Exposure to Whole-Body Vibration and Mechanical Shock: A Field Study of Quad Bike Use in Agriculture

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Objectives: The purpose of this study was to determine exposure to whole-body vibration (WBV) and mechanical shock in rural workers who use quad bikes and to explore how personal, physical, and workplace characteristics influence exposure.

Methods: A seat pad mounted triaxial accelerometer and data logger recorded full workday vibration and shock data from 130 New Zealand rural workers. Personal, physical, and workplace characteristics were gathered using a modified version of the Whole Body Vibration Health Surveillance Questionnaire. WBVs and mechanical shocks were analysed in accordance with the International Standardization for Organization (ISO 2631-1 and ISO 2631-5) standards and are presented as vibration dose value (VDV) and mechanical shock (Sed) exposures.

Results: VDVZ consistently exceeded European Union (Guide to good practice on whole body vibration. Directive 2002/44/EC on minimum health and safety, European Commission Directorate General Employment, Social Affairs and Equal Opportunities. 2006) guideline exposure action thresholds with some workers exceeding exposure limit thresholds. Exposure to mechanical shock was also evident. Increasing age had the strongest (negative) association with vibration and shock exposure with body mass index (BMI) having a similar but weaker effect. Age, daily driving duration, dairy farming, and use of two rear shock absorbers created the strongest multivariate model explaining 33% of variance in VDVZ. Only age and dairy farming combined to explain 17% of the variance for daily mechanical shock. Twelve-month prevalence for low back pain was highest at 57.7% and lowest for upper back pain (13.8%).

Conclusions: Personal (age and BMI), physical (shock absorbers and velocity), and workplace characteristics (driving duration and dairy farming) suggest that a mix of engineered workplace and behavioural interventions is required to reduce this level of exposure to vibration and shock.

Keywords: agriculture; fieldwork; mechanical shock; quad bikes; whole-body vibration

INTRODUCTION

Agriculture has a dominant role in the New Zealand economy, contributing to >60% of export earnings and employing 9% of the workforce. However, injury and musculoskeletal disorders in the rural workplace are a recognized occupational health concern (Firth et al., 2002). Exposure to vehicle-induced occupational whole-body vibration (WBV) in combination with awkward work postures and manual material lifting is thought to cause musculoskeletal disorders in the low back as well as the neck, shoulder, and thoracic regions (Rehn et al., 2002; Palmer et al., 2003; Hagberg et al., 2006; Rehn et al., 2009). There are in excess of 80 000 quad...
bikes used on New Zealand farms (OSH, 2002; Moore, 2007) putatively exposing rural workers to high levels of occupational WBV (Scarlett et al., 2005; Milosavljevic et al., 2010). WBV has previously been recognized as a major source of discomfort for agricultural vehicle operators during typical farm operations (Matthews, 1966; Scarlett et al., 2007; Bovenzi and Betta, 1994; Lines et al., 1995).

Exposure to occupational WBV is thought to be associated with mechanical and structural spinal disorders, such as a herniated lumbar disc, damage to the vertebral end plates, and accelerated degeneration of the spine (Bovenzi and Hulshof, 1998; Pope et al., 2002; Bovenzi et al., 2006; European Union, 2006; Hadjipavlou et al., 2008). It is also thought to alter mechanoreceptor sensitivity in the peripheral nervous system, as well as disturb visual and vestibular mechanisms leading to kinaesthesic and balance disturbances (Seidel and Heide, 1986; Miyashita et al., 1992; Bonney, 1999; Zahov and Medzhideva, 2005). Such neurophysiological disturbances can perturb postural control, dynamic balance, and motor control and are considered an alternative pathway leading to low back injury (Olson et al., 2009; Oullier et al., 2009; Mani et al., 2010).

