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An Examination of Shoulder Postures and Moments of Force Among Different Skill Levels in the Wool Harvesting Industry

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The wool harvesting industry employs workers of varying skill levels that differ in both quality and number of harvested fleeces. As it was unknown how skill affected parameters such as joint posture and loading, the current study comparatively examined 140 wool harvesting workers representing 4 skill levels during wool harvesting competitions. Three-dimensional upper limb postures and peak and cumulative shoulder moments were calculated for each worker. Results indicated that elite wool harvesters, in general, used different shoulder postures to perform the harvesting tasks and were thus exposed to different shoulder moments as compared to the lower skill levels. It is plausible that these adopted postures allow the higher class workers to perform their job with higher quality and greater speed as compared to the lower ranked workers. Postural-based training may help improve technique in lower ranked workers and enable these workers to achieve higher ranked status.

performance ergonomics sheep shearing biomechanics shoulder skill posture

1. INTRODUCTION

Wool harvesting is an economically important rural industry in a number of countries including New Zealand, Australia, the United Kingdom, Ireland, and South Africa. Wool harvesting has three distinct occupations: sheep shearing to remove the fleece, wool handling to grade and sort different fleece components, and wool pressing to package the wool into bales. Each of these industry sectors will handle many millions of fleeces annually. While not statistically documented or separated in injury compensation databases, anecdotal evidence suggests that shearers sustain the greatest number of injuries as compared to wool handlers and wool pressers.

Of the three sectors, only shearing has been previously examined from a biomechanical perspective [1, 2, 3, 4, 5]. These studies have examined sheep shearing and the risk of sustaining

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a low back injury [3]; ergonomic considerations while using a supportive trunk harness on spine posture and loading [2, 4], and on shoulder postures and moments [5]; and the effects of using alternative shearing tools to reduce the risk of injury to the worker [1]. However, these studies have only examined highly ranked shearers, with no documented investigation of the less skilled shearers, and there are no published studies that have examined the other two wool harvesting sectors; the wool handlers and wool pressers.

Shearers and wool handlers who successfully undertake formal skill advancement training programs are awarded a higher skill ranking that meets higher quality standards. These higher ranked shearers and wool handlers, respectively, have higher daily tallies of shorn sheep and sorted fleeces—and are highly valued by the wool harvesting industry as setting the benchmarks for quality of harvested wool as well as productivity. However, it is unknown whether individuals in each of the industry-recognized skill levels perform the tasks differently in regards to adopted postures and loading.

Many studies have examined the effect of skill level on kinematic and kinetic variables during a variety of sporting activities, yet only a few have examined the effect of skill level on such variables during occupational tasks. These occupational-based studies explored the effect of skill on low back loading, in particular during manual material handling [6, 7, 8]. These studies found that untrained, or lower skilled individuals, are exposed to higher spinal loading during lifting when compared to experienced workers. Keir and MacDonell examined the effect of skill in health care professionals while performing patient transfers, and found that experienced workers show different trunk muscle activation patterns when compared to less skilled workers, specifically higher levels of latissimus dorsi and trapezius muscle activation [9].

Determining the different posture and loading patterns across the skill levels in workers in the wool harvesting industry will help better our understanding of why some individuals are able to perform these tasks faster and more accurately than others. The current study has examined the three-dimensional shoulder postures and moments of sheep shearers and wool handlers from various skill levels. The purpose of the study was to document these parameters and to determine if differences exist between the skill levels within each occupational group. It was hypothesized that individuals in each of the skill levels for both sheep shearers and wool handlers would adopt different postures and be exposed to different shoulder moments.

2. METHODS

2.1. Wool Harvesting Occupations

2.1.1. Shearing

Shearing involves catching a sheep from the holding pen, dragging the animal to the shearing stand, and then removing the fleece from the animal with powered hand clippers. A typical shearer can shear a sheep in ~2 min, with higher ranked shearers completing the task in a shorter amount of time while still maintaining quality standards. Skill levels in the shearing occupation include open class (highest rank), followed by senior, intermediate, and junior classes in a decreasing skill classification.

2.1.2. Wool handling

There is little documented research of the wool-handling task. Following removal of the fleece from the sheep, the wool handler prepares, grades, and separates the various wool components of the fleece. Dependent on a farmer's wool harvesting strategy, as well as fleece quality, the task of wool handling usually involves three main components: gathering and throwing the fleece onto a wool-sorting table (Figure 1); skirting, when lower quality wool is removed from the edges of the fleece; and clean-up, including floor sweeping. Skill levels in the wool handling occupation include open class (highest ranking), followed by senior, and junior. Note that no intermediate class exists for wool handlers.

