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The Influence of Body Mass on Whole-Body Vibration: A Quad-Bike Field Study

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Abstract: *Objectives*: The aim of this field study was to explore the relationship between body mass and quad bike induced whole-body vibration (WBV) exposure in a group of New Zealand rural workers.

Methods: WBV exposure was recorded using a seat pad mounted tri-axial accelerometer while rural workers (n=34) were driving a quad bike for approximately half an hour on a pre-marked track on farm terrain. Personal factors such as age, height and quad bike driving experience were also surveyed and included as co-variates. Vibration dose value (VDV) was calculated by analyzing the recorded raw vibration data samples (n=34) using vibration analysis software and corrected to a one hour equivalent exposure for further statistical analysis. To evaluate for the relationship between variables of interest (body mass, height, age and driving experience) and one hour VDV_Z ($1hrVDV_Z$), univariate and multivariate linear regression analysis were conducted.

Results: Mean $1hrVDV_Z$ was 13.2 $m/s^{1.75}$ exceeded the VDV exposure action value of 9.1 $m/s^{1.75}$. Univariate analysis demonstrated body mass ($R^2 = 0.340$) significantly ($p < 0.0003$) associated with $1hrVDV_Z$ while age, body height and quad bike driving experience were not. In a multivariate backward linear analysis body mass, height, and experience combined to explain 38% ($R^2 = 0.376$) of the variance in 1hr VDV_Z, however, only body mass ($p = 0.0004$) demonstrated statistical significance.

Conclusion: Body mass is significantly and negatively associated with quad bike induced WBV ($1hrVDV_Z$) in a group of New Zealand rural workers.

Keywords: Whole-body vibration, body mass, vibration dose value, quad bikes.

1. INTRODUCTION

Although occupational whole-body vibration (WBV) has been identified as a risk factor for spinal musculoskeletal disorders and balance disturbances [1-3] dose response relationships have yet to be clearly determined [4, 5]. Intrinsic and extrinsic factors are likely to be modulators of vibration induced injury risk. Intrinsic factors include: age, anthropometry (height, body mass, posture, experience and driving behavior). Extrinsic factors include: magnitude, frequency and duration of vibration exposure, nature of terrain, type of seat, seat and cabin suspension, tyre pressure and vehicle type [6].

In New Zealand more than 80,000 four wheel drive quad bikes are regularly used by rural workers for various farming purposes including stock mustering, personal transport and carriage of implements [7]. Recent literature suggests that on-farm use of a quad bike exposes rural workers to high levels of WBV (VDV_Z ~ 17.0 $m/s^{1.75}$) well above the recommended *exposure action value* of 9.1 $m/s^{1.75}$ [8-11]. Drivers of all-terrain vehicles (including quad bikes) are exposed to high levels of WBV and are known to experience low back pain (LBP) as well as pain in the neck, shoulder and thoracic regions [2, 8, 10, 12-14]. Although rural workers who use quad bikes are exposed to high levels of WBV and have a high prevalence of spinal pain [8, 10], not all workers report spinal complaints and thus musculoskeletal injury risk may also be associated with a combination of intrinsic and extrinsic factors.

Body mass (kgs) and body mass index (BMI) are commonly described intrinsic factors. Both excessive body mass and high BMI are considered as risk factors in the development of work-related musculoskeletal disorders such as LBP [15, 16]. However, the evidence linking LBP to high body mass (or BMI) in professional drivers is conflicting [17, 18]. Although high levels of WBV have been associated with occupational LBP, body mass may be an important intrinsic factor which modulates this relationship in different ways. Several laboratory studies (Table **1**) have investigated the influence of body mass on various WBV exposure measures (including mechanical impedance, absorbed power, vibration transmission and apparent mass) under varying experimental conditions including; seat cushion, seat suspension, back rest, seat and tyre pressure, vibration magnitude and frequency [19-26] Extrapolation from these laboratory studies generally demonstrates negative associations between increased body mass and vibration exposure.