While high levels of WBV exposure have been recorded from other forms of all-terrain vehicles (Rehn et al., 2002, 2005a,b,c), farm tractors (Solecki, 2007), professional drivers (Tiemessen et al., 2008), and heavy vehicle operators (Waters et al., 2008), the current evidence for vibration and mechanical shock exposure from agricultural quad bike use (Milosavljevic et al., 2010) has only used small sample sizes, and thus, it is difficult to extrapolate the results to a wider farming population and to determine how personal, physical, and workplace characteristics might influence exposure. Several factors influencing exposure have, however, been identified in drivers of other vehicles, including fork-lift trucks, forestry machines, forwarders, mobile cranes, trucks, tractors, subway trains, and taxis (Tiemessen et al., 2007). These include personal and physical factors such as driving experience, driving speed, body mass, and posture as well as other workplace and vehicle characteristics such as track condition, suspension systems, type of seat, load, and maintenance of vehicle.

The primary aim of this study was to determine the level of quad bike-induced WBV and mechanical shock exposure in a larger sample of New Zealand rural workers. The secondary aims are to explore how personal, physical, vehicle, and workplace characteristics influence such exposure.

MATERIALS AND METHODS

Design
An observational fieldwork investigation of WBV and mechanical shock exposure in a sample of New Zealand rural workers in the South Otago region of New Zealand. A pilot ($n = 12$) vibration dose value (VDV) of $16.6 \text{ m s}^{-1.75}$ in the vertical (Z) direction (SD = $5.6 \text{ m s}^{-1.75}$) (Milosavljevic et al., 2010) led to a population sample estimate of 130 workers in order to predict a 95% confidence interval of $\pm 1.0 \text{ m s}^{-1.75}$.

Community databases were used to recruit workers from a radius of farms based around the regional township of Balclutha. Workers were contacted by telephone to describe the study, seek consent to visit the farm, and provide further detail regarding their potential participation. Consent was sought from each worker following further description of the study during the farm visit. In this way, 131 workers were approached in order to recruit a convenience sample of 130 consenting participants (111 males and 19 females). These workers were accepted as representing New Zealand mixed stock and dairy farms where quad bikes are regularly used (Milosavljevic et al., 2010). The study was approved by the University of Otago Human Ethics Committee.

Survey
An adapted version of the Whole Body Vibration Health Surveillance Questionnaire (WBVHSQ) (Pope et al., 2002) was used to collect data on demographics (age, height, mass, farming, and quad bike experience); work environment information including type of farm (dairy, sheep, beef, mixed stock, and other) and type of farm terrain (flat, rolling flat, hilly, and steep hilly); quad bike vehicle specifications (mass, engine capacity, and suspension); driving behaviours (duration, distance, and velocity); and 7-day and 12-month prevalence of musculoskeletal disorders in the low back, upper back, neck, and shoulders.

Vibration and mechanical shock measurements
Vibration and mechanical shock data were continuously collected during a worker-defined typical working day and were measured in accordance with the International Organization for Standardization [ISO 2631-1 (1997); ISO 2631-5 (2004)] standards. A rubberized seat pad containing a series 2 (10 g), eighth order, 1.2 elliptic triaxial accelerometer (NEXGEN Ergonomics) was taped to the seat of each quad bike directly under the ischial tuberosities of each worker (Fig. 1). The accelerometer channels...
were aligned with the quad bikes with $x$ as anterior–posterior, $y$ medio–lateral, and $z$ superior–inferior. Participants were asked to undertake their daily chores as per normal, allowing collection of data representing a full day’s exposure to quad bike-induced vibrations. Vibration data were digitally recorded, stored, and time stamped, in a Biometrics™ (Data-LOG W4X8) eight channel data logger mounted on the rear carrying rack of the quad bike (Fig. 1).

In order to analyse a 0.5–80 Hz ISO 2631 recommended vibration spectrum, the sampling frequency was set at 2000 Hz with an eighth order anti-aliasing filter set at the 500 Hz cut-off frequency as recommended by the supplier (NEXGEN Ergonomics Inc.). Each worker’s odometer readings were recorded at the beginning and end of the workday to calculate distance travelled (kilometre). Cumulative daily exposure to vibration and shock was calculated using Biometrics PC Datalog software (V7.0) to summate vibration exposure epochs within the full day vibration record. This was done by extracting non-driving (flat line) and idling data (low magnitude) from the full daily log. Mean daily velocity for each worker was calculated by dividing distance travelled (kilometre) by driving time (hour) and presented as kilometres per hour.