Figure 1. Fleece throw by a wool handler: (a) the wool handler with the fleece still bundled up just after she releases the fleece, (b) the fleece unfolds like a blanket on the wool sorting table.

2.2. Participants

2.2.1. Shearers

Eighty shearers from four class levels (20 junior, 19 intermediate, 20 senior, and 21 open class) were recruited from two shearing competitions in the South Island of New Zealand. Their characteristics are summarized in Table 1. In such competitions, the shearer's score is based on both the time taken to shear the sheep as well as the quality of the removed fleece. In the current study, each participating shearer was videotaped catching, dragging, and shearing three sheep, with the exception of the junior shearers who only shore two sheep. Catching involves securing a sheep from the catching pen and dragging it out to the shearing stand. Shearers were videotaped from two different camera locations during each catch and drag and shearing cycle. One camera was located ~30 m from the participant with a frontal orientation, and the other camera was located ~10 m from the participant with a sagittal orientation.

2.2.2 Wool handlers

Sixty wool handlers from three class levels (20 junior, 20 senior, and 20 open class) were recruited from the same wool harvesting competitions in the South Island of New Zealand. Wool handler characteristics are also found in Table 1. In wool harvesting competitions, specifically wool handling, score is determined based on the quality of wool preparation and

TABLE 1. Mean (*SD*) of Sheep Shearer and Wool Handler Information

Skill Level	*n*	Gender	Age (years)	Height (m)	Mass (kg)	Experience (years)	Estimated Daily Sheep/ Fleece Tally
Shearers							
junior	20	all male	19.2 (4.0)	1.78 (0.07)	83.50 (10.74)	1.4 (0.9)	198 (27)
intermediate	19	all male	21.7 (3.3)	1.83 (0.05)	86.63 (13.70)	2.3 (1.6)	267 (29)
senior	20	all male	27.2 (8.8)	1.80 (0.08)	85.60 (11.56)	6.8 (5.7)	302 (23)
open	21	all male	32.9 (7.6)	1.80 (0.07)	85.14 (11.24)	13.9 (7.5)	391 (24)
Wool handlers							
junior	20	f = 19, m = 1	22.9 (5.7)	1.62 (0.06)	69.75 (14.91)	4.9 (5.1)	218 (23)
senior	20	f = 18, m = 2	27.9 (7.6)	1.66 (0.07)	73.28 (19.84)	9.3 (6.0)	217 (15)
open	20	f = 17, m = 3	32.0 (10.0)	1.68 (0.08)	73.08 (14.31)	14.2 (8.4)	259 (14)

Notes. f—female, m—male. The estimated daily sheep/fleece tally was determined by extrapolating the time taken to shear each sheep for each shearer and the time taken to prepare and classify each fleece for each wool handler in competition to an 8-h workday.

classification as well as the time taken to complete the task. Dependent on skill level, each wool handler prepared and classified either two or three fleeces in the competition, during which each participant was videotaped from two different camera locations. All videos were prepared and formatted to comply with North American video format as per Gregory, Milosavljevic, and Callaghan [4]. Each participant reviewed and consented to an outline of the experiment, approved by the University of Otago Human Ethics Committee.

2.3. Video Capture

Following video format alteration, each video was captured to AVI digital format. Each video file for each shearer (separate video file for each sheep shorn, therefore, either two or three videos depending on the participant skill level) was ~1.5 min, and ~5 min for each wool handler (combined time for all fleeces classified). The wool handlers were not examined per fleece, but rather all fleece classifications were examined together, as the wool handling task includes not only fleece classification but cleaning between each fleece. Each captured video trial was analyzed at 3 frames/s; the acceptable sample rate sufficient to calculate cumulative loading as determined by Andrews and Callaghan [10].

2.4. Upper Limb Posture and Shoulder Moment Analysis

3DMatch (University of Waterloo, Waterloo, ON, Canada) is a specialized program designed to calculate cumulative moments about each anatomical axis of the shoulders using a posture matching approach. Specifically, 3DMatch software uses upper limb posture inputs selected from binned postures determined for each frame of the video, combined with external three-dimensional hand forces, to determine three-dimensional moments about each shoulder. There are six posture bin selections for trunk flexion/extension, three for each of trunk lateral bend and axial twist, four for head flexion/extension, two for head lateral bend, three for head twist, six for each of shoulder flexion/extension and abduction/adduction, and five for elbow flexion/extension. For a more detailed description of 3DMatch, refer to Gregory et al. [4].

