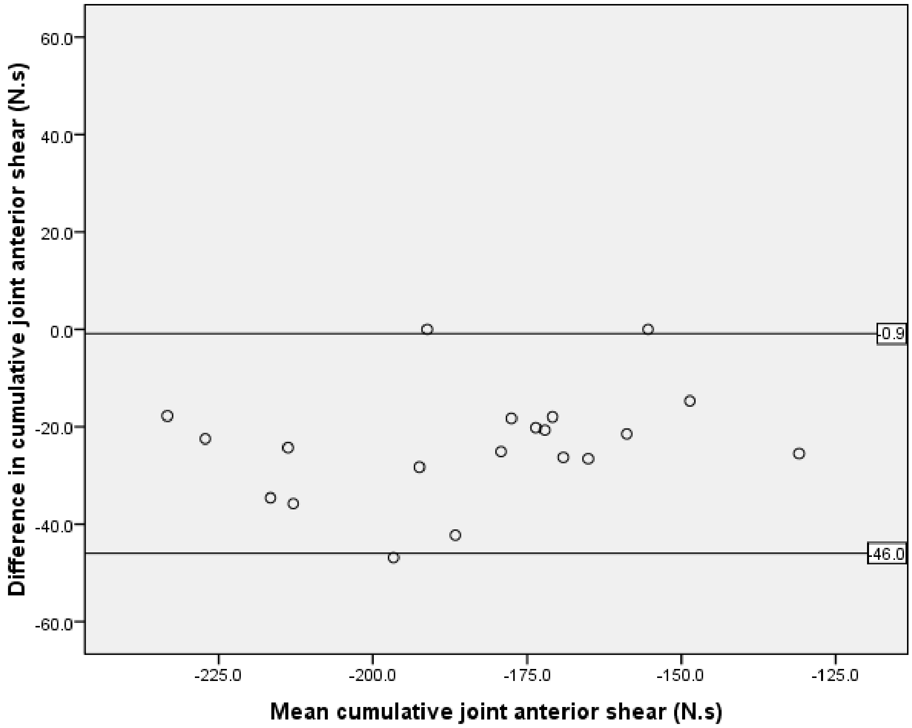

FIGURE 4.30: Bland Altman plot showing the inter-rater agreement for cumulative joint anterior shear

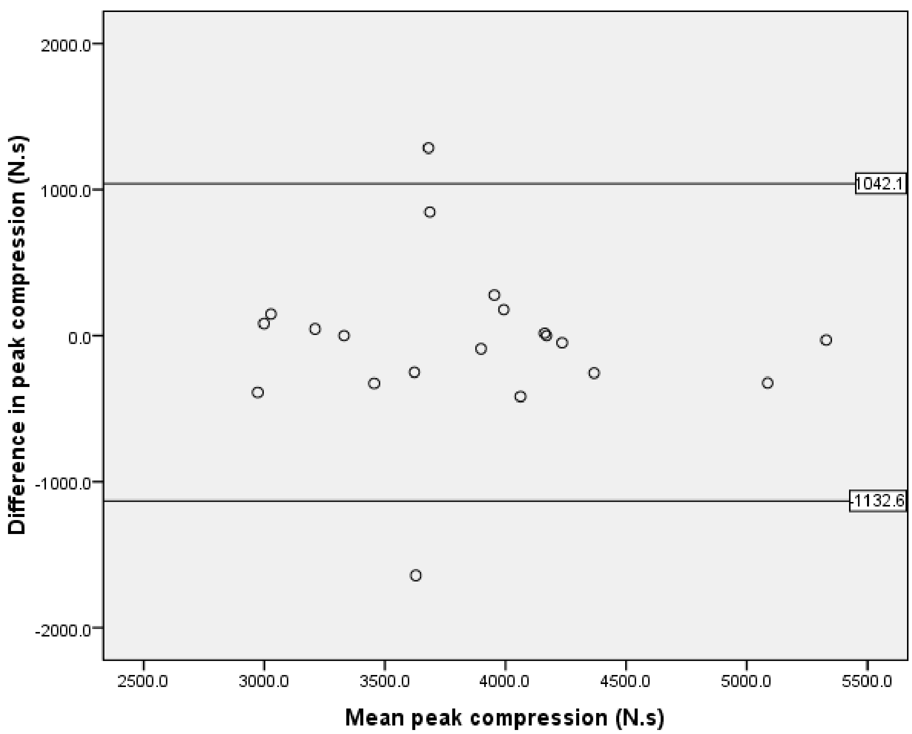

FIGURE 4.31: Bland Altman plot showing the inter-rater agreement for peak compression.

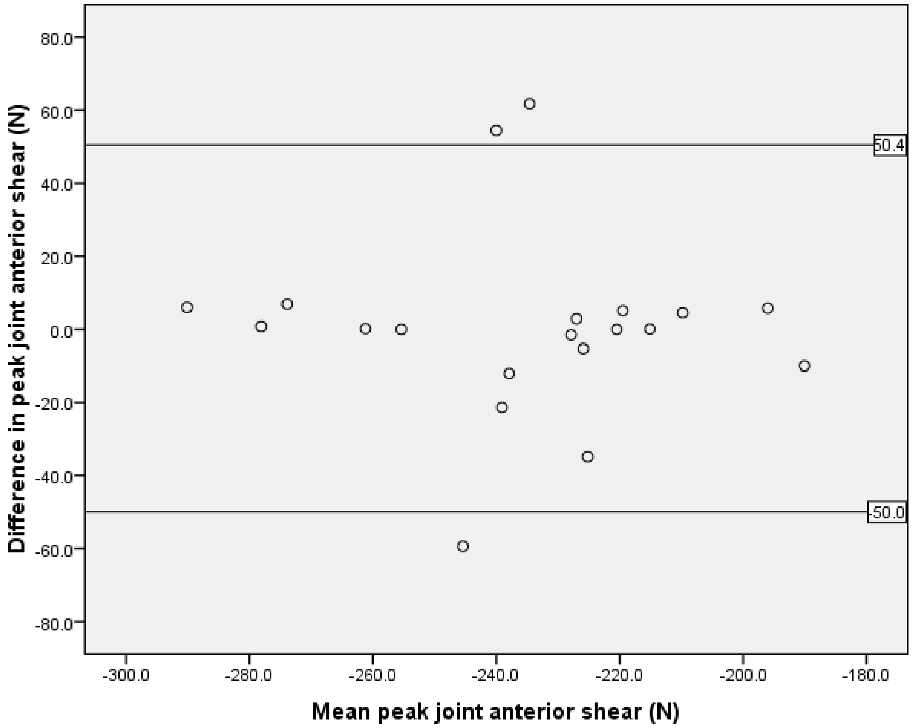

FIGURE F: Bland Altman plot showing the inter-rater agreement for peak joint anterior shear.

CHAPTER 5

DISCUSSION

DISCUSSION

Although optimal productivity and profitability are primary drivers within the wool industry a high prevalence of occupational LBP is also a considerable health issue for the wool harvesting workforce in New Zealand and Australia. The wool harvesting industry has a focus on improving skill and productivity (tally) as well as reducing the incidence of LBP. Shearers and wool handlers are encouraged to attend skill training courses to upgrade their skills and promote efficiency and productivity. Wool harvesting educators also consider that improved skill level will reduce risk of LBP injury. This suggests that higher skilled workers have reduced spinal loads, fewer episodes of LBP requiring clinical intervention (LBP-Clin), as well as increased productivity and work efficiency. This research thus explores the influence of a previous history of and skill and LBP-Clin on the generation of peak and cumulative spinal loads in both shearers and wool handlers. This chapter discusses the results relative to shearers and then wool handlers and then discusses these results in relation to the wool harvesting industry as a whole.

5.1 Shearers

While there was no statistically significant difference in height, weight and BMI between each skill level of shearers, each skill level is significantly older and more experienced than its lesser skilled counterpart. As expected there were strong correlations between age and years of experience, and between skill and tally but only moderate correlations between tally and years of experience and between skill and years of experience. Thus as experience and age increase there is an associated increase in skill level and tally. The strength of the significant correlation between LBP-Clin and years of experience was weak to moderate indicating that the prevalence of LBP-Clin increased as work experience increased. Daily predicted tally also increased in a significant and linear manner that was strongly correlated to both skill and experience. A correlation matrix revealed strong relationships between age, work experience, tally, skill and LBP-Clin.

Previous research has established that, sheep shearing is ranked amongst the highest injury risk agricultural occupations and approximately 90% of shearers will experience moderate to severe occupational back pain over their working life [6, 9, 41, 137]. Although none of the shearers in the current study reported an acute or recent episode of LBP-Clin the survey results are consistent with a high prevalence of LBP-Clin (44%) in the shearing population that is strongly correlated to experience, skill, and increasing productivity. Interestingly skill does not show any predictive relationship with cumulative and peak loads. Despite no increase in cumulative and peak loads as skill progresses the results still portray a high prevalence of LBP in shearers. Although the cross-sectional nature of this study does not allow a cause and effect relationship to be established these results demonstrate an increased prevalence of LBP-Clin in a high risk occupation that is exposed to high compressive and shear forces that are present from early in the shearers career. It may be that the considerable increase in productivity (tally) comes at the expense of LBP-Clin that is brought on by such spinal load exposures. The influence of skill may be a factor of increased productivity within a consistent high level of spinal loads.