High amplitude peaks, crest factors >9.0, and the likelihood of mechanical shock in the pilot trial (Milosavljevic et al., 2010) led to vibration exposures being expressed as the VDV (in m/s$^{1.75}$), while exposure to mechanical shock was expressed in megapascals as the daily equivalent static compression dose ($S_{ed}$) (ISO 2631-1; ISO 2631-5). All values were calculated with the use of the Vibration Analysis ToolSet™ (V3.4.4) proprietary vibration analysis software supplied by NEXGEN Ergonomics. Vibration and shock results were also normalized to a 1-h unit of time in order to most clearly determine how non-temporal variables influenced vibration and mechanical shock exposure.

In accordance with the recommendations of the ISO 2631-1 (1997), ISO 2631-5 (2004), and the European Union Physical Agents Vibration Directive (EUPA(V)D) (2002) standard, the daily exposure health effects were evaluated as follows:

- A VDV score $<9.1$ m s$^{-1.75}$ is below the (EUPA(V)D) exposure action value (EA V),
- A VDV score $\geq21.0$ m s$^{-1.75}$ is above the [EUPA(V)D] exposure limit value (ELV),
- An $S_{ed} <$0.5 MPa indicates (ISO 2631-5) low probability adverse health effect (LAHE),
- An $S_{ed} >$0.8 MPa indicates (ISO 2631-5) high probability adverse health effect (HAHE).

**Frequency spectrum**

The 0.5–80.0 Hz frequency spectrum was calculated by using a one-third octave analysis fast Fourier transform (FFT) of the respective $x$, $y$, and $z$ peak root mean square acceleration data, allowing the results to be compared with the known resonant frequencies of the adult human spine (Mansfield, 2004).

**Statistical analyses**

Data were analysed using SPSS™ (version 16.0) and presented in both tabular and graphic format. The four dependent variables were daily and 1-h VDV$_Z$ (m/s$^{1.75}$), as well as daily and 1-h $S_{ed}$ (megapascals). Independent variables included age (years), height (metre), mass (kilogram), body mass index (BMI) (kilograms per square metre), farming experience (years), quad bike experience (years), type of quad bike rear suspension, engine capacity (cc),
quad bike mass (kilogram), quad bike age (years), farm type, farm terrain, distance driven (kilometre), driving duration (hours), and mean velocity (kilometre per hour). Farm type (0 = dairy, 1 = beef, 2 = sheep, 3 = mixed stock, and 4 = other), farm terrain (0 = flat, 1 = rolling flat, 2 = hilly, and 3 = steep hilly), and type of rear suspension (0 = swing arm with fixed rear axle and two shock absorbers, 1 = fully independent, and 2 = swing arm with fixed rear axle and single central shock absorber) were structured into a categorical dummy format for inclusion in the linear model. All other independent variables, including personal, anthropometric, work experience, and vehicle characteristics and exposures, were recorded as continuous data. Seven-day and 12-month prevalence of musculoskeletal disorders in the low back, upper back, neck, and shoulders were categorically classified (0 = no and 1 = yes) for each anatomical region and have been presented descriptively. Univariate linear regression was used to test for associations between independent and dependent variables with an independent variable accepted for inclusion in the multivariate linear model when \( P \leq 0.20 \).