During each catch and drag trial, a pull force was considered to act on each hand of the shearers, specifically 126.7 and 222.6 N in the right and left hands, respectively (total 349.3 N), based on the findings of previous unpublished data examining the pull force during catch and drag, quantified by using a harness in series with a load cell. These values are similar to those reported by Harvey, Culvenor, Payne, et al., who reported a total drag force in the hands of 388.2 N over a wooden surface, similar to the surface in the current study [11]. During the shearing trials, a 10-N load was assumed to act in the hand that held the clippers to account for the mass of the clippers (1 kg). During the fleece throw, a 27.9-N downward force was input for each hand (total mass of fleece 5.6 kg based on Johnstone's industry report [12]) and any time a tool was used (e.g., a broom), the mass of that tool was input as a force applied to the hand holding the tool. The moments calculated for each frame (sample rate 3 frames/s) were integrated over the entire duration of either the shearing trial or the wool handling trial to determine the cumulative shoulder moment for one complete shearing/wool handling exposure. These cumulative moments were then extrapolated to an 8-h workday. For the shearing trials, the catch and drag cumulative moments were extrapolated out to 20% of the workday, and the shearing cumulative moments were extrapolated out to the remaining 80% of the workday. These ratios were chosen based on Gmeinder [13]. For the wool handling trials, the length of time required to prepare and classify the fleece in the competition was linearly extrapolated to 8 h. In addition to the three-dimensional cumulative moments, peak moments were also determined for each participant. Last, the percentage of time spent in flexed and adducted/abducted shoulder postures was determined for each shearing/wool handling trial. For flexion, <20° flexion was defined as neutral, 20–90° flexion was defined as mild, and severe was considered >90° flexion [14, 15]. For abduction, >45° abduction was considered

neutral, 45–90° abduction was mild, and severe was defined as >90° abduction [15], whereas adduction was defined as any shoulder posture medial to neutral.

2.5. Statistical Analysis

One-way analysis of variance (ANOVA) between skill level (junior, senior, intermediate [shearers only], open) was performed using the 95% rejection level for all posture variables, as well as peak and cumulative shoulder moments. A Tukey post hoc test was further used to determine significance between the different levels of skill.

3. RESULTS

Table 2 summarizes the effect of skill level on the percentage of time spent in shoulder postures

TABLE 2a. Summary of All Mean (*SD*) Shoulder Postures for Sheep Shearers for Each of the 4 Sheep Shearing Skill Levels: Junior, Intermediate, Senior, and Open

Sheep Shearer Shoulder Postures (% time)		Junior		Intermediate		Senior		Open		*p*
Right arm	neutral flexion	6.63 (1.58)		7.54 (1.75)		7.27 (1.99)		7.67 (1.96)		.3500
	mild flexion	48.31 (7.06)	*	46.30 (10.47)	*	64.48 (7.59)	#	62.05 (8.04)	#	<.0001
	severe flexion	45.06 (7.68)	#	46.15 (10.72)	#	28.25 (7.15)	*	30.28 (8.10)	*	<.0001
	adduction	2.54 (1.10)	*	2.90 (1.71)	*	4.34 (1.47)	*	11.81 (7.07)	#	<.0001
	neutral abduction	91.36 (4.32)	#	89.64 (4.26)	#	91.89 (2.22)	#	85.40 (6.72)	*	.0020
	mild abduction	5.98 (4.38)	#*	7.18 (3.84)	#	3.73 (1.98)	*	2.77 (1.45)	*	.0020
	severe abduction	0.12 (0.18)		0.28 (0.56)		0.04 (0.09)		0.02 (0.09)		.2200
Left arm										
	neutral flexion	8.78 (2.27)	#*	9.88 (2.06)	#	8.23 (1.93)	*	9.68 (2.17)	#	.0400
	mild flexion	55.23 (5.99)	*	51.26 (9.61)	*	71.22 (6.88)	#	65.29 (7.02)	#	<.0001
	severe flexion	35.99 (6.67)	#	38.87 (9.69)	#	24.11 (6.59)	*	25.03 (6.76)	*	<.0001
	adduction	4.84 (2.57)	#*	3.68 (1.42)	*	4.57 (2.04)	*	10.42 (8.66)	#	.0020
	neutral abduction	87.74 (4.61)		85.47 (5.70)		91.12 (3.07)		87.89 (8.42)		.0600
	mild abduction	7.37 (4.15)	@	10.53 (5.23)	#	4.15 (2.44)	*	1.69 (1.13)	*	<.0001
	severe abduction	0.05 (0.08)	*	0.32 (0.54)	#	0.16 (0.37)	#*	0.01 (0.03)	*	.0040