Both skill and LBP-Clin and their interaction (LBP-Clin*skill) were explored in a multivariate analysis that demonstrated no significant effect on cumulative and peak compressive and anterior shear forces during shearing. Peak catch and drag extensor moment was the only spinal load that demonstrated a significant relationship with LBP-Clin suggesting that peak catch and drag extensor moment could be a differentiator for shearers with and without a history of LBP. Peak catch and drag extensor moments are produced by spinal extensor muscular contraction and it may be that attention to technique during this task may ultimately help reduce this moment and also influence the prevalence of LBP-Clin [33].

Despite no influence for skill and LBP-Clin on cumulative forces it is of interest to compare these results to those of Gregory et al. [33]. The mean lumbo-sacral CC and CFWC for shearers in this study is 82.6 and 84.8 MN.s respectively, a similar CC result to that of Gregory et al. [33] who calculated CC of 85.4 MN.s, while the CFWC is somewhat lower than that calculated by Gregory et al.103.7MN.s. [33]. Mean CJAS for shearers is 5.4 MN.s, slightly greater than the 3.5 MN.s calculated by Gregory et al. [33]. Mean CJARS was 11.8 MN.s while Gregory et al. [33] reported a mean CJARS of 9.9 MN.s. Mean CEM in shearers was 4.2 MNm.s similar to Gregory et al. [33] who measured 4.1 MNm.s.

The differences between the current research and Gregory et al.'s [33] study could be due to various reasons; including methodological differences, characteristics of study participants, sample size, accountability of rest periods and extrapolation of results. These are explained as follows: the sample of Gregory et al.'s [33] study had a total of 12 shearers (open = 7 and senior = 5) compared to the 80 shearers (open = 20, senior = 20, intermediate = 20 and junior = 20) in this current study. The data collection process in Gregory et al.'s [33] study was an experimental framework where the video data was captured concurrent with motion analysis and trunk muscle EMG data capture. This non-competitive experimental setup would likely allow the shearers to work at a slower rate than the shearers in this study. This study reported cumulative forces including the cumulative forces experienced by shearers during both the shearing and catch and drag phase while Gregory et al. [33] reported cumulative forces by considering the shearing and drag phase only. The catching of sheep during shearing is an important component of the task with hand forces of between 49 to 392 N reported for this study; excluding such high forces even for the short duration of catching phase may influence the force calculations. Gregory et al. extrapolated the time that shearers spent in dragging and shearing from a previous study by Gmeinder et al. [6] who calculated that shearers spent 80% time while shearing and 20% time dragging sheep. This current study timed the catch and drag phase for each skill level and extrapolated the results of catch and drag phase for each skill level. This current study did not take into account rest periods that a shearer would normally take during a typical working day and this could add to the differences with Gregory et al's [33] study. Other factors that may have influenced the cumulative forces in Gregory et al's [33] study are the use of different sheep, weight of sheep (approximate weight of 637.4N), tally (open shearers = 301, senior shearers = 282), different work stations, different anthropometric characteristics (mean age = 40.2yrs, mean height = 1.82m, mean weight = 87.9kg) and the inclusion of junior and intermediate shearers in the current study. Although there was no difference in the weight, height and BMI however there were significant differences in the mean age of shearers. The average tally for this current study for seniors and open shearers was 302 and 355 sheep/ day.

All the factors described above will influence the cumulative and peak loads. The CC for this current study and Gregory et al's [33] was similar, which is plausible as even though this current study had included juniors and intermediates but skill showed no influence on CC. The CJAS and CJARS were higher than the values reported by Gregory et al. [33]; CJARS is considered to be the result of the mass of the upper body (and hand forces) creating anterior shear forces at the lumbo-sacral joint while CJAS is the sum of reaction shear and the restraining muscle/ligament shear and represents the actual anterior shear experienced at the L4-L5 joint. 3D Match software considers the age, height, weight and body mass when calculating the cumulative and peak loads. These two results have no significant difference in the height and weight but differed in the mean age and hand forces. Gregory et al. [33] had used a constant hand load of 194.2 N for the drag phase while this current study had used changing hand loads (49 to 392N) for the catch and drag phase. It is therefore plausible that this current study reports higher values of CJAS and CJARS. The value of CFWC is influenced by a weighting factor, which basically equalizes exposure so that cumulative loading from different magnitudes of compression represents same risk of injury [33]. This CFWC is calculated by taking a percentage of the maximum joint strength; therefore a higher force exposure will lead to lower values of cumulative loads prior to injury occurrence [33]. Perhaps, this accounts for the differences between CFWC values in Gregory et al's [33] and the current study.

Mean PC force in this study for shearers was 3828.7N, slightly lower than Gregory et al. [33]4328.06N and considerably greater than Milosavljevic et al. [34, 55] 2822N. Although Milosavljevic et al. [34] used a different system involving motion analysis™ software to create a 3D inverse dynamics model the predominant difference involved Milosavljevic et al. [34] only analysing the shearing task and not the catch and drag phase. The substantial increase in mean PC forces of this study (136%) and that of Gregory et al. [33] (153%), when compared to that of Milosavljevic et al. [34], together with the mean PC for just the catch and drag phase of 4265.3 N in the present study, highlight the importance of including the catch and drag when investigating force exposures of the shearing task.

The PJAS for shearers in this study was 230.0 N, greater than the 191.9N found by Gregory et al. [33]. Mean PJARS was 458.3N, similar to the 470.3N of Gregory et al. [33] and 458.0N of Milosavljevic et al. [34]. It should also be noted that PJARS is considered to be the result of the mass of the upper body (and hand forces) creating anterior shear forces at the lumbo-sacral joint while PJAS is accepted as the sum of reaction shear and the restraining muscle/ligament shear and represents the actual anterior shear experienced at the L4-L5 joint. The PEMs for shearers was 185.1Nm, slightly lower than Gregory et al. [33] who reported a group mean peak PEM value in shearers to be 219.Nm.

Depending on skill levels shearers manoeuvre daily between 100 to 350 sheep each sheep weighing between 588.4 to 784.5N. This subjects shearers to a daily catch and drag forces of approximately 6 to 28 tonnes of live, awkward and often unpredictable animal. The task of catching, tipping and dragging sheep into the shearing position is reported by shearers to be the most physically demanding component of shearing with a high injury risk [35]. Previous analysis by Gmeinder [6] reports that shearers spend approximately 10.7% of the time catching sheep which implies that over an 8-hour working day, shearers spend nearly an hour catching sheep. This is a considerable repetitive daily workload and energy demand on the shearer and most likely to be without parallel in other industries. The catch and drag component of shearing subjects the spine to higher loads and is an important risk factor for the development of LBP yet there is limited research on the forces and postures involved in these tasks. Due to practical constraints of capturing the catch and drag phase in the shearing competitions six shearers were individually videotaped and the most representative clip was then used for all skill levels. However as each skill level performed this task with varying duration, the cumulative loads were extrapolated for each skill level. The above method of using a single representative clip/ person for a large number of participants have been used previously by Norman et al. [14] and their results confirmed that by using such a method did not affect the results of the study. Till date no research has been conducted on quantifying the cumulative forces during the catch and drag phase of shearing and this study is the first in doing so. The cumulative catch and drag forces on shearers is considered to be the first of its kind to be reported. Gregory et al. [33] used the hand loads estimated by Harvey et al. [20] to calculate cumulative and peak loads during the drag phase of shearing. The current study used a hand held load cell to calculate the changing hand loads during the catch and drag phase (pages 43 to 45 in methodology chapter). The previous study by Harvey et al. [20] used a constant hand load (194.0N/ 19.8kgs) for the drag phase with no account of the catching part. However in this current study three different loads were used. These three hand loads (49 to 393.2N) were calculated based on three sub-divisions (catching, tipping and dragging) identified within the catch and drag phase (see appendix 5). Further these loads were calculated for the dominant and non-dominant hands of shearers. The dominant hand was considered as the hand that the shearer used for shearing the sheep. In the present study it is felt that using three different loads for the catch, tipping and drag phases, versus using a constant load, will improve validity of the peak and cumulative forces during catch and drag phase. Moreover previous studies documenting the forces during the catch and drag (Gregory et al.[33]) have not considered the initial tipping of the sheep, where the present study found the greatest hand forces. This current study has a limitation in that a single video clip was used to calculate the cumulative and peak forces during the catch and drag phase for all shearers however experimentally by including the catch tipping an dragging components it is considered a more valid representation of the forces in the catch and drag phase when compared to existing literature.

The mean PC during the catch and drag phase for open, senior, intermediate and junior shearers are 4096.2 (687.2), 4581.6 (737.7), 4591.3 (759.3) and 3825.6 (585.9) N. Results show that skill especially junior did significantly ($p<0.001$) influence PC, indicating that skill beneficially influence PC forces during the catch and drag phase whereby as the shearer advances in skill level, particularly beyond junior level, there is a significant decrease in spinal PC forces. This observation provides some promise to the wool harvesting educators and senior colleagues of the industry as their training programs are geared towards improving skill in the catch and drag to reduce LBP injury rates thereby reduce the cost of injury treatment and compensation which will subsequently lead to improve the productivity and work efficiency.

The PJAS force during the catch and drag phase in shearers was found to be 694.6 (37.5) and in the open, senior, intermediate and junior shearers was found to be 684.2 (42.1), 697.9 (34.0), 704.1 (43.0) and 693.7 (28.8) N. Thus the mean and 95% CI value of PJAS are approximately the same for all shearers (Table 7). The PJARS force during the catch and drag phase is 698.2 (34.2) N and in the open, senior, intermediate and junior shearers are 695.3 (32.6), 700.0 (32.8), 704.2 (43.0) and 694.0 (29.2). The PEM force during the catch and drag phase in shearers is 189.2 (24.6) and for the open, senior, intermediate and junior shearers is 188.3 (20.4), 197.9 (25.9), 194.2 (25.9) and 176.6 (22.6). The results for PJAS, PJARS and PEM suggests that essentially skill does not seem to influence these values suggesting that other factors may have a vital role in the development of LBP-Clin. Some factors worth thinking about could be working techniques, working postures, time spent in working postures and LBP characteristics.