RESULTS

Survey data

Participants had a mean age of 40.6 years, mean height of 1.77 m, mean mass of 87.0 kg, mean BMI of 27.6 kg m\(^{-2}\), mean 19.1 years of work experience, and a mean 14.6 years of quad bike experience (Table 1). Following removal of the non-driving and idling data from the mean 8.4-h daily WBV log, vibration data were combined with vehicle odometer records demonstrating that these workers drove their quad bikes for a mean 2.1-h vibration exposure, over a mean distance of 22.2 km, giving a mean velocity of 11.4 km h\(^{-1}\) (Table 1). They worked on several different types of farm, including dairy (30.8%), beef (1.5%), sheep (10.8%), mixed (sheep and beef ± venison) livestock (53.8%), and ‘other’ (3.1%) that included cropping and venison production. The four main classes of farm terrain were described as flat (15.4%), rolling flat (36.9%), hilly (30.0%), and steep hilly (17.7%).

Quad bike characteristics

An examination of rear suspensions revealed that 46.9% of quad bikes used by these workers had a swing arm fixed axle with two shock absorbers, 30.8% used a swing arm fixed axle with one central shock absorber, and the remaining 22.3% used a fully independent system. All quad bikes had fully independent suspension on the front axle. Mean quad bike age was 3.7 years (SD = 3.2) ranging from newly purchased to 19.0 years of use, mean engine capacity (from manufacturer specification) was 447.2 cc (SD = 92.4 cc) ranging from 300 to 800 cc, and mean vehicle mass (manufacturer specification) was 268.7 kg (SD = 11.2 kg) ranging from 250 to 303 kg.

Musculoskeletal disorders

Prevalence of musculoskeletal disorders experienced during both the last 7 days and the previous 12 months were collected from the WBVHSQ (Table 2). This information is categorized by anatomical location and focuses on low back, neck, upper back, and shoulder disorders. Twelve-month prevalence was greatest for low back (57.7%) and least for upper back (13.8%).

FFT spectrum

Mean peak FFT values and amplitude characteristics for \(x\), \(y\), and \(z\) directions are presented in Fig. 2. The predominant peak amplitude was 3.8 m s\(^{-2}\) in the \(z\)-axis occurring at 4.0 Hz and was considerably greater than peak amplitude for the \(x\) and \(y\) directions. A secondary peak between 1.2 and 1.5 m s\(^{-2}\) can be observed between 20.0 and 50.0 Hz in the \(z\)-axis. There is a considerable overlap between plots.

<table>
<thead>
<tr>
<th>Table 1. Worker information</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>16.0</td>
<td>67.0</td>
<td>40.6</td>
<td>13.0</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.60</td>
<td>1.96</td>
<td>1.77</td>
<td>0.08</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>50.0</td>
<td>129.0</td>
<td>87.0</td>
<td>16.0</td>
</tr>
<tr>
<td>BMI (kg m(^{-2}))</td>
<td>17.7</td>
<td>41.6</td>
<td>27.6</td>
<td>4.3</td>
</tr>
<tr>
<td>Work experience (years)</td>
<td>0.5</td>
<td>51.0</td>
<td>19.1</td>
<td>13.2</td>
</tr>
<tr>
<td>Quad bike experience (years)</td>
<td>0.7</td>
<td>30.0</td>
<td>14.6</td>
<td>8.3</td>
</tr>
<tr>
<td>Duration (h)</td>
<td>0.2</td>
<td>5.8</td>
<td>2.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Distance travelled (km)</td>
<td>5.0</td>
<td>60.0</td>
<td>22.2</td>
<td>10.8</td>
</tr>
<tr>
<td>Mean velocity (km h(^{-1}))</td>
<td>3.4</td>
<td>24.5</td>
<td>11.4</td>
<td>4.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Self-reported 7-day and 12-month prevalence of musculoskeletal disorders</th>
<th>7 day (%)</th>
<th>12 month (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low back</td>
<td>46 (35.4)</td>
<td>75 (57.7)</td>
</tr>
<tr>
<td>Shoulder</td>
<td>18 (13.8)</td>
<td>41 (31.5)</td>
</tr>
<tr>
<td>Neck</td>
<td>14 (10.8)</td>
<td>34 (26.2)</td>
</tr>
<tr>
<td>Upper back</td>
<td>9 (6.9)</td>
<td>18 (13.8)</td>
</tr>
</tbody>
</table>
for $x$ and $y$ directions with both occurring at 1.5 Hz. However, peak amplitude in the $x$ (2.8 m s$^{-2}$) direction is slightly greater than in the $y$ (2.4 m s$^{-2}$) direction.