Notes. Means with different symbols are significantly different from each other within a single row ($p < .05$), while means with no symbol are not significantly different from any other skill level mean.

TABLE 2b. Summary of All Mean (*SD*) Shoulder Postures for Wool Handlers for Each of the 4 Sheep Shearing Skill Levels: Junior, Intermediate, Senior, and Open

Wool Handler Shoulder Postures (% time)		Junior		Senior		Open		*p*
Right arm	neutral flexion	39.21 (9.66)	#	35.29 (6.84)	#	29.52 (5.24)	*	.0077
	mild flexion	49.79 (7.90)	*	52.74 (7.08)	*	57.40 (4.28)	#	.0190
	severe flexion	11.00 (3.02)		11.96 (2.87)		13.08 (2.54)		.2400
	adduction	4.75 (1.87)	#*	3.55 (1.51)	*	5.98 (1.88)	#	.0002
	neutral abduction	81.70 (5.20)	#*	84.49 (4.93)	#	78.37 (4.03)	*	.0006
	mild abduction	13.25 (5.41)		11.57 (5.01)		15.09 (4.30)		.0900
	severe abduction	0.30 (0.34)		0.38 (0.29)		0.57 (0.47)		.2100
Left arm								
	neutral flexion	39.61 (9.78)	#	33.20 (7.55)	*	30.07 (5.57)	*	.0210
	mild flexion	51.89 (8.69)		57.39 (8.05)		59.42 (4.42)		.0670
	severe flexion	8.50 (2.74)		9.41 (2.26)		10.51 (2.21)		.1100
	adduction	7.13 (3.34)	#*	4.80 (2.47)	*	7.93 (3.44)	#	.0030
	neutral abduction	79.69 (5.51)	*	84.43 (4.69)	#	77.66 (6.07)	*	.0005
	mild abduction	12.95 (4.75)		10.45 (3.80)		13.74 (4.59)		.0530
	severe abduction	0.22 (0.25)		0.31 (0.48)		0.67 (0.80)		.0680

Notes. Means with different symbols are significantly different from each other within a single row ($p < .05$), while means with no symbol are not significantly different from any other skill level mean.

including flexion/extension, and adduction/abduction for both the sheep shearers and wool handlers. Increasing skill in sheep shearers was accompanied by more time in mild shoulder flexion (and consequently less time in severe shoulder flexion) in open class and senior class shearers as compared to junior and intermediate shearers. The open class shearers also spent more time in adducted postures when compared to the other skill levels and consequently less time in shoulder abduction. For the wool handlers, open class workers spent more time in mild shoulder flexion compared to the neutral positioning in the other skill levels, more time in adducted shoulder postures as compared to the other skill levels and consequently less time in neutral abduction.

Tables 3–4 summarize the effect of skill level on the peak and cumulative shoulder moments including flexor/extensor, internal/external, and adductor/abductor moments. The following findings were found to be significant ($p < .05$) and individual p values can be found in Tables 3–4.

TABLE 3a. Summary of All Mean (*SD*) Peak Shoulder Moments for Each of the 4 Sheep Shearing Skill Levels: Junior, Intermediate, Senior, and Open