5.2 Wool handlers

This study is the first to calculate the cumulative and peak loads on the lumbo-sacral spine of wool handlers and aims to help establish a baseline of the cumulative and peak forces for the wool handlers in the sheep wool harvesting industry. As such this database may then be useful for generating guidelines comparable to other occupational groups and will likely be useful for further LBP prevention and research.

There was no significant difference in the height, weight and BMI for each skill level within the group. However there were significant age differences between juniors, seniors and open wool handlers although the age range within each skill level was similar. Similar to shearers, there is a strong correlation between age, experience, skill and tally level. Although years of work experience is not correlated to LBP-Clin although higher skill level wool handlers had a higher prevalence of LBP-Clin than the junior wool handlers.

While shearers are paid by the number of sheep they shear daily; and have a clear understanding of their daily working tallies wool handlers are paid by the hour and not by the number of fleeces that they process. Therefore the tally for wool handlers in this study was calculated by extrapolating the time taken to sort the wool from three (open and senior) and two (junior) fleeces to an 8-hr working day. There appears to be no difference in mean predicted tallies for junior and senior wool handlers while mean predicted tally for the open shearer is significantly greater than others. Correlation analysis revealed a moderate interaction for tally with skill but only a weak correlation with work experience.

This study shows that this sampled working population of competing wool handlers had a LBP-Clin working life time prevalence of 40%. With advancing skill, the LBP prevalence raises from 25% to 50% in the 4 years of working time for senior wool handlers and from 25% to 45% for open wool handlers occurs in a working time frame of 5 years. Interestingly, even though the workload for junior and senior is approximately the same the prevalence of LPB-Clin increases from 25% to 50% however skill does not shows any significant influence on cumulative and peak loads.. The prevalence of LBP in open wool handlers and senior wool handlers is more or less the same suggesting that the difference between these two skill levels may not be due to the daily tally but perhaps that open wool handlers' self- regulate their working technique. This could imply that other factors also play important role in the occurrence of LBP such as different working mechanics, time spent in various postures or the cumulative effect of loading over working years.

LBP-Clin in wool handlers did not show any predictive relationship with anthropometric characteristics, work characteristics, peak and cumulative forces in a univariate analysis. This study shows that LBP-Clin did not influence any of the above variables. Correlation analysis also revealed no significant correlation between LBP-Clin, anthropometric and work characteristics. However a high correlation existed between age and work experience, moderate correlation between age and skill implying that each one of these variables are interrelated and the true individual influence of any one of them on the dependent variables could not be determined in the presence of the other. Although skill and LBP-Clin did not have a statistically significant correlation with each other yet the combined influence of both skill and LBP-Clin on cumulative and peak forces was explored by stepwise multivariate analysis by creating three new variables (skill-levels*LBP-Clin). The results of the multivariate analysis also revealed no significant effect for LBP-Clin, skill or the combination of LBP-Clin*skill on the cumulative and peak loads during wool handling.

The mean CC was 48.7 MN.s; CFWC 48.9 MN.s; CJAS 2.53 MN.s; CJARS 5.7 MN.s. with no predictive influence for skill on these loads. This can be considered as a positive finding in that wool handlers are in fact not subjected to increased cumulative loads as they advance in skill, age, years of experience and tally. The above observation suggest that other factors might influence the occurrence of LBP-Clin in wool handlers such as working years, working postures, time spent in the various working postures, working techniques and age. The mean CEM in wool handlers was 0.023 MNm.s and skill especially junior level did show a significant influence on

CEM values whereby an increase in skill level is associated with a decrease in CEM values. This is again an important finding and should be emphasised to workers of the wool harvesting industry as well as industry experts. Another interesting observation is that the prevalence of LBP-Clin remains more or less the same for open and senior shearers suggesting that the only difference between these two skill levels may be due to tally as open wool handlers may be more capable of self-regulating their workloads.

Mean PC was 3194.2N; PJAS 189.2N; PJARS 391.4N; and PEM 165.1 Nm. Similar to shearers, the cumulative forces generated during wool handling show that advancing skill has no effect on these forces in wool handlers or that these forces are more or less constant irrespective of skill level or work experience.

5.3 Anthropometric and LBP-Clin characteristics of the wool harvesting industry

A pooled comparison between shearing and wool handling participants shows that the shearers were all male compared to the predominant number of females in the wool handling group. The shearers' also demonstrated a 1.09 height and 1.18 weight differential compared to wool handlers. Despite this there was no appreciable change in BMI and age across skill levels for both shearers and wool handlers. The years of working experience was similar for the open skill levels (14.2, 13.8 yrs for wool handlers and shearers respectively). However senior and junior wool handlers (9.3yrs and 4.9 years respectively) had approximately 2.5 years more work experience than senior and intermediate shearers (6.8 yrs and 2.3yrs respectively) and junior wool handlers had 3.5 yrs more work experience than junior shearers (1.4yrs).

When the open and senior skill levels (combined skill level) were compared with the junior and intermediate shearers (combined skill levels), the analysis showed that the higher skill levels had a 9.85 (±95% CI; 3.45 to 28.12) greater risk of developing LBP-Clin than the intermediate and junior shearers ($P<0.0001$). This result implies a considerable risk for LBP-Clin in this occupation given that the mean difference in age between the Junior and Open Class shearers was only 13.2 years. These results indicate that the risk of developing LBP-Clin significantly increases every year by a factor of 0.75 and is consistent with arduous work demands, postures and the amount of load manipulated by a shearer in comparison to a wool handler. Shearers manipulate between 588.4 to 784.5N per shearing cycle in comparison to wool handler who manipulated between 49 to 98.1N per wool handling cycle. Interestingly a higher skill grouping in wool handlers did not show any significant increase in risk compared to junior wool handlers.

When LBP-Clin prevalence is broken down into a one year equivalent; the LBP-Clin incidences at each skill level is derived by dividing the change in relative LBP-Clin occurrence by the increase in years of experience at each skill level. For example the LBP-Clin prevalence for open shearers in a one year equivalent is calculated by dividing the difference between the LBP-Clin prevalence between open and senior shearers with the difference in the years of experience between the open and senior shearers; [(77 - 60)/ (13.8 - 6.8) = 17/7 = 2.4]. For the open skill level, the one year equivalent LBP-Clin incidence is 2.4% for shearers and -1.0% for wool handlers. For the senior and junior shearers the one year equivalent LBP-Clin incidence is 7.6% and 7.1% respectively. Senior and junior wool handlers had an incidence of 5.6% and 5.1%. Overall the highest incidence was for intermediate shearers with a value of 17.8%. This suggests that per year the incidences of LBP are similar for both senior and junior in shearers and in wool handlers. Although open skill level also has a higher incidence of LBP-clin the predominant change appears to occur in intermediate shearers.

5.4 Cumulative forces in the wool harvesting industry

The CC in shearers and wool handlers is 82.6 (16) MN.s and 48.7 (8.9) MN.s. Norman et al. [94] calculated the cumulative compression in automobile workers for those with (cases = 104) and without (controls = 130) LBP. The values of CC for participants with LBP and healthy subjects were 21.0 (4.7) and 19.5 (3.8) MN.s respectively. Kumar [13], also calculated the cumulative compressive force at the thoraco-lumbar and lumbo-sacral regions in male and female institutional aides; with and without back pain. In male workers with and without LBP the CC values was 4.3 (3.1) and 6.6 (5.5) MN.s at the lumbosacral region. In female workers with and without LBP the CC values was 6.0 (5.4) and 9.3 (7.7) MN.s at the lumbosacral region.

Seidler et al. [129] calculated the cumulative load on the lumbar spine during lifting and extreme flexion in symptomatic spondylosis and control groups. The cumulative exposure for combined lifting and flexion was calculated by modified model (Mainz-Dortmund dose model) [129]. They found that during extreme flexion the load at L5/S1 was 1700N and the cumulative dose in cases during a combined lifting and extreme flexion was 9 $x10^6$ Nh (32400MNs) with an odds ratio of 8.5.

Compared to other occupational groups, the CC values for shearers and wool handlers in this study are greater by approximately 4 to 6 and 2 to 4 fold respectively. Methodological issues such as the use of peak static spinal load multiplied by the number of repetitions and duration of each task to estimate cumulative loads as performed by Norman et al. [14] or the use of a static approach of reducing the number of frames (5Hz) to represent a dynamic task to estimate the cumulative loads by Kumar [13] and sample size could explain some of this considerable difference in the loads experienced by the workers of the wool harvesting industry. Callaghan et al. [64] documented the errors in estimating the cumulative spinal loading by using six different approaches: a) rectangular integration of all frames collected at 30Hz (gold standard), b) rectangular integration with a reduced sample rate of 5Hz c) spinal loading at the initiation of the lift multiplied by the duration of the task d) cycle divided into work and rest, the work phase of the cycle and e) lastly cycle divided into four components (get load, lift load, place load and return). The errors in estimating the cumulative spinal forces for the task cycle on using the above methodologies were 1.8%, 70%, 35%, 27% and 39% respectively. The study by Callaghan et al. [64] found that inclusion of rest periods in the cumulative load calculation also reduced the error in calculating these loads and that the lesser the rest duration the lesser was the reduction in the estimated error. This present study calculated the cumulative spinal loads in 8-hour work duration without including the 1-hour lunch break and two half an hour tea breaks (10-hour working day). The exclusion of this rest duration may influence the loads calculated however the error resulting by using a reduced sampling rate is less than 3% [12] therefore suggesting that shearers and wool handlers are at a higher risk of cumulative forces exposure suggesting greater risk of developing back pain than other occupational groups that have been researched previously.