A small number of field studies (Table **2**) have been conducted on urban taxi drivers, metropolitan bus drivers,

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Table 1. Laboratory Studies: Relationship Between Body Mass and Whole-Body Vibration Exposure

Author & Year	Objective	Study Participants	Data Collection Setup	Outcome Measure	Data Analysis	Results/Conclusion
Toward *et al.* 2010 [26]	To determine any association between subject characteristics and the apparent mass of the human body on VV	80 individuals M-41; F-39 Age: 33.7 ± 13.1 yrs BM: 70.5 ± 13.4 kg Height: 1.71 ± 0.113 m BMI: 24.1 ± 3.8 kg/m^2	VG: electro-hydraulic vibrator Acc (z-axis): 0.5, 1.0, 1.5 m/s^2 Freq: 0.6 &12 Hz Conditions: 4 (with & without backrest: rigid & foam/inclined & upright) DE: 60 sec/condition RL: FP as seat & platform (A)	Apparent mass	Multiple Linear regression	BM is the strongest predictor (β= 0.84, 0.92 & 0.61) of apparent mass at 0.6 Hz, at resonance & at 12 Hz. Increased BMI was associated with a decrease in resonance frequency of 0.5 to 1.7 Hz.
Rakheja *et al.* 2008 [24]	To investigate the absorbed power characteristics under HV at two driving points	8 individuals M-8; F-0 Age: 21-51 yrs BM: 71.2 ± 10.6 kg Height: 1.73 ± 0.025 m BMI: NS	VG: HV simulator Acc (x & y-axis): 0.25, 0.5, 1.0 m/s^2 Freq: 0–10 Hz DE: NS RL: platform & seat back (A), seat pan & back rest (FP)	Absorbed power	Single factor linear regression analysis	Magnitude of the absorbed power is strongly correlated ($R^2 > 0.8$) to subject's weight.
Wang *et al.* 2006 [23]	To evaluate energy absorption characteristics of seated human occupants exposed to vertical vibration under different postural conditions	27 individuals M-13; F-14 Age: 39.6 ± 8.5 yrs BM: 70 ± 16 kg Height: 170.9 ± 7.13 m BMI: 18.1 ± 32.2 kg/m^2	VG: whole body vertical simulator Acc (z- axis): 0.5 to 1.0 m/s^2 Freq: 0.5-40 Hz Type of seat: rigid (off-road vehicle) Postures: 36 (hands position, seat pan, back support) DE: NS RL: seat (A)/between the seat and simulator (FP)	Absorbed power	Single factor linear regression analysis	Magnitude of the absorbed power is strongly correlated to individual's BM (R^2 >0.94) & BMI (R^2 >0.84).
Bluthner *et al.* 2006 [22]	To investigate the significance of body mass and vibration magnitude on seat transmissibility	12 individuals M-12; F-0 Age: 31 ± 11 yrs BM: 75.4 ± 11.4 kg Height: 181.2 ± 8.8 m BMI: NS	VG: electro-hydraulic hexa pod Acc (x axis): 0.9 - 2.03; y axis: 0.77-1.57 m/s^2 Freq: NS Types of seat: 2 (truck & tractor) DE: 2.8 min/2 trials RL: platform/seat frame/seat cushion/back rest (A)	SEAT	Univariate & multiple linear regression analysis	A significant influence of the body mass (R^2=0.8) on SEAT values was found for y-direction only.
Holmlund *et al.* 2000 [21]	To investigate the mechanical impedance of the human body under vertical vibration	30 individuals 15 M & 15 F Age: 31 ± 11 BM: 70 ± 11 kg Height: 173 ± 7 m BMI: NS	VG: electrodynamic shaker Acc (z-axis): 0.5,0.7,1.0, 1.4 m/s^2 Freq: 2-100 Hz DE: 20 min Posture: erect/relaxed upper body RL: seat plate (A)/between the seat plate (FP)	Mechanical driving point impedance (z-axis)	Linear regression	Magnitude of the impedance is strongly correlated (R^2=0.8) to subject's weight up to about 4 Hz.
Huston *et al.* 1999 [20]	To determine if the air cushions affect the natural resonance of the seat in off-road mining vehicles	3 individuals M/F: NS Age: NS BM: 55/71/95 kg (LW-55, MW -71, HW-95) Height: NS BMI: NS	VG: servo hydraulic Acc: NS Freq: 1-10 Hz (representative of off-road mining vehicles) Type of seat: mechanical spring suspension No of air cushions: 5 DE: 5 min/2 trials RL: seat base & seat pad (A)	Ratio of transmission in different frequency bands	NS	LW: high resonance (1-2.5 Hz), MW: low (3-4 Hz) & high (>5 Hz), resonance, HW: low resonance (> 3 Hz).
Lundstrom *et al.* 1998 [25]	To investigate WBV energy absorption during different experimental conditions	60 individuals (VV/HV) M-15; F-15 Age: 31 ± 11/37 ± 11 BM: 70 ± 11/69 ± 10 kg/m^2 Height: 173 ± 7/172 ± 27 m BMI: NS	VG: electrodynamic shaker Acc-z-axis: 0.5,0.7,1.0,1.4 m/s^2; x,y-axis: 0.25,0.35,0.5, 0.7, 1.0,1.4 m/s^2 Freq: 2-80 (z-axis) & 1.13- 80 Hz (x,y-axis) DE: HV-3,VV-10 min RL: seat plate (A/FP)	Absorbed power	ANOVA & Wilcoxon non-parametric method	Absorbed power increased with the body weight more specifically in females.