Sheep Shearer Peak Shoulder Moments (Nm)		Junior		Intermediate		Senior		Open		*p*
Right arm	flexor	16.69 (2.19)		17.98 (1.91)		17.23 (2.26)		18.04 (2.83)		.680
	extensor	13.32 (2.82)	#	15.01 (3.19)	#*	17.00 (3.00)	*	17.57 (3.21)	*	.005
	abductor	6.50 (1.45)	*	7.63 (1.91)	#	6.27 (1.69)	*	7.60 (1.77)	#	.049
	adductor	9.75 (1.97)	*	10.51 (2.33)	*	10.88 (2.36)	#*	12.50 (2.38)	#	.002
	internal rotation	7.61 (2.45)	*	7.92 (2.32)	*	7.87 (2.36)	*	10.67 (2.11)	#	.008
	external rotation	15.36 (2.83)		16.25 (2.21)		15.95 (1.95)		16.07 (2.70)		.990
Left arm										
	flexor	10.90 (2.36)		11.26 (1.90)		10.86 (1.86)		11.21 (1.88)		.970
	extensor	10.25 (2.36)		10.52 (1.92)		11.33 (2.34)		11.50 (2.29)		.570
	abductor	5.43 (1.48)		5.73 (1.37)		5.07 (1.17)		5.72 (1.30)		.380
	adductor	6.93 (1.37)		7.88 (1.80)		7.55 (1.29)		8.28 (2.11)		.180
	internal rotation	7.03 (1.52)		7.41 (2.07)		6.02 (0.93)		6.58 (1.51)		.200
	external rotation	10.57 (2.18)		10.98 (1.81)		10.47 (2.23)		10.43 (1.87)		.690

Notes. Means with different symbols are significantly different from each other within a single row ($p < .05$), while means with no symbol are not significantly different from any other skill level mean

TABLE 3b. Summary of All Mean (*SD*) Cumulative Shoulder Moments for Each of the 4 Sheep Shearing Skill Levels: Junior, Intermediate, Senior, and Open

Sheep Shearer Cumulative Shoulder Moments (kNm·s)		Junior		Intermediate		Senior		Open		*p*
Right arm	flexor	145.54 (26.99)	#	164.16 (30.88)	#	105.42 (22.37)	*	119.91 (30.80)	*	<.0001
	extensor	434.71 (27.18)		442.12 (18.02)		463.02 (73.90)		447.84 (34.08)		.3500
	abductor	27.90 (6.24)	*	34.99 (8.30)	#	31.02 (5.53)	#*	27.84 (6.29)	*	.0030
	adductor	55.85 (5.26)	*	65.71 (8.50)	#	65.60 (13.76)	#	63.55 (10.84)	#*	.0082
	internal rotation	7.86 (2.11)	*	11.40 (3.21)	*	12.92 (5.29)	*	21.59 (10.97)	#	<.0001
	external rotation	106.89 (27.17)	#	124.79 (28.03)	#	98.21 (14.20)	*	82.37 (18.90)	*	.0003
Left arm										
	flexor	67.73 (17.38)	#	77.56 (20.04)	#	44.40 (13.93)	*	56.83(15.57)	*	<.0001
	extensor	421.68 (27.15)		430.99 (16.85)		451.42 (64.95)		420.05 (32.06)		.1000
	abductor	26.35 (4.10)	*	33.87 (7.07)	#	26.95 (4.15)	*	26.80 (5.45)	*	<.0001
	adductor	14.15 (4.39)	*	13.45 (4.85)	*	20.56 (6.10)	#	24.97 (5.68)	@	<.0001
	internal rotation	7.33 (4.60)	*	6.02 (2.07)	*	6.64 (1.88)	*	15.52 (6.73)	#	<.0001
	external rotation	67.46 (18.89)		78.73 (23.13)		66.19 (12.18)		64.56 (13.37)		.0730

Notes. Means with different symbols are significantly different from each other within a single row ($p < .05$), while means with no symbol are not significantly different from any other skill level mean

TABLE 4a. Summary of All Mean (*SD*) Peak Shoulder Moments for Each of the 3 Wool Handling Skill Levels: Junior, Senior, and Open

Wool Handler Peak Shoulder Moments (Nm)		Junior		Senior		Open		*p*
Right arm	flexor	21.44 (3.81)		22.75 (4.16)		24.10 (3.77)		.0820
	extensor	6.85 (1.32)		7.58 (2.43)		7.06 (2.13)		.4100
	abductor	4.86 (2.10)	*	4.85 (2.03)	*	6.86 (3.31)	#	.0083
	adductor	15.96 (5.54)		14.71 (4.76)		15.85 (6.04)		.8100
	internal rotation	5.71 (1.77)		5.66 (1.94)		6.32 (2.12)		.3100
	external rotation	11.14 (3.57)		12.15 (4.32)		13.21 (4.07)		.1600
Left arm								
	flexor	21.30 (3.70)		22.93 (4.50)		23.89 (3.35)		.0810
	extensor	7.43 (1.96)		8.24 (2.65)		8.18 (2.36)		.2500
	abductor	5.14 (2.80)		4.71 (1.73)		5.28 (1.70)		.6500
	adductor	15.67 (4.14)		15.14 (4.44)		16.46 (5.88)		.7000
	internal rotation	6.82 (3.62)		6.41 (2.50)		7.65 (1.90)		.2200
	external rotation	10.08 (2.42)	*	10.62 (2.36)	#*	12.20 (2.68)	#	.0210