On comparing this cumulative dose limit proposed for Germany (19.8MN.s) with the results of this current study shows that shearers and wool handlers obviously are exceeding this dose limit by 4 to 2 times respectively. However there is no validity to the proposed dose limit and as the corresponding metric is unknown, more research is needed to clarify the proposed limit [30]. Waters et al. [30] also proposes that it would be desirable to develop a lifetime exposure limit for cumulative spinal loading and how the body adapts to this load.

Within the wool harvesting profession, the CC value for the shearers of this study were in general twice that of the wool handlers, suggesting that shearers are exposed to more force than wool handlers and therefore may be at a higher risk of developing LBP than wool handlers. Each skill level among shearers is also consistently higher than their corresponding skill levels of wool handlers. Similarly CFWC, CJAS, CJARS and CEM values for shearers are nearly twice the CFWC, CJAS, CJARS and CEM values of wool handlers. These results are consistent with shearers being under considerably greater spinal loading and suggest that such increased physical loading is one of strong factor for the increased prevalence of LBP-Clin. Other factors that can contribute for increase in cumulative loads in shearers in comparison to wool handlers include the prolonged stooped working postures adopted by shearers' and the that is more demanding than the standing postures of wool handlers.

Cumulative compressive and anterior shear forces were on average 1.7 and 2.1 times higher in shearers than wool handlers. These increases may be over estimated considering the relative small extensor moment given to wool handlers where slight forward bending at the wool table (less that 15 degrees) is considered upright with no extensor moment in the 3D Match software and conversely shearers in the fully flexed position may experience a reducing extensor relaxation phenomena. In addition, as with peak forces, an increase in L5/L5 disk area of the shearer will also reduce cumulative stress differences between the two groups. However, an increase in compressive forces but a larger relative increases in anterior shear forces are indicated.

Although the predominant focus of this study was whether cumulative loads and skill influence LBP-Clin it must be appreciated that causes of musculoskeletal disorders are considered multifactorial in nature [138]. Individual factors, workplace physical requirements, organizational factors and psychosocial factors are known to be associated with injury risk [14, 139-141]. Epidemiological reviews shows that workplace physical factors account for 11 – 80 % of lower back injuries while psychosocial factors account for 14 – 63 % of lower back injuries [141-143]. There is an increasing interest in research of psychosocial factors and work organizational factors [142, 144, 145] by NIOSH (job satisfaction, supervisor support, safety climate, work stress) as these will increase the knowledge base of the risk factors related to musculoskeletal disorders/ injuries [138]. This current study has not taken into account the above risk factors that have been shown to influence the development and/ reporting of LBDs.

5.5 Peak forces in the wool harvesting industry

The PC forces for shearers and wool handlers are 3828.7N and 3194.2 N and thus the peak loads for shearers are approximately 630N greater than wool handlers. PJAS and PJARS values in shearers for the group and each skill level are also higher than the PJAS and PJARS values of wool handlers by approximately 50N and 70N respectively with PEM values in shearers being approximately 20N higher than wool handlers. These results are consistent with shearer working postures and workloads which are more flexed, more sustained and involve the catching and dragging of sheep – clearly a much heavier workload than wool handlers.

Peak compressive and anterior shear forces were both on average 1.2 times higher in shearers than wool handlers. If however we assume a 1.1 to 1.2 increase in L5/S1 disk area, as seen with height and weight with no difference in BMI, then the increase in stress on the L5/L4 spine (force per area) may only be showing marginal increases. In the catch and drag phase of shearing, peak compressive, anterior shear and reaction anterior shear force were on average 1.3, 3.7 and 1.8 times higher than in wool handlers indicating a relatively larger increase in anterior shear forces compared to peak compressive forces. Despite this, as skill progresses cumulative compressive and anterior shear forces do not significantly change over a standard 8-hour working day. This research has demonstrated that increasing skill does not influence daily cumulative or peak loads in either shearing or wool handling and therefore does not support the premise that increasing skill will reduce spinal loading and therefore reduce risks of LBP. An increased skill was associated with an increased efficiency and reduced cumulative loading per sheep but was offset by an increased daily tally with no significant changes to overall daily cumulative spinal forces. Improving skill level is beneficial in terms of production and efficiency; a positive from this study is that this does not expose the worker to increased cumulative or peak spinal loading and therefore an associated increased risk of LBP. However, the working lifetime prevalence of LBP-Clin in shearers increased from 10% (juniors) to 77% (open) in a working span of twelve years while in wool handlers it increased from 25% (juniors) to 45% (open) in five years. When comparing the cumulative loading between shearers and wool handlers there is a significant increase in cumulative spinal loading and increase in LPB.

5.6 Future research considerations:

It is desirable to observe whether the presence of a current episode (acute/ subacute and chronic) of LBP relates to anthropometric, work characteristics and spinal forces (peak and cumulative) in shearers and wool handlers. Another interesting observation is to conduct a longitudinal study to document the influence of skill, LBP (current and previous), anthropometric characteristics, and work characteristics on cumulative and peak forces. A large sample of the shearing population should be approached through TectraTM New Zealand and subjects should be followed from when they start their shearing/ wool handling training programs up to when they retire from the work force. Subjects can be videotaped every year during shearing competitions and any updates on their anthropometric characteristics, tally and any history of episodes of LBP can be gathered. Similar to this current study, 3DMatch can be used to analyse the data and generate cumulative and peak loads for each participant. The influence of skill, LBP, anthropometric and work characteristics on these forces can then be explored. The wool harvesting workforce also consists of wool pressers, and till date no research has documented the cumulative or peak loads in this workforce nor has the prevalence of LBP been explored. It would also be desirable to determine the influence of LBP on the cumulative and peak forces in this workforce.

Recent research has documented the cumulative and peak loads and postures on the shoulder joints for each skill levels of shearers and wool handlers. A previous study by Gregory et al. [53] was the first to document the cumulative loads and postures of the shoulder joint in 7 open shearers and 5 senior shearers. The posture files generated by this current study included raw data for cumulative and peak loads as well as the posture of each joint (neck, shoulder, elbow, trunk etc). This evaluation of the shoulder loads and joint postures has recently been published by Gregory et al. [146] since the submission of the thesis. The shoulder loads and posture were not included in this study as lower back loads and the influence of skill and LBP on these loads were considered sufficient for the purpose of a PhD thesis.

On comparing the results of this study with the NIOSH guidelines and the ISO 11228-1 guidelines [125] it is imperative to determine what is driving these forces and what ergonomic workplace modifications can be done to decrease them. Cumulative loading is a factor of the loads handled, the repetitiveness of the tasks as well as the postures assumed by the subjects. The hand loads for both shearers and wool handlers were constantly changing with the hand loads being highest during the catch and drag phase for shearers and for wool handlers is when they picked up the fleece for sorting out. The postures assumed by shearers and wool handlers were asymmetric and repetitive. A study by Granata et al. [147] claimed that variations in the biomechanical performance and spinal loading during lifting tasks might influence the risk of LBD. Mirka and Marras [148] argue that biomechanical variability influences the relative number of repeated exertions that might exceed the NIOSH lifting guidelines. It is also argued that workplace factors (including experience) that influence biomechanical variability will also influence the risk of exceeding injury tolerance and risk [147].

Granata et al. [147] found that peak spinal loads increased with increase in the hand loads and asymmetrical movements and surprisingly that experienced workers sustained significantly greater spinal compression, anterio-posterior shear and lateral shear forces compared to inexperienced colleagues. The rationale for the above observation being that experienced workers generated greater lifting (sagittal and twisting) moments and muscle co-contraction. In addition, hand loads and experience significantly influenced spinal variability where the anterio-posterior shear and compressive loads at the L5/S1 spine increased by 43% and 20%

respectively. Although the above result is only applicable to the peak forces however the rationale can be applied to cumulative loading to explain in the observations as to why the cumulative forces in highly skilled shearers are higher compared to lesser skilled shearers.

When the asymmetric movement was examined the variability in the anterio-posterior shear was 64% greater than sagittal symmetric tasks. In addition, experienced workers seem to generate variability of 80%, 66% and 38% more than inexperienced colleagues for lateral, anterio-posterior and compressive directions. It has been reported that the risk of LBD increases with increased asymmetric postures in workplaces [149, 150]. Spinal load and the load variability increased with asymmetric tasks [147] and load variability and asymmetric task will likely increase the exertion that may exceed the biomechanical tolerance limits. This study had not explored forces such as lateral shear and rotational forces which are worth exploring so as to identify the characteristic variable that may help distinguish workers at risk of LBD.