(Table 1) contd…..

Author & Year	Objective	Study Participants	Data Collection Setup	Outcome Measure	Data Analysis	Results/Conclusion
Burdorf *et al*. 1993 [19]	To evaluate the effect of seat suspension on the driver's exposure to vibration	2 individuals M/F: NS Age: NS BM: 53/95 kg Height: NS BMI: NS	VG: NS Acc (z-axis): 2.05 m/s^2 (tractors) 0.95 m/s^2 (lorry); 1.00 m/s^2 (fork-lift) Freq: NS No of suspended seats: 11 DE: 5 min/3 trials RL: seat surface/floor of the vehicle (A)	Tz & seat level RMS acceleration (z-axis)	NS	Tz significantly low in a specific suspended seat with 95 kg volunteer than with 53 kg subject.

M- males, F- females, BM- body mass, WBV- whole body vibration, HV- horizontal vibration, VV- vertical vibration, A-accelerometer, FP-force plate, DE: duration of exposure, SEAT- seat effective amplitude transmissibility, Tz- vibration transmission coefficient, RMS- root mean square, Sed- static compression dose, VDV- vibration dose value, VG: vibration generator, RL- level of vibration/force recording, NS- not specified, LW- light weight, MW- medium weight, HW- heavy weight.

and fork-lift truck drivers. While four studies [27-30] demonstrated a casual observation to significant negative association between body mass and vibration exposure the other two studies found no such relationship [19, 31]. While our recent quad bike research [8-10] has not identified body mass as being associated with WBV this was not the primary aim of these projects which were undertaken on a variety of different farms, terrains, quad bikes, and with different groups of workers. Thus, it is possible that these extrinsic factors contributed sufficiently to obscure the influence of body mass.

The primary aim of this field study was to explore the relationship between body mass and quad bike WBV exposure in a group of New Zealand rural workers when controlling for such extrinsic factors. The secondary aim was to explore personal factors such as age, height and quad bike driving experience as co-variates to determine whether these are also associated with exposure.

2. MATERIALS AND METHODS

2.1. Study Design

A cross sectional observational study was conducted on a South Otago (New Zealand) sheep and beef farm to investigate the relationship between body mass and vibration exposure in a group of rural workers (n= 34 males; age = 18 to 60 years) who regularly use quad bikes. This study was approved by the University of Otago Human Ethics committee. This study was a part of a larger project designed to investigate balance disturbances following exposure to a period of quad bike induced WBV.

2.2. Recruitment

Inclusion criteria were: currently working full time, in good health with no history of significant illness or injury to spine or limbs which required clinical intervention in the past 6 months. A convenience sample of 39 full time male rural workers was contacted by using publicly available community resources, including farm location maps. For practical reasons recruitment started near the provincial township of Balclutha, spreading outwards. Farms were contacted by telephone to describe the study, and seek verbal agreement by the worker to participate in the survey and recording of vibration exposure. In this manner 34 workers agreed to participate in the study.

2.3. Survey

On the day of experiment, each participant was surveyed to ensure they met the inclusion criteria and provided written informed consent to participate in the study. The survey also recorded self-reported age (yrs), height (m), weight (kgs), quad bike driving experience (years), and average daily driving period (hours). BMI was calculated by dividing body mass (kgs) by the square of height (m) [32].