**Peak and crest factors**

Mean crest factors for $x$, $y$, and $z$ were >9.0 ($Z = 34.5$) and considerably higher than the critical ratios described in the ISO 2631-1, indicating that relatively high and irregular peak shocks at the seat were likely when using the quad bike and that use of the VDV and mechanical shock exposure measures would be appropriate.

**Vibration dose value**

Mean VDV$_x$ was 7.9 m s$^{-1.75}$ (ranging from 3.8 to 13.3 m s$^{-1.75}$), mean VDV$_y$ was 7.5 m s$^{-1.75}$ (3.4–14.3 m s$^{-1.75}$), mean VDV$_z$ was 17.2 m s$^{-1.75}$ (7.3–33.5 m s$^{-1.75}$) with a mean VDV$_{sum}$ 18.8 m s$^{-1.75}$ (8.3–33.8 m s$^{-1.75}$) (Fig. 3). Mean 1-h VDV$_z$ was 14.7 m s$^{-1.75}$ (SD = 3.9 m s$^{-1.75}$). All but one worker ($n = 129$) exceeded the daily VDV EAV of 9.1 m s$^{-1.75}$ in the $z$ direction and only three were under this value for a 1-h vibration exposure. Twenty-eight workers exceeded the daily VDV ELV of 21.0 m s$^{-1.75}$ in the $z$ direction while seven exceeded this value within a 1-h time frame.

**Variables associated with daily and 1-h VDV$_z$**

Age, work experience, quad bike experience, BMI, rear suspension, referent farm type (dairy), duration, and distance demonstrated statistically significant univariate associations ($P < 0.05$) with daily VDV$_z$; all variables meeting the ($P \leq 0.20$) criteria for inclusion into a multivariate VDV$_z$ model are presented in Table 3. As age, work experience, and quad bike experience were highly collinear ($R^2 = 0.51$), age was chosen as the variable having the strongest association with vibration for the multivariate models. For the 1-h VDV$_z$ model, duration and its derivatives of distance travelled and velocity were removed from the analysis while quad bike mass ($P = 0.003$) and engine size ($P = 0.033$) reach univariate statistical significance and quad bike age met inclusion criteria ($P \leq 0.20$) for the multivariate model.

In the multivariate stepwise models, 33% of the variance ($R^2 = 0.33$) in daily VDV$_z$ is explained by the combination of age ($R^2 = 0.16$), driving duration ($R^2 = 0.09$), the use of a fixed axle rear suspension with two shock absorbers ($R^2 = 0.04$), and working on a dairy farm ($R^2 = 0.04$). Similarly, the multivariate stepwise analysis for the 1-h VDV$_z$ model ($R^2 = 0.20$) demonstrates the significant predictors, including age ($R^2 = 0.13$), the use of a fixed axle rear suspension with two shock absorbers ($R^2 = 0.05$), and working on a dairy farm ($R^2 = 0.02$).

**Daily equivalent static compression dose ($S_{ed}$)**

Daily $S_{ed}$ values for intradiscal pressure from shock exposure ranged from 0.1 to 0.8 MPa with a resultant mean of 0.39 MPa (SD = 0.17 MPa). Forty-one workers either reached or exceeded the $S_{ed}$ LAHE threshold of 0.5 MPa and while five workers reached the HAHE threshold of 0.8 MPa, none exceeded it. One-hour $S_{ed}$ values also ranged from 0.1 to 0.8 MPa with a resultant mean of 0.35 MPa (SD = 0.15 MPa). Twenty-six workers either reached or exceeded the $S_{ed}$ LAHE threshold of 0.5 MPa during 1-h exposure while only one worker would reach the HAHE threshold of 0.8 MPa.