A cross sectional study by Punnet et al.[151] found ergonomic exposures (non-neutral postures, work pace, vibration, manual forces to handle tools and parts, and mechanical pressure concentrations from hand held tools in the subject's usual job) are also predictors of upper extremity disorders. This study found that by reducing occupational ergonomic exposures especially repetitive tasks, non-neutral postures, and forceful exertions would protect against both new and persisting upper extremity musculoskeletal morbidity. The results of the current study agree with a majority of studies published on (other) musculoskeletal disorders showing that exposure to ergonomic stressors such as repetitive movements, non-neutral postures, or forceful exertions contribute to the occurrence of upper extremity MSDs in manufacturing,[152] food processing,[153] clerical work, [154] health care, [155] forestry, [156] and mixed occupations [157]. Although Punnett et al. [151], suggestions in regards to repetitive task and non-neutral postures are only applicable to upper extremity disorders, the argument is also considered to be applicable to other musculoskeletal injuries or disorders such as those occurring in the wool harvesting occupations.

Recently published research compares the trunk postures, peak and cumulative loads on the spine using a novel upright shearing technique with the traditional stooped shearing technique [158].

It has been shown that an excessive amount of cumulative loading is associated with increased potential for the development of lower back injuries and LBP [158]. The upright posture shearing platform (UPSP) is designed to raise the sheep onto a raised platform (level of the hips) without the need to catch, tip and drag the sheep prior to shearing. The sheep's extremities are clasped which enables the shearer to manoeuvre the sheep during shearing. The study found that shearers using the UPSP experienced 93% lower average cumulative compression and 97% lower average anterior shear at L4/L5 compared to shearers using the traditional method. Shearers using the UPSP also spent less time in severe trunk flexion (11% compared to the traditional 100% of the time) and more time in neutral trunk flexion (48% of the time as compared to 0% of the time when using the traditional method) [158]. The development of UPSP will lead to a considerable reduction in lower back injury and will likely be an area of more research.

A recent publication by Marras et al. [138] summarises the literature on the various factors that influence the risk of musculoskeletal injuries, the interaction of these factors on injury risk and also identifies areas of future research directions addressing occupational health and safety. Some of the research directions identified are directly applicable to the wool harvesting industry. For example:

1. traditionally high forces and highly repetitive loading of the musculoskeletal system has been linked to high demand occupational task. However recently there are changes to workplace and the nature of the work (raised board shearing sheds compared to traditional floor shearing areas, use of UPSP compared to traditional stooped shearing). Therefore research must now be directed to examine these new workplaces and adapted working patterns for musculoskeletal loading.
2. This current research explores the influence of LBP-Clin, skill and a few anthropometric data on the cumulative loads on the spine; however research has identified that the risk of musculoskeletal injury is multifactorial in nature therefore other risk factors such as psychosocial, epidemiological should be explored. It has been reported that psychosocial factors influence injury risk at low force levels while biomechanical factors override psychosocial factors at higher levels of force.

3. Shearers and wool handlers have a high risk of lower back and upper limb injuries, and most of them return to work. No research till date has looked at these workers specifically to identify the risk of secondary injury associated with a return-to-work.

5.7 Reliability of 3D Match:

Previous studies by Jackson et al. [105] shows excellent inter-rater reliability for using 3DMatch, and also document that 3DMatch was more reliable at calculating spine compression, anterior/posterior shear and flexion/extension moments compared to a previously used 2D model. However this study was conducted in a laboratory with a single sagittal view and therefore an inter-rater reliability of large sample of data gathered at industry was needed to validate the results of this study. Sullivan et al. [59] also determined the inter- and intra observer reliability for calculating cumulative spinal loads using the same 3DMatch software. Their results also show; high ICC values indicating excellent intra-rater reliability; little variability across days and across all observers for joint moment, joint compression, joint shear and reaction shear forces. However, again this study was experimental with one video file consisting three tasks, each task of fairly short durations (5 to 6 seconds).

The inter-rater reliability of 3DMatch was also explored in this study by two raters (principal investigator and a research assistant) it was dee med necessary to seek a moderate to excellent agreement and thus indicate that the process of evaluation was a reliable and repeatable methodology. .Video clips of 20 randomly selected shearers were used for this calculation, intra-class correlation coefficients and Bland Altman plots were used to evaluate the inter-rater reliability. The guidelines proposed by Portney and Watkins [136] was that ICC values greater than 0.5 but less than 0.75 are considered moderate agreement and values greater than 0.75 are considered as good to excellent. The inter-rater reliability was carried out for the four variables; CC, CJAS, PC and PJAS and result shows excellent reliability for CC and CJAS and moderate reliability for PC and PJAS. The inter-rater Coefficient of Variation (1.96*sd) was ± 369.2, ± 22.6 Ns, ± 1087.4 Ns and ±50.2Ns respectively. The mean inter-rater difference for CC was 81.1Ns (95% CI ±82.6; $p = 0.069$) indicating no difference between the two raters however

CJAS had a mean inter-rater difference of (-23.5) Ns (95% CI, ±5.0; p = <0.001) indicating a significant difference between raters. PC and PJAS had a mean inter-rater difference of (-45.2) N (±243.1) and 0.2N (±11.2, 95% CI). Although the values for these mean inter-rater differences are statistically significant but they are considered negligible compared to the actual values of CJAS, PC and PJAS.

This can be more clearly seen by on observing the Bland Altman plot where for CC the difference between the two raters for CC, CJAS, PC and PJAS is evenly distributed across mean values of 2500 to 3500N.s, (-225) to (-150N.s), 3000 to 4500Ns and 200 to 240 N.s respectively. The above shows a good agreement between the two raters for all variables analysed.

5.8 Summary:

This study shows that skill and LBP-Clin do not appear to have a significant separate or combined interaction effect on either cumulative or peak forces during shearing (shearing inclusive of catch and drag phase) and wool handling. However skill does influence peak compressive force within the catch and drag phase in junior, intermediate and senior shearers and also decreases the cumulative extensor moments in junior and senior wool handlers. Some studies have shows that the peak forces are higher in the highly skilled workers than their lesser skilled colleagues. However, this current study has only explored the forces in the sagittal axis; a more recent publication by Pal et al. [159] has explored the influence of skill and LB-Clin on lateral shear and rotational forces.

In the current study LBP-Clin was only associated with an increased peak extensor moment during the catch and drag phase of shearers. Although there is no significant difference between the cumulative or peak forces between skill levels yet the prevalence of LBP-Clin in shearers and wool handlers is high with advancing skill levels therefore although a direct causal link between LBP-Clin and such force magnitudes is unknown but is suspected. It will take cohort investigations and perhaps case control studies to determine how increasing forces, experience and skill interact and create (or ameliorate) risk for back injury in this workforce. Further research will also explore the influence of skill and LBP on medio-lateral shear, lateral bend and axial twist moments as well as percentage time in working postures.

A comparison of the shearing and wool handling occupations reveals the difference in shearing task demands of the catch and drag phase and prolonged stooped posture, which comprises approximately 90% of the shearing task, results in greater relative increases in anterior shear forces than seen in compressive forces between the two occupations. A previous study by Milosavljevic et al.[50] shows that these prolonged stooped postures result in adaptive changes to the spine; decrease in lumbar lordosis, increase in hip flexion and a loss of lumbar extension. Therefore shear force would appear to be the dominant difference in spinal loading between the two occupations and appears to be task specific. These observations in peak and cumulative spinal loading are consistent across all skill levels however the prevalence of LBP-Clin is not.

The estimated incidence of LBP per year at different skill levels reveals no appreciable difference between the two occupations with the notable exception of the intermediate shearers. Where a considerable increase in the yearly incidence of LBP occurred (17.8%) in a time span of 2.3 years; approximately one year on from the junior shearers. Further, it would seem plausible that the increased LBP-Clin associated with shearing compared to wool handling is likely attributable to the beginning of the profession and becoming accustomed to the unique loading demands of higher peak compressive and shear peak forces of the catch and drag, higher workload (tally), and cumulative forces of the stooped posture. Eliminating the higher incidences of LBP-Clin in these initial shearing years (intermediate shearer) may well reduce the LBP-Clin prevalence between shearers and wool handlers. This may be a more graduated introduction into the profession, specific skill training, or strength/flexibility training to the task demands. Perhaps the use of other interventions, such as the use of wooden floor parallel to the direction of sheep drag to decrease the drag force is needed, or alternative mechanical device to reduce these loads, remove the catch and drag and/or eliminate the stooped posture may have a role to play in the reduction of incidence of LBP in shearers.

It can also be seen that higher skill level shearers and wool handlers seem to self-regulate their workloads whereby although there is a significant increase in the workloads it does not lead to an increase in cumulative or peak loads. This observation does not preclude cumulative loading as a key contributor to the higher prevalence of LBP-Clin seen in these two occupations that are 2 to 6 times higher than other occupational groups, but may explain the difference seen in LBP-Clin between the shearing and wool handling occupations.

5.9 Limitations

A limitation of this study is that shearers and wool handlers who competed in these annually held shearing competitions did so to either attain a higher skill level or a higher ranking within each skill category. One could easily assume that the working patterns of these workers during these wool harvesting competitions are more challenged or perhaps in some way different from normal practice but personal communication with industry experts disagree with the above assumption. Senior colleagues and industry experts argue that shearers are graded based on many factors such as time to shear, neatness of shearing, execution of tasks in an orderly manner and shearing a sheep with minimal cuts so all shearers and wool handlers take all the necessary precautions as they would during a typical day in the shearing shed. This study is unable to pick up differences between skill levels on the cumulative and peak forces for the following reasons; all participants would have probably worked to the best of their ability, each one of them trying to reach their optimal level thereby there is a reduction in the variability; being a competitive environment of a short duration (<10mins for each run/heat) would mean that there is no/ reduced slackness and lapses in attention ruling out motivation as a confounding factor and finally; a better presentation and execution of the key shearing patterns at each skill level for that short duration in the competition compared to the whole day of shearing/ wool handling.