2.4. Experiment Setup

2.4.1. ATV and Test Route

A commonly used 4 wheel drive quad bike (Fig. **1**, Yamaha Big Bear 400) with a fixed arm, single shock absorber rear suspension, and a fully independent front suspension, was chosen for the whole-body vibration exposure. Immediately prior to use, the vehicle was serviced by a trained mechanic and tire pressure set and maintained at the manufacturers recommended inflation pressure of 20.7 kPa (or 3.0 psi). Each participant drove the quad bike over the same pre-defined track. Following a consensus discussion with an experienced local farmer this track was chosen to represent a typical example of New Zealand mixed stock rolling farmland. This test route included a mixture of (farmer defined) flat, rolling flat, hilly and steep hilly terrains that included both paddocks and farm tracks [10]. The total distance of the track was 10.0 kilometres with each worker asked to drive over the same track in approximately 30 minutes to complete the circuit at an average vehicle velocity not to exceed 20 km/hour. The 30 minute period of vibration exposure was chosen by calculating the mean of the longest epoch of continuous driving gathered from 30 participants who took part in a previous full day quad bike vibration exposure study [9]. This recommended time, distance and average velocity were confirmed by the landowner after repeated trials driving over the test route at normal work speed.

2.4.2. Whole-Body Vibration Exposure

On arrival at the experimental site all participants were given specific driving instructions which include: nature of the test route using a farm map, to remain in a seated position, to drive at a speed not exceeding 20 km/hour, to not stop or dismount from the vehicle until the completion of the test ride. Each participant was also asked to sit (ischial

Table 2. Field Studies: Relationship Between Body Mass and Whole-Body Vibration Exposure

Author & Year	Objective	Study Participants	Data Collection Setup	Outcome Measure	Data Analysis	Results/Conclusion
Blood *et al.* 2010 [31]	To determine any differences in WBV exposures based on body weight and seat pressure settings in metropolitan bus drivers	12 part/full time bus drivers Age: 50.8 ± 6.8 yrs M-6; F-6 BM: 80.9 ± 19.8 kg Light (<70 kg): 5; Moderate (71- 93 kg): 4; Heavy (>94 kg): 3 Height: NS BMI: NS DE: 9.9 ± 9.3 yrs DT: 5.5 ± 1.9 hrs	Vehicle: ST (Same low floor bus/no passenger) Track: ST Distance: 52 km including 10 speed humps Speed/duration: NST RL: seat & floor of the bus	VDV, RMS acceleration, Sed, acceleration peak & SEAT	Repeated measures ANOVA	No significant weight related behavior across seat and road types.
Blood *et al.* 2010 [30]	To compare the differences in WBV exposure between 2 types of suspensions in fork-lift operators	12 fork-lift operators M/F: NS Age: 44.3 ± 11.6 yrs BM: 98.3 ± 19.4 kg Height: NS BMI: 31.0 ± 4.7 kg/m^2 DE: 17.7 ± 13.9 yrs DT: NS	Vehicle: ST (Same fork-lift) Track: ST Types of suspension: mechanical & air suspension Distance: 3.5 km Speed: NST Recording duration: 12-15 min RL: seat & floor	VDV, RMS acceleration, Sed, acceleration peak & SEAT	Repeated measures ANOVA & non-parametric Wilcoxon rank-sum tests	WBV exposure decreased with body mass in mechanical seat & better exposure reduction in LW drivers (<84 kg) under air suspension.
Chang *et al.* 2003 [29]	To identify important WBV predictors to quantify individual WBV exposure among urban taxi drivers	247 taxi drivers M-247, F- 0 Age: 44.6 ± 8.3 yrs BM: 68.9 ± 11.8 kg Height: NS BMI: NS DE: 9.2 ± 7.3 yrs DT: 9.7 ± 2.3 hrs	Vehicle: ST (Different models of taxi) Track: NST Usual taxi driving practices; different traffic hours; vacant/short/long rides; Usual speed & driving patterns: NST Distance: NS Recording duration: 30 min RL: seat level	RMS acceleration (Z axis)	Mixed effects model; Likelihood ratio test & covariate entering the model: 0.20 level	Body weight is a highly significant (p=0.002) predictor of WBV exposure in urban taxi drivers.
Malchaire *et al.* 1995 [28]	To compare the influence of cushion and inflated tyres on vibration exposure in fork-lift trucks	3 skilled fork-lift drivers Age: NS BM: 72/55/72 kg Height: NS BMI: NS	Vehicle: NST 5 types of fork-lift trucks; 4 – types of tyres,2 – types of seat; 2- loaded/unloaded conditions Track: ST Rough (300 m) & smooth (280 m) tracks Instructed drive ‘as usual’ Speed: ST Duration of ride: NS RL: seat & floor of the vehicle	Seat & floor RMS acceleration	ANOVA & multiple regression analysis	Casual observation: high RMS acceleration in 55 kg individual and low RMS in the 72 kg individual. Regression coefficient (0.138) No effect of worker’s weight on seat vibration.
Burdorf *et al.* 1993 [19]	To evaluate the effectiveness of seat suspension on vibration transmissibility through the driver’s seat of lorries, tractors & fork-lift trucks	2 participants Age: NS BM: 53 & 95 kg Height: NS BMI: NS DE/DT: NS	Vehicle: NST (lorries, tractors & fork-lift) 11 types of seats Track: ST 24 working environments 2 working conditions: high speed on smooth terrain; low speed on rough terrain Distance: NS Speed: ST Duration of ride: ST (5 min) RL: seat & floor of the vehicle	Tz & seat level RMS acceleration (z axis)	NS	Tz & RMS acceleration are not dependent on driver’s weight.