**Variables associated with daily and 1-h mechanical shock ($S_{ed}$)**

All variables meeting the ($P \leq 0.20$) criteria for inclusion into a multivariate daily $S_{ed}$ model are presented in Table 4. Age, farm experience, quad bike experience, farm type (dairy farming compared to sheep and mixed farming), and duration demonstrated statistically significant ($P < 0.05$) univariate associations. For the 1-h $S_{ed}$ model, age, farm and quad bike experience, farm type (dairy farming compared to sheep and mixed farming), and quad bike mass reached univariate statistical significance, while duration was removed. As age had the strongest association with mechanical shock, it was chosen for inclusion in the multivariate analysis. In the multivariate stepwise model, 17% of the variance...
in daily $S_{eq}$ is significantly ($P < 0.05$) explained by the inclusion of age ($R^2 = 0.13$) and dairy farming ($R^2 = 0.04$). The 1-h $S_{eq}$ model ($R^2 = 0.13$) also demonstrates a combined association for age ($R^2 = 0.09$) and dairy farming ($R^2 = 0.04$).

**DISCUSSION**

**Vibration exposure**

Rural quad bike use creates resonant spinal WBVs (4.0–6.0 Hz) and mechanical shocks exceeding industry recommended action limits. These results support previous pilot research and indicate that these workers are at some risk of cumulative mechanical effects and consequential spinal musculoskeletal injury (Milosavljevic et al., 2010). Higher frequency lower amplitude (20–50 Hz) exposures were also observed. These are known to disturb mechano and proprioceptive responses and may also be linked to musculoskeletal injury of the spine through vibration-induced disturbance of neuromuscular control of the trunk (Li et al., 2008; Mani et al., 2010). The 7-day and 12-month prevalence rates for low back pain and neck pain in these workers are also consistent with previous research (Rehn et al., 2002; Milosavljevic et al., 2010) and suggest considerable occupational risk from vibration/shock exposure. While the study design precludes a comparative longitudinal analysis between exposure and risk the data is consistent with at risk occupations for spinal musculoskeletal disorder being exposed to high levels of WBV and mechanical shock (Bovenzi and Betta, 1994; Rehn et al., 2002; Chen et al., 2003; Palmer et al. 2003).

**Association with personal factors**

Age, work experience, and quad bike driving experience are significantly and negatively associated with daily and 1-h $VDV_Z$, as well as daily and 1-h $S_{eq}$ demonstrating that rural workers who are older and more experienced appear to choose quad bike driving techniques and terrain pathways that are less vibration and shock intensive. A *post hoc* analysis of the age distributions among the workers on the different farm types also reveal three statistically significant results ($P < 0.001$) for dairy workers who were a mean 11.0 years younger, with a mean 12.4 years less work experience, and a mean 6.7 years less quad bike driving experience. Thus, these younger workers have likely had less time to experience, learn, and adjust driving styles to reduce vibration and shock exposure. For the older and more experienced rural workers, it is likely that prior exposures to vibrations and shocks have either induced injury or provoked pre-existing injury sufficiently to alter driving behaviour as the worker ages. Time, farm, and task demands on the older rural worker may also be considerably divergent from those placed on the younger generation, allowing the older worker a more conservative choice of
terrains, pathways, speed, and duration to complete given tasks. Age is closely correlated with work and driving experience and although there is some evidence for mitigating effects for work experience on vibration exposure in the urban (Chen et al., 2003) and forestry (Rehn et al., 2005b) environments, this has not been previously identified in an agricultural setting. Decreased injury risk and risk taking behaviours have also been associated with increased age in other occupations and workforces (Salminen, 2004; Breslin and Smith, 2005; Gyekye and Salminen, 2009; Chau et al., 2010).

In comparison to height and weight alone, BMI was considered the more robust composite variable for anthropometric influence and showed statistically significant but weak associations with daily and 1-h VDV$_Z$ exposure indicating that increased body mass has an attenuative effect on WBV transmission into the body. Tiemessen et al. (2007) similarly described an attenuating effect of increased body mass on vibration transmission with a predominant effect seen with smaller vehicles—an observation consistent with the small relative size of quad bikes.