Another limitation is in regards to the catch and drag segment of this study where a proxy video clip was used for the catch and drag segment analysis for all shearers. It is well established that tasks such as dragging, pulling and pushing activities [20, 21] are important risk factors in the development of LBP. Also the total daily catch and drag forces amounts to approximately 15 to 20 tonnes. Where there is likely to be a high risk factor for back injuries in this phase of shearing it is a limitation to be using a proxy video clip of open shearers for all skill types.

The average time of catch and drag phase was calculated to be 11.3s, 9.7s, 8.9s and 8.5s for the junior, intermediates, senior and open shearers respectively. These values were obtained by timing the video clips of a sample (2-3 shearer) of each skill level and using this time as the *representative time* of each skill level. The shearing time was 143.5s, 98.1s, 86.1s and 64.9s for the junior, intermediates, senior and open shearers. This implies that catch and drag phase represents 7%, 9%, 9% and 12% of the total shearing time which is contrary to the findings of Gmeinder et al. [6] who calculated that shearers spent 80% time while shearing and 20% time dragging sheep.

The proxy clip used for the posture-matching analysis incorporated the anthropometric data of each individual shearer. The cumulative catch and drag loads generated by this clip was then extrapolated to the *respective time* for each skill level and added to the cumulative shearing loads. Although this method is limiting in assuming that each skill level shearer has the same catch and drag time and the extrapolation of a proxy clip load therefore likely errors in the calculation of cumulative forces and especially if the cumulative forces in the catch and drag phase is explored. Although Norman et al. [14] also used a proxy method in place of an actual worker, the study had used twenty proxies in a sample size of 104 subjects while this current study used 80 proxies in a sample of 80 subjects.

Another limitation is the method used in calculating the catch and drag forces. As previously described in section 3.7.3 a load cell was connected to a harness and the catch and drag forces were measured. This method is limiting in the sense that the grip contact between the shearer and the sheep is not as in an actual shearing environment and the timing and mode of force generation might be affected. However the force profiles for each catch and drag graph in appendix 5 is similar yet the direction of pull was affected and which could have affected the force profiles. Nevertheless this research study used the force magnitude and not the mode or timing of force generation so it is assumed that this would have not influenced the results to a significant extent. The reliability of obtaining these forces was not considered which might have compromised the hand forces estimated once in a day by the use of the load cell. However, the reliability of obtaining this hand forces was affected by practical limitations such as arranging for another session of data collection at the convenience of the shearers, keeping the same sheep to be caught and dragged as well as using the same location for the data capture.

Another key limitation is that the sample size for calculating working lifetime prevalence of LBP-Clin. In each group of 20 shearers between 2 and 17 shearers had experience LBP and a difference by one subject will make a considerable difference to the percentages of LBP at each skill level. A future study with a larger survey of lifetime prevalence of LBP, tally, age, and experience would reveal more representative values across the shearing industry.

Cumulative loads were calculated by using a binned posture approach therefore it is impossible to rule out errors occurring due to human selection while using 3D Match. In order to increase the accuracy of the posture bin selection Sutherland et al. [106] has recommended the use two camera views. However due to practical limitations of setting the data capture in an actual shearing competition only one camera view was possible for this study. However the error arising by using one camera view should not majorly influence the results of the study as the participants were still captured in their optimal working positions as recommended by Sutherland et al. [106]. Nevertheless a reliability study was also undertaken to determine the inter-rater error associated with this analysis. The results of the reliability study showed excellent agreement for CC and CJAS forces and showed moderate agreement for the PC and PJAS forces. However the main aim of this current study was to determine the influence of skill and LBP-Clin on cumulative and peak forces, therefore a consistent under or over estimation of the cumulative and peak loads will not affect the results of this study.

The cumulative load estimates for this study might be slightly higher than previous studies however as mentioned before different methodologies evolved over the decade all attempting to quantify cumulative loads therefore an over or under-estimation does not reflect flaws of previous or current methodologies but rather a step towards better and easier ways of documenting cumulative loads. Moreover it helps forming a database for future research and comparisons. Some additional reasons could be that the extrapolation of data captured from the wool harvesting competitions did not take into account the occasional breaks that shearers and wool handlers take if they were working in their own environment. These breaks could range from 30 to 60mins for an entire working day. However one of the main purposes of this study was to determine the influence of skill and LBP-Clin on cumulative spinal loads of shearers, therefore an over or under estimation of the cumulative loads will not affect the comparative results of this study.

5.10 Conclusion

This study reports the cumulative and peak spinal forces for all formal skill categories within shearers and wool handlers. Correlation analysis shows that skill and LBP-Clin are moderately correlated for shearers and weakly correlated for wool handlers however advancement in skill does not result in a decrease in LBP-Clin prevalence for shearers or wool handlers. With the exception of peak extensor moment and peak compressive forces in the catch and drag, and cumulative extensor moment during wool handling skill or LBP-Clin or the combination of skill*LBP-Clin does not statistically influence cumulative or peak loads during shearing, catch and drag phase of shearing and wool handling.

Recommendations for the wool harvesting industry is to continue the formal skill training as skill does have an effect on reducing peak compressive force during the catch and drag in shearers and cumulative extensor moment in wool handlers. LBP-Clin did have an influence on peak extensor moment during catch and drag phase. Skill learning appears to have a role to play particularly at the intermediate level. These relationships were not strong but present, and would agree with the high incidences especially when considering the prevalence of LBP-Clin the intermediate years. Previous research has also shown the beneficial influence of skill in reducing energy expenditure per sheep. Subsequently improving skill means increase in working tally which is beneficial in terms of production and efficiency. Perhaps the most important finding of this study is that increase in skill level does not expose the worker to increased cumulative or peak spinal loading and probably reduces the risk of LBP.

Further research with a larger within-skill sample size and perhaps a prospective study is needed to clarify all the above findings. Future research should explore the influence of skill and LBP on forces in other directions (medio-lateral shear, lateral bend and axial twist moments) as well as percentage time in working postures.

This research study is in agreement with previous research about sheep shearing being a physically demanding occupation with a high risk of back injury and the catch and drag component of shearing subjecting the spine to higher loads. Research has also established that the use mechanical interventions such as back harness, manipulators and change in shearing shed design does reduce cumulative and peak loads substantially. Wool harvesting industry show focus on research ideas directed towards interventions that eliminate or at least reduce some of the risk factors identified in the shearing profession; namely the peak loads, cumulative loads and anterior shear forces associated with the catch and drag and sustained stooped postures. Interventions such as alternative shearing techniques; upright posture shearing techniques to eliminate prolonged stooped shearing and catch and drag phase of shearing is desirable.

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Appendix 1

Ethical approval: UoO Ethics Committee

UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo
NEW ZEALAND

Academic Services
Manager, Academic Committees, Mr Gary Witte

05/120

24 September 2010

Dr S Milosavlijevic
School of Physiotherapy

Dear Dr Milosavlijevic

I am writing to let you know that, at its recent meeting, the Ethics Committee considered your proposal entitled "**Cumulative Loads on the Body during Wool Harvesting.**".

As a result of that consideration, the current status of your proposal is:- **Approved**

For your future reference, the Ethics Committee's reference code for this project is:- **05/120**.
The comments and views expressed by the Ethics Committee concerning your proposal are as follows:-

Please amend the title of the consent form for participants to read "Consent Form" not "Information Sheet".

Approval is for up to three years. If this project has not been completed within three years from the date of this letter, re-approval must be requested. If the nature, consent, location, procedures or personnel of your approved application change, please advise me in writing.

Yours sincerely,

Mr Gary Witte
Manager, Academic Committees
Tel: 479 8256
Email: gary.witte@otago.ac.nz

c.c. Professor G D Baxter Dean School of Physiotherapy

Appendix 2

Information sheet

University of Otago
SCHOOL OF PHYSIOTHERAPY

INFORMATION SHEET FOR PARTICIPANTS

CUMULATIVE LOADS ON THE BODY DURING WOOL HARVESTING

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request.

What is the aim of the project?

The aim of this study is to look into the daily exposure of forces on the low back in the various jobs involved in sheep shearing. These will include: the catching and dragging of sheep from the holding pens to the workstation; shearing; wool handling; and wool pressing.

What types of Participants are being sought?

We wish to conduct our research on the following groups:

- 20 'open class' male shearers and 20 'open class' wool handlers;
- 20 'senior' male shearers and 20 'senior' wool handlers;
- 20 'novice' male shearers and 20 'novice' wool handlers.

All participants must be fulltime shearers or wool handlers.

People who are in one or more of the categories listed below will not be able to participate in the project because, in the opinion of the researchers and the University of Otago Human Ethics Committee, it may involve an unacceptable risk to them:-

- Participants with a history of spinal surgery will be excluded from the study.

What will Participants be asked to do?

Should you agree to take part in this project, you will:

- Be videotaped whilst doing your normal job. We will videotape 6 repetitions of your normal work cycle. The camera will be placed in a position that does not affect your work performance.
- The time allocated for your participation will be for however long it takes to complete 6 repetitions of your work cycle.

- This research does not involve the placement of any devices on you and we do not foresee the potential for any harm or discomfort.
- Please be aware that you may decide not to take part in the project without any disadvantage to yourself of any kind.

Can Participants change their mind and withdraw from the project?

You may withdraw from participation in the project at any time and without any disadvantage to yourself of any kind.

What data or information will be collected and what use will be made of it?