Notes. Means with different symbols are significantly different from each other within a single row ($p < .05$), while means with no symbol are not significantly different from any other skill level mean

TABLE 4b. Summary of All Mean (Standard Deviation) Cumulative Shoulder Moments for Each of the 3 Wool Handling Skill Levels: Junior, Senior, and Open

Wool Handler Cumulative Shoulder Moments (kNm·s)		Junior		Senior		Open		p
Right arm	flexor	66.42 (11.41)	*	78.91 (22.88)	#*	85.19 (20.07)	#	.018
	extensor	20.04 (8.84)	#*	20.60 (7.42)	#	14.70 (4.83)	*	.043
	abductor	58.17 (17.55)		58.10 (20.07)		61.71 (14.89)		.600
	adductor	4.39 (2.16)	*	4.07 (2.33)	*	6.53 (3.15)	#	.009
	internal rotation	4.27 (1.72)	*	3.80 (1.85)	*	6.77 (3.24)	#	.001
	external rotation	42.04 (11.30)		43.63 (15.61)		48.38 (13.56)		.240
Left arm	flexor	63.76 (11.07)	*	76.64 (21.43)		81.19 (19.95)	#	.022
	extensor	22.54 (9.51)		21.57 (7.17)		17.09 (5.75)		.180
	abductor	56.50 (15.67)		55.72 (18.83)		62.54 (19.71)		.400
	adductor	6.50 (3.41)		5.92 (2.72)		8.26 (3.86)		.067
	internal rotation	5.37 (2.84)	*	5.77 (2.85)		8.10 (4.23)	#	.027
	external rotation	42.53 (9.11)		42.02 (13.63)		49.61 (16.6)		.150

Notes. Means with different symbols are significantly different from each other within a single row ($p < .05$), while means with no symbol are not significantly different from any other skill level mean

Higher peak right shoulder extensor moments were observed in the senior and open class shearers, and higher adductor and internal rotation moments were observed in open class shearers as compared to the other skill levels. Conversely, open and senior class shearers showed lower cumulative flexor moments when compared to junior and intermediate shearers in both the left and right shoulders, and lower external rotation moments about the right shoulder only. On the other hand, senior and open class shearers showed higher cumulative adductor shoulder moments about the left arm and open class shearers showed higher cumulative internal rotation shoulder moments about the right arm as compared to all other skill levels. Peak abductor moments did not show the same ascending/descending trend with increasing/decreasing skill level; in particular it was observed that open and intermediate class shearers had the highest peak abductor moments about the right shoulder.

Significant differences were also found for the wool handlers with higher peak abductor moments about the right arm and higher peak external moments about the left arm in the open class shearers. Further, higher cumulative

flexor (both shoulders), internal rotation (both shoulders), adductor (right arm only) moments were found for the open class handlers when compared to all other skill levels, and lower cumulative extensor moments about the right arm in the open class wool handlers as compared to the senior workers.

4. DISCUSSION

The wool harvesting industry plays an important role in the rural economy of several countries including New Zealand. Training programs and wool harvesting competitions have strengthened the drive for higher quality shorn fleece as well as more accurate classification of wool, and have created the distinct skill levels evident in both shearing and wool handling. This study aimed to quantify differences in shoulder postures and moments of workers in the wool harvesting industry, and found that in general, open class, or highest ranked, wool harvesting workers showed altered or distinctive shoulder postures as compared to the lower ranked workers and consequently are exposed to altered shoulder moment exposures. This suggests that higher ranked individuals perform wool harvesting tasks differently to produce higher quality wool more efficiently. It is well known in the industry how these skill levels differ from a quality and tally perspective, such that open class shearers and wool handlers produce higher quality fleeces and wool classifications, and have a higher daily tally; however, the current study was the first to examine the effect of skill on biomechanical variables.