(Table 2) contd…..

Author & Year	Objective	Study Participants	Data Collection Setup	Outcome Measure	Data Analysis	Results/Conclusion
Boileau *et al*. 1990 [27]	To evaluate the effect of 4 suspension seats on WBV exposure in log skidders in the forest industry	2 participants Age: NS BM: 77 & 102 kg Height: NS BMI: NS DE/DT: NS	Vehicle: NST Track: NST Typical terrains but in different terrains. Distance: NS Speed: ST Duration of ride: ST (5 min) RL: seat & floor of the vehicle	SEAT, weighted overall excitation amplitude; expected daily exposure time	NS	Lighter individuals had higher exposure amplitude.

M- males, F- females, BM- body mass, WBV- whole body vibration, DE- driving experience, DT- driving duration/day, HV- horizontal vibration, VV- vertical vibration, SEAT- seat effective amplitude transmissibility, Tz- vibration transmission coefficient, RMS- root mean square, Sed- static compression dose, VDV- vibration dose value, RL-Level of vibration recording, NS- not specified, ST- standardized, NST- not standardized, LW- light weight, MW- medium weight, HW- heavy weight

tuberosities on the accelerometer pad) in their normal seated driving posture and to complete a continuous quad bike driving epoch for approximately 30 minutes on the pre-marked test route. Raw vibration data collected continuously during the 30 minute drive were accepted as satisfying the minimum 20 minute recording time conditions described within the ISO 2631-1 (1997) and ISO 2631-5 (2004) standards. A circular seat-pad containing a series 2 (10 g), 8th order, 1.2 elliptic, tri-axial accelerometer (NEXGEN Ergonomics) was mounted on the seat of the quad bike directly under each participant's ischial tuberosities. The accelerometer channels X, Y and Z were aligned as anterior-posterior, medio-lateral, and superior inferior respectively with regards to the quad bike. Thus, the X channel recorded vibrations in a fore and aft direction, Y recorded side to side vibrations and Z recorded vertical vibrations. Vibration data were digitally recorded, stored, and time stamped in a Biometrics (DataLog W4X8) 8 channel data logger (Biometrics™) mounted on the rear of the quad bike. In order to analyze a 0.5 to 80 Hz ISO 2631 recommended vibration spectrum the sampling frequency was set at 2000 Hz with an 8th order anti-aliasing filter set at the 500 Hz cut-off frequency as recommended by the supplier (NEXGEN Ergonomics Inc).

2.5. Outcome Measure and Analysis

2.5.1. Vibration Outcome Measure

As quad bike vibration exposure has previously demonstrated crest factors exceeding 9.0 [8] the vibration dose value (VDV) was chosen as the most appropriate quantitative measure of vibration exposure. The VDV (expressed in $m/s^{1.75}$) is considered to be a more sensitive indicator of the relationship between vibration magnitude and discomfort. It is also specifically sensitive to impulse vibration and also allows analysis of lower vibration magnitude for durations shorter than 8 hours [5, 33]. In accordance with the recommendations of the European Union Physical Agents Vibration Directive (EUPA (V)D) (2002) for daily exposure health effects a VDV score < $9.1 m/s^{1.75}$ would be below the exposure action value (EAV) and a score ≥ $21.0 m/s^{1.75}$ would be above the exposure limit value (ELV).