Participants – gender, age, height, weight, work force survey data, and spinal forces calculated from the videotape analysis will be recorded.

This information will be used by the researchers to investigate the spinal loads during the shearing tasks and determine the total exposure in a given working day. The survey will be used to determine whether previous back pain is associated with specific shearing tasks.

The results of the project may be published and will be available in the University library but every attempt will be made to preserve your anonymity. You are most welcome to request a copy of the results of the project should you wish.

The data collected will be securely stored in such a way that only the investigators will be able to gain access to it. At the end of the project any personal information will be destroyed immediately except that, as required by the University's research policy, any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed.

What if Participants have any questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:-

Dr Stephan Milosavljevic
School of Physiotherapy,
University of Otago
University Telephone Number 03 479 7193
Freephone 0800 687 489
Email: stephan.milosavljevic@otago.ac.nz

or

Dr Alan Carman
School of Physiotherapy,
University of Otago
University Telephone Number 03 479 3979
Email: allan.carman@otago.ac.nz

This project has been reviewed and approved by the University of Otago Human Ethics Committee

Appendix 3

Consent form

University of Otago
SCHOOL OF PHYSIOTHERAPY

Consent Form

CUMULATIVE LOADS ON THE BODY DURING WOOL HARVESTING

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:-

1. my participation in the project is entirely voluntary;
2. I am free to withdraw from the project at any time without any disadvantage;
3. the data will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed;
4. the results of the project may be published and available in the library but every attempt will be made to preserve my anonymity.

I agree to take part in this project.

....
(Signature of participant) (Date)

This project has been reviewed and approved by the University of Otago Human Ethics Committee

Appendix 4

Demographic sheet

Cumulative loads on the spine during wool harvesting

Demographic details for participants.

For Participants

Name: Age

Sex: Ethnicity:

Ranking: Tally:

Weight (Kg):

Height (M):

Any history of spinal surgery:

Any history of low back pain/ injury requiring treatment:

For Researcher

Date of data collection:

Location of data collection:

Body mass Index (BMI) (Kg/M^2):

Appendix 5

Hand forces in shearers during Catch and Drag

Force profile of dominant hand:

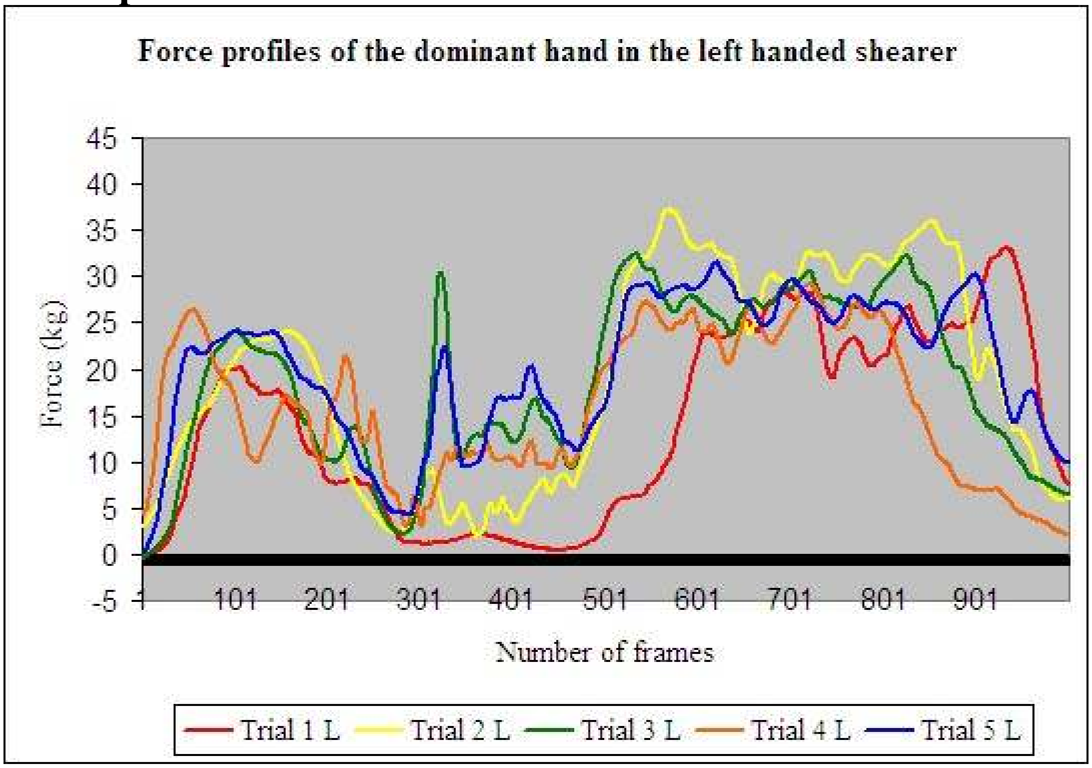

Figure 1: Force profiles of the dominant hand in the left-handed shearer

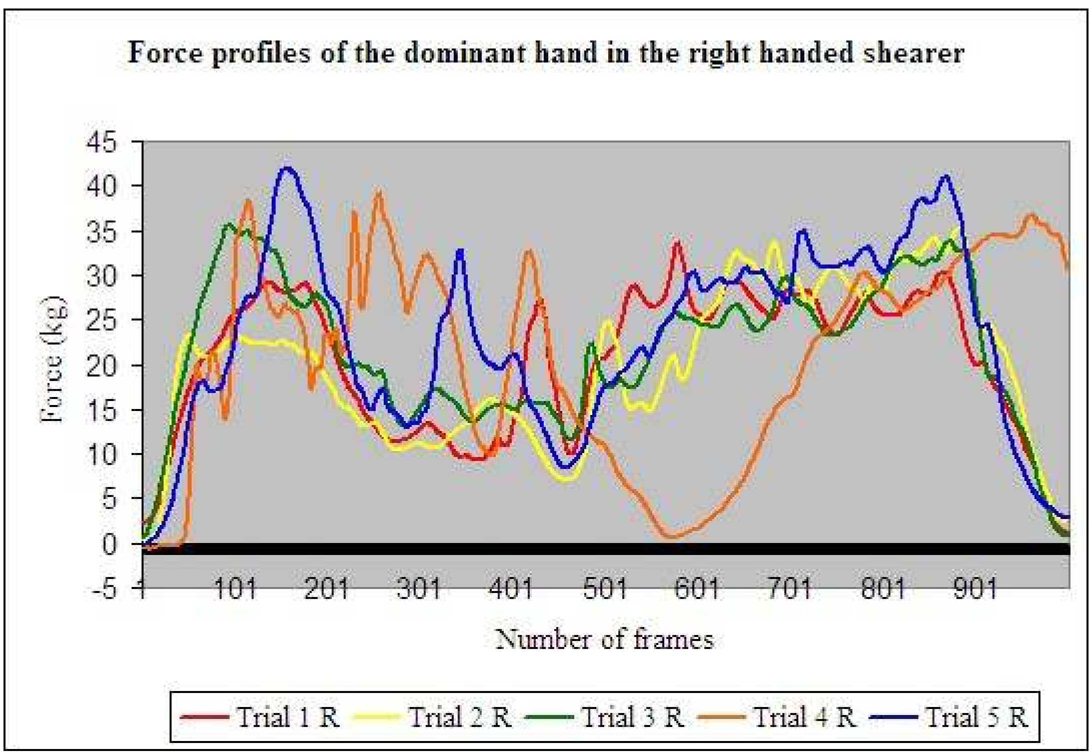

Figure 2: Force profiles of the dominant hand in the right-handed shearer

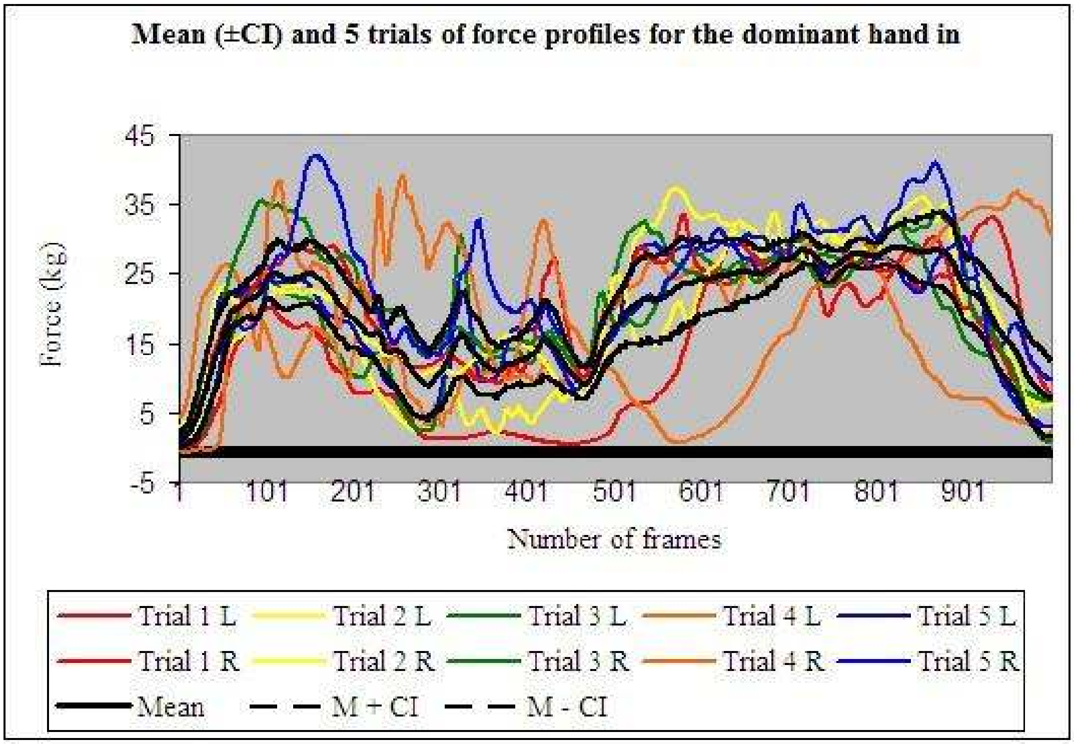

Figure 3: Mean (± 95% confidence interval (CI)) and 5 trials of force profiles for the dominant hand in both shearers