**Farm type and terrain**

Workers on dairy farms have a significantly greater level of daily and 1-h VDV$_Z$ vibration as well as daily and 1-h mechanical shocks. Other than experience, terrain observation on a New Zealand (NZ) dairy farm also offers a plausible explanation for this

| Table 3. Univariate and multivariate regression analysis for daily and 1-h VDV$_Z$ exposure |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Univariate      | Daily VDV$_Z$   | VDV$_Z$ 1 h     |
|                 | β                | Lower          | Upper          | Significance    | R$^2$           |
| Age (years)     | −0.15            | −0.21          | −0.09          | *<0.001         | 0.16            |
| Farm exp (years)| −0.13            | −0.19          | −0.07          | *<0.001         | 0.12            |
| Quad exp (years)| −0.15            | −0.25          | −0.05          | *<0.004         | 0.06            |
| BMI (kg m$^{-2}$)| −0.21            | −0.41          | −0.02          | *<0.031         | 0.04            |
| Dairy farm (Ref.)| 18.90            | 17.48          | 20.33          |                | 16.16           |
| Beef farm       | −7.04            | −13.66         | −0.41          | *<0.038         | −5.89           |
| Sheep farm      | −5.28            | −8.11          | −2.45          | *<0.001         | −4.18           |
| Mixed farm      | −1.90            | −3.71          | −0.10          | *<0.039         | 0.12            |
| Flat terrain (Ref.)| 18.65            | 16.50          | 20.80          |                | 16.24           |
| Rolling flat    | −1.70            | −4.26          | 0.86           | *0.019          | −2.02           |
| Hilly           | −1.70            | −3.80          | 0.39           | *0.111          | 0.16            |
| Steep hilly     | −1.66            | −4.00          | 0.67           | *0.161          | 0.03            |
| Suspension 1 (Ref.)| 16.07            | 14.86          | 17.27          |                | 13.99           |
| Suspension 2    | 1.52             | −0.61          | 3.64           | 0.160           | 3.64            |
| Suspension 3    | 2.53             | 0.61           | 4.44           | *0.010          | 0.05            |
| Vehicle age (years) | −0.16          | −0.37          | 0.05           | *0.140          | 0.02            |
| Vehicle mass (kg)| −0.09            | −0.15          | −0.03          | *0.003          | 0.07            |
| Vehicle engine (cc)| −0.01            | −0.02          | 0.00           | *0.033          | 0.04            |
| Duration (h)    | 1.71             | 0.94           | 2.48           | *<0.001         | 0.13            |
| Distance (km)   | 0.11             | 0.04           | 0.19           | *<0.04          | 0.06            |
| Velocity (km h$^{-1}$)| −0.20           | −0.41          | 0.02           | 0.069           | 0.03            |

| Multivariate    | Daily VDV$_Z$   | VDV$_Z$ 1 h     |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | β                | Lower          | Upper          | Significance    | R$^2$           |
| Constant        | 18.77            | 15.33          | 22.21          |                | 18.50           |
| Age (years)     | −0.10            | −0.16          | −0.04          | 0.002           | 0.16            |
| Duration (h)    | 1.25             | 0.54           | 1.96           | 0.001           | 0.25            |
| Suspension 1    | −1.91            | −3.34          | −0.48          | 0.009           | 0.29            |
| Dairy farm      | 2.08             | 0.39           | 3.76           | 0.016           | 0.33            |

Ref., referent; suspension 1: fixed rear axle, swing arm, two shock absorbers; suspension 2: fully independent rear suspensions; suspension 3: fixed rear axle, swing arm, one shock absorbers; Farm exp (years), years of farming experience; Quad exp (years), years of quad bike experience.
phenomenon. Most dairy farms have designated gravel pathways for vehicle and animal movement about the farm while many paddocks have roughened (or pugged) surfaces caused by movement of cattle. Thus, the farmed surfaces of a dairy farm are considerably different and more intensively grazed than that of a sheep or mixed stock farm, offering an explanation of higher vibration and shock exposures. Interestingly, farm terrain per se (flat, rolling flat, hilly, and steep hilly) had no significant effect on vibration or shock exposure indicating that how the land was farmed (dairy, sheep, beef, mixed, and other) influenced surface conditions and had the stronger effect on vibration and shock.