Previous work examining the biomechanical differences in trained versus untrained manual material handlers found that trained individuals were exposed to lower (spinal) loading [6, 7, 8], while the current study did not find consistent reductions in shoulder moment magnitude in the elite shearers and wool handlers. Rather, it found that certain shoulder moments were higher in the open class workers, while other moments were lower. Further, the current study found that open class shearers and wool handlers, in general, assumed different shoulder postures than all the other skill levels, e.g., increased time spent in mildly flexed postures (as compared to the time in severe flexion observed in junior and intermediate class shearers, and as compared to neutral flexion observed in junior and intermediate wool handlers) as well as increased time spent in adducted shoulder postures in both occupations. Therefore, shoulder postures adopted while shearing or wool handling set the elite apart for the other skill levels, and may be required to perform these jobs well from both a speed and quality perspective. For example, according to Tectra Ltd., the major wool harvesting training institute in New Zealand, to properly prepare the fleece for skirting and classification, it is essential to throw the fleece high enough such that it lands unfolded on the wool table [16]. Tectra recommends 30° of shoulder flexion during this throw to accomplish proper positioning of the fleece on the wool table. Thirty degrees of flexion falls within the mild flexion category according to the bin divisions used by 3DMatch, which is the category open class wool handlers spent significantly more time as compared to junior and senior class wool handlers. The open class skill level is the highest ranked level; therefore, it would be anticipated that these individuals would assume postures that would accomplish proper fleece positioning during handling. Further, the lower ranked skill levels were not consistently different from one another with respect to posture and moments, unlike the open class individuals, who tended to score either the highest or lowest postures and moments of all the skill levels, depending on the variable examined. Rarely did open class individuals fall between the other skill levels in terms of magnitude of shoulder moment exposure or time spent in various shoulder postures. This suggests that advancement between the skill levels is not linear in that the step from senior to open is larger than between the other skill levels.

It is clear that postural, and thus related loading exposures in the shoulders are distinct for the higher class shearers and wool handlers. This begs the question, are these postural findings a result of properly learned shearing and handling techniques in the elite workers? If so, can these

postural techniques be transferred to the lower class rankings to allow them to reach elite levels? Training that incorporates these documented open class shoulder postures may prove beneficial and warrants future research.

Speculating how these altered postures and moments may affect open class workers' risk of injury is difficult. While certain variables suggest a decrease in injury risk (i.e., an increased time spent in neutral shoulder postures), open class shearers and wool handlers tend to harvest more wool in a work day, which affects their cumulative load exposures, and possibly increases their risk of injury. It is known that upper limb injuries are prevalent in the shearing workplace, totalling 53% of all injury claims according to Australian Wool Innovation [17]. Similar information is not available for wool handlers nor are the statistics tracked by skill level. The current study has found that open class shearers and wool handlers spend more time in neutral or mild shoulder postures which suggests that their risk of sustaining an injury to the upper limb may be lower than that of other skill levels. This is a motive for incorporating these documented open class shoulder postures in shearing and wool handling training. While injury statistics are not available for wool handlers specifically, it has been speculated that injury rates of wool handlers are very similar to those of the entire farming industry, which are considerably lower than the injury rates for shearers alone (personal communication with Australian Wool Innovation). The current study has shown that cumulative shoulder moments in wool handlers are lower than those of shearers, and may be a potential explanation for the speculated lower number of injury reports in wool handlers. Further, wool handlers also spend more time in neutral shoulder flexion when compared to the shearers, a factor which may help explain this lower number of speculated injury reports among wool handlers.

While the current study successfully examined and documented the effect of skill on shoulder postures and loading, there were some limitations. First, data were collected at wool harvesting competitions, which may not be an optimal representation of how the tasks are performed in an occupational setting. While shearers and wool handlers perform their very best in a competition setting, score is determined not only based on speed, but also quality. These characteristics also hold true in an occupational setting, as shearers' and wool handlers' wages are set according to their skill level (related to both speed and quality). Peak and cumulative moments about the shoulder were calculated using a binned posture approach. The size of the bins and the accuracy of selecting the correct bin may have resulted in error in the calculated moments. To minimize error, two camera orientations were used to ensure both frontal and sagittal views of each participant, increasing the likelihood that the proper posture bin was selected as per the recommendation of Sutherland, Albert, Wrigley, et al. [18]. The cumulative shoulder moments were extrapolated to an 8-h workday; however, this extrapolation did not take into consideration minor breaks throughout the day. Therefore, the 8-h cumulative moments documented in the current study may be slightly overestimated. However, the purpose of this study was to examine differences across skill level; therefore, this mild overestimation did not likely affect this comparison since all groups were treated with the same extrapolation approach.