Force profile of non-dominant hand:

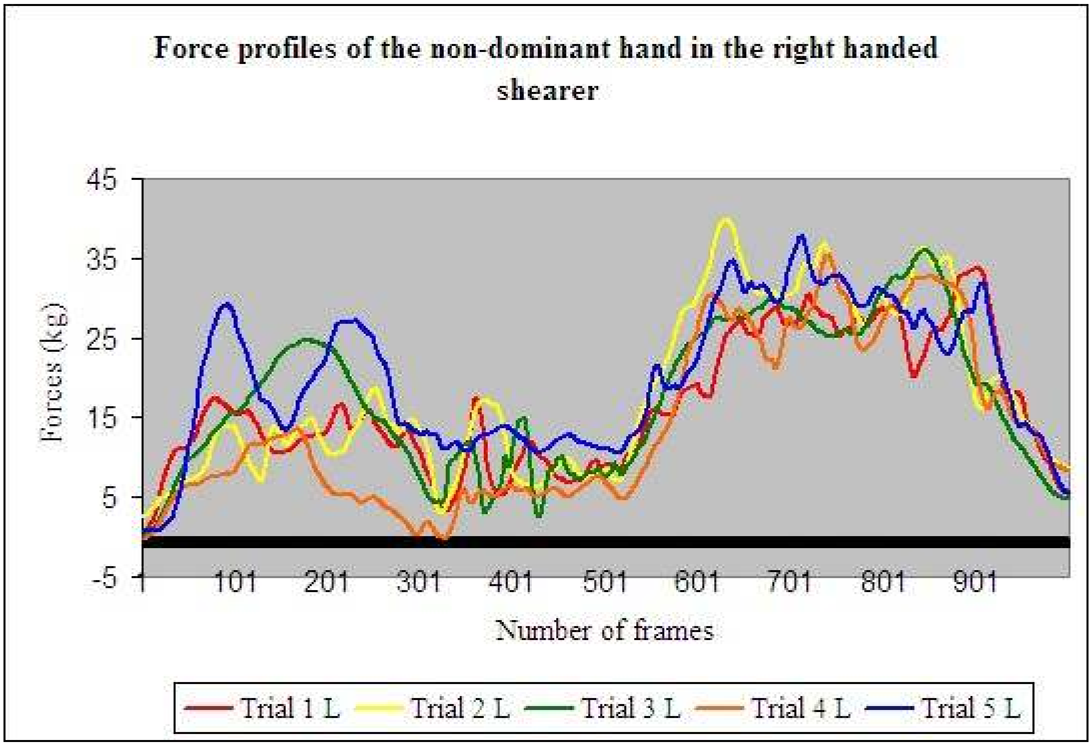

Figure 4: Force profiles of the non-dominant hand in the left-handed shearer

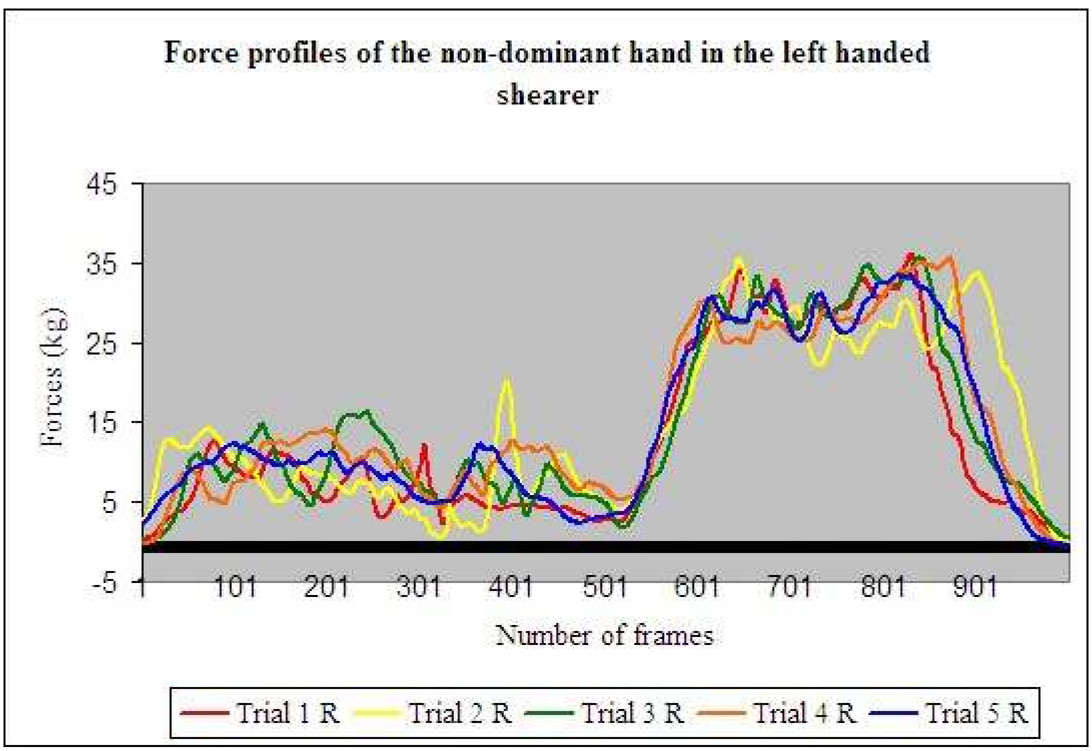

Figure 5: Force profiles of the non-dominant hand in the right-handed shearer

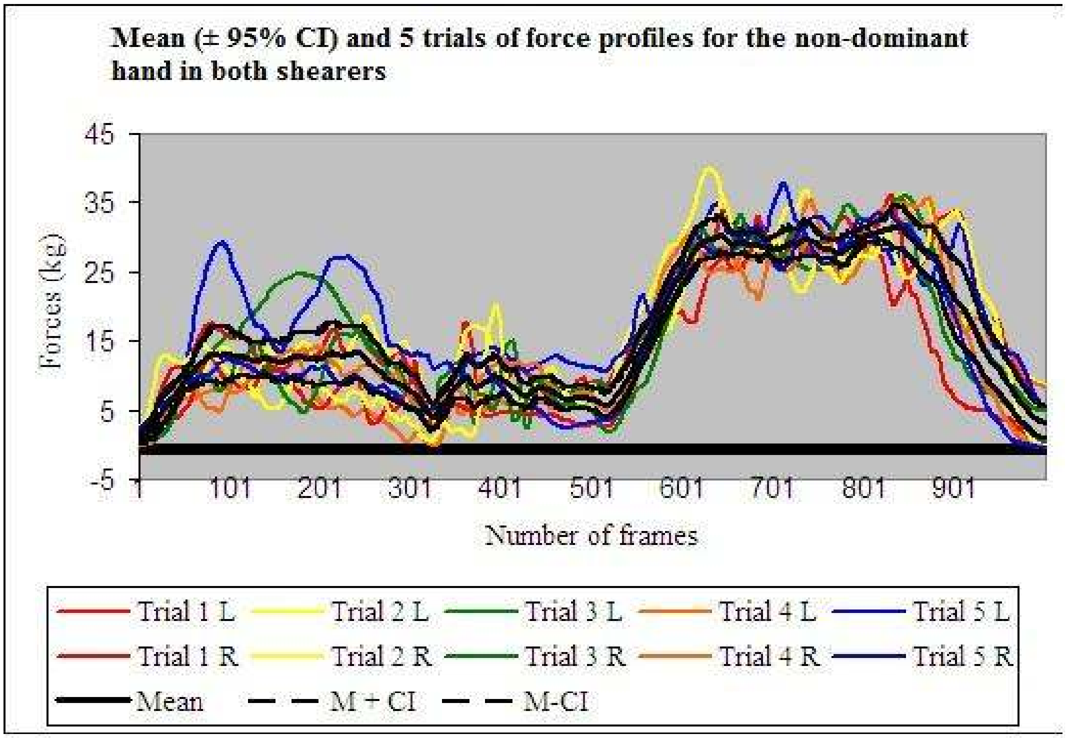

Figure 6: Mean (± 95% CI) and 5 trials of force profiles for the non-dominant hand in both shearers

Appendix 6

Publications

Publications:

Journal articles are not included in this thesis for copyright reasons and are cited below.

1. Pal, P., D.E. Gregory, S. Milosavljevic, A.B. Carman, and J.P. Callaghan, *A review of risk factors associated with low back injury in wool harvesting.* Journal of occupational health and safety - Australia and New Zealand, 2008. **24**(5): p. 435-453.

2. Pal, P., S. Milosavljevic, D.E. Gregory, A.B. Carman, and J. Callaghan, *The influence of skill and low back pain on trunk postures and low back loads of shearers.* Ergonomics, 2010. **53**(1): p. 65-73.
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