**Vehicle and driving characteristics**

Although a dual shock absorber, swing arm, and solid rear axle transmitted significantly less amounts of vibration in both the daily and the 1-h VDVZ models compared to single shock absorbers (on a swing arm and solid rear axle), this was not observed in the full day and 1-h \( S_{vd} \) mechanical shock models. Thus, a quad bike with dual shock absorbers is likely to offer a significant vibration reduction in comparison to a single shock absorber rear axle but will not reduce shock exposure. The lack of effect on mechanical shock exposure suggests that vehicle size, short wheelbase, and lightweight will minimize the effectiveness of shock absorbers in attenuating for brief, terrain-induced mechanical shocks. Interestingly, increased vehicle mass had significant but weak negative effects appearing to reduce the magnitude of mechanical shocks and vibrations in the 1-h vibration and shock models but not the full day models. As exposure time is fundamental to the equations for calculating both daily VDVZ and \( S_{ed} \) exposure, duration is a significant predictor for both daily vibration and mechanical shock exposure. While distance driven is also associated with duration, it is only significantly associated with daily VDVZ vibration exposure.

**Multivariate models**

For daily VDVZ, the effects of age, duration, twin shock absorbers, and working on a dairy farm combine to account for 33% of data variance while for 1-h VDVZ, only duration was excluded from the model \( (R^2 = 0.20) \). Thus, an older rural worker, driving for less time, on a quad bike with two rear shock absorbers on a fixed axle, and who does not work on a dairy farm will be exposed to substantially less vibration exposure. For both daily \( (R^2 = 0.17) \) and 1-h \( (R^2 = 0.13) \) \( S_{ed} \), increased age reduced the
magnitude of shock exposure whereas working on a dairy farm increased it. Thus, a young dairy farm worker will likely be exposed to the highest level of mechanical shock.

While the use of a quad bike in agriculture will generate high levels of WBV and mechanical shock, age and experience are the predominant factors observed to reduce such exposures. For vibration, riding duration is an important component of exposure; vehicle suspension also has an effect, as does the type of farming being undertaken. This predominance for age and experience influencing vibration and shock exposure strongly supports an argument for behavioural change occurring in rural workers over time. Surprisingly, no significant associations were found between age and driving duration, age and distance driven, or age and mean vehicle velocity, although both age and duration contributed strongly to the multivariate daily vibration and shock models. Thus, older workers tended to drive their quad bikes for about the same amount of time for the same distance at the same speed. It seems therefore that older workers have either been exposed to, or have identified, a number of non-temporal risk factors and will somehow factor these into their work ethic as they age and mature. The driving routes and surface conditions they choose to drive on when traversing their farm terrain are a logical and plausible factor. Future research will search for such factors that identify change in behaviour and consider ways of implementing these in behavioural models of injury prevention (Tiemessen et al., 2007).

CONCLUSIONS

Rural workers in NZ who regularly use quad bikes during their daily activities have high 7-day and 12-month prevalence rates for low back and neck pain. They are also exposed to considerable levels of WBV and mechanical shock. Increased age was the variable most strongly associated with reduced exposure to vibration and shock, while duration of measured daily exposure had a strong influence on daily vibration and a weaker influence on daily shock. The type of farming also significantly influenced exposure as did the type of rear suspension. Engineered interventions designed to reduce transmission of terrain-induced WBVs through the seat as well as interventions designed to address changes in quad bike driving behaviour will be needed in order to most effectively reduce exposure to vibration and mechanical shock and reduce risk of musculoskeletal disorder.

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