5. CONCLUSIONS

The current study documented shoulder postures and loading exposures of New Zealand sheep shearers and wool handlers of varying skill levels. Results illustrated altered shoulder postures in open class (ranked highest) shearers and wool handlers as compared to the lower skill levels (senior, intermediate, and junior), suggesting that it is the adoption of these postures that set the elite apart from the other skill levels. Postural-based training should, therefore, be examined as a possible method for improving shearing and wool handling techniques. If postural-based training does improve the quality of performance, more workers will be able to achieve the higher ranked status.

REFERENCES

1. Marshall RN, Burnett AF. A kinematic, kinetic and electromyographic comparison of stooped sheep shearing techniques and shearing with a sheep manipulator. Appl Ergon. 2004;35:137–45.
2. Milosavljevic S, Carman AB, Milburn PD, Wilson BD, Davidson PL. The influence of a back support harness on spinal forces during sheep shearing. Ergonomics. 2004;47:1208–25.
3. Milosavljevic S, Carman AB, Schneiders AG, Milburn PD, Wilson BD. Three-dimensional spinal motion and risk of low back injury during sheep shearing. Appl Ergon. 2007;38:299–306.
4. Gregory DE, Milosavljevic S, Callaghan JP. Quantifying low back peak and cumulative loads in open and senior sheep shearers in New Zealand: examining the effects of a trunk harness. Ergonomics. 2006;49: 968–81.
5. Gregory DE, Milosavljevic S, Pal P, Callaghan JP. An examinations of shoulder kinematics and kinetics when using a commercial trunk harness while sheep shearing. Appl Ergon. 2008;39:29–35.
6. Chany AM, Parakkat J, Yang G, Burr DL, Marras WS. Changes in spine loading patterns throughout the workday as a function of experience, lift frequency, and personality. Spine J. 2006;6:296–305.
7. Daynard D, Yassi A, Cooper JE, Tate R, Norman R, Wells R. Biomechanical analysis of peak and cumulative spinal loads during simulated patient handling activities: a substudy of a randomized controlled trial to prevent lift and transfer injury of health care workers. Appl Ergon. 2001;32:199–214.
8. Videman T, Nurminen T, Tola S, Kuorinka I, Vanharanta H, Troup JD. Low-back pain in nurses and some loading factors of work. Spine. 1984;9:400–4.
9. Keir PJ, MacDonell CW. Muscle activity during patient transfers: a preliminary study on the influence of lift assists and experience. Ergonomics. 2004;47:296–306.
10. Andrews DM, Callaghan JP. Determining the minimum sampling rate needed to accurately quantify cumulative spine loading from digitized video. Appl Ergon. 2003;34:589–95.
11. Harvey JT, Culvenor J, Payne W, Cowley S, Lawrance M, Stuart D, et al. An analysis of the forces required to drag sheep over various surfaces. Appl Ergon. 2002; 33:523–31.
12. Johnstone J. Clutha District sheep and beef farm statistics 2006. Balclutha, New Zealand: Shand Thomson; 2007.
13. Gmeinder GE. Back complaints among shearers in Western Australia: a pilot study. Australian J Physiother. 1986;32:139–44.
14. McAtamney L, Corlett EN. Ergonomic workplace assessment in a health care context. Ergonomics. 1992;35:965–78.
15. Jackson J, Reed B, Andrews DM, Albert WJ, Callaghan JP. Usability of 3DMatch—an evaluation of the inter- and intra-observer reliability of posture matching to calculate cumulative low back loading [unpublished presentation]. 34th Annual Conference of the Association of Canadian Ergonomists; London, ON, Canada; 2003.
16. Tectra wool handling handbook. Christchurch, New Zealand: Tectra; 2006.
17. Australian Wool Innovation. Wool Harvesting OH&S Injury and Cost Evaluation Review 2005-06 Analysis & Update of 5 Year Analysis (Project WP197); 2007. Retrieved October 15, 2009, from: http://images.wool.com/pub/ingOHSInjuryandCost.pdf
18. Sutherland CA, Albert WJ, Wrigley AT, Callaghan JP. The effect of camera viewing angle on posture assessment repeatability and cumulative spinal loading. Ergonomics. 2007;50:877–89.