2.5.2. Vibration Data Analysis

Vibration dose values ($VDV_{X,Y,Z \text{ and sum}}$) were calculated using VATS™ (V3.4.4) proprietary vibration analysis software supplied by NEXGEN Ergonomics Inc. The 0.5 Hz to 80.0 Hz peak frequency spectrum was calculated by using a $^{1}/_{3}$ octave analysis Fast Fourier Transform (FFT) of the X, Y and Z axis peak RMS acceleration data. This allowed the determination of exposure to spinal resonant frequencies [33]. Low amplitude (non-driving) data were removed from the beginning and end of each participant's vibration log with the use of Biometrics DataLog software allowing the calculation of mean exposure period (driving duration). In order to control for the effect of variation in driving time, each participant's VDV_Z was corrected to a one hour equivalent exposure, *One hour* VDV_Z *(*$1hrVDV_Z$*)* for further statistical analysis. Mean driving velocity (km/h) for each worker was also calculated by dividing distance travelled (10 km) by mean driving time (hrs).

Fig. (1). Quad bike (Yamaha Big Bear 400).

2.5.3. Data Analysis

All data were analyzed using SPSS (version 16.0) and are presented descriptively in both tabular and graphic format. A univariate linear regression model included $1hrVDV_Z$ *(*$m/s^{1.75}$*)* as the dependent variable while *Body mass* (kgs), *Body height* (m), *Age* (yrs) and *Quad bike driving experience* (yrs) were entered separately as independent variables. A multivariate backward linear regression model was also used to determine the influence of *Body mass*, *Body height and Quad bike driving experience* as co-variates.

3. RESULTS

3.1. Participant Information

Participants had a mean age of 40.3 (yrs), mean body mass of 94.9 (kgs), mean body height of 1.80 (m), mean BMI of 29.0 (kg/m^2), with a self-reported quad bike driving experience of 19.2 (yrs) and a daily quad bike driving duration of 2.2 hours. The mean recorded vibration exposure duration (hrs) was 0.5 hours and the mean driving velocity was 19.8 km/hr (Table **3**).

Table 3. Participant and Vehicle Exposure Information

	Mean	Std. Deviation	Minimum	Maximum
Participant				
Age (yrs)	40.3	10.6	18.0	57.0
Body mass (kgs)	94.9	14.0	68.0	129.0
Body height (m)	1.80	0.08	1.60	2.00
BMI (kg/m^2)	29.0	3.5	22.8	42.1
Driving experience (yrs)	19.2	7.7	2.0	30.0
Daily driving (hrs)	2.2	1.2	0.5	4.5
Vehicle Exposure				
Exposure duration (hrs)	0.5	0.1	0.4	0.6
Driving velocity (km/hr)	19.8	2.4	16.0	27.0
VDV_X (m/s$^{1.75}$)	5.7	0.6	4.2	6.7
VDV_Y (m/s$^{1.75}$)	5.5	0.4	5.0	6.8
VDV_Z (m/s$^{1.75}$)	11.1	1.6	8.0	15.4
VDV_{sum} (m/s$^{1.75}$)	12.4	1.4	9.3	16.0
$1hrVDV_Z$ (m/s$^{1.75}$)	13.2	1.8	9.5	18.7

3.2. Vibration Dose Value

Mean VDV_X was 5.7 m/s$^{1.75}$, mean VDV_Y 5.5 m/s$^{1.75}$, mean VDV_Z 11.1 m/s$^{1.75}$ and mean VDV_{sum} 12.4 m/s$^{1.75}$ (Table **3** and Fig. **2**). Mean one hour VDV_Z ($1hrVDV_Z$) was 13.2 m/s$^{1.75}$ (Table **3** and Fig. **3**). Both VDV_Z and VDV_{sum} exceeded the VDV exposure action value (EAV) of 9.1 m/s$^{1.75}$ for all participants (Fig. **3**) although none exceeded the VDV exposure limit value of 21.0 m/s$^{1.75}$.

3.3. FFT Spectrum

Mean peak FFT values and amplitude characteristics for X, Y and Z directions are presented in Fig. (**4**). The highest peak amplitude was 3.72 m/s^2 in the Z axis occurring at 4.0Hz and considerably greater than the peak amplitudes observed at 2.5Hz for the X (2.34 m/s^2) and Y (1.68 m/s^2) directions respectively.

3.4. VDV_Z Relationships

Body mass demonstrated a statistically significant (p = 0.0003) univariate association (Table **4** and Fig. **5**) with *$1hrVDV_Z$* (R^2 = 0.340) while *Body height*, *Age* and *Quad bike driving experience* did not. Further analysis also showed BMI was significantly associated (p = 0.0003; R^2 = 0.337) with 1hr VDV_Z (Fig. **6**) however the strength of the association was similar than that for *Body mass* alone. In a multivariate *backward* linear model (Table **4**) *Body mass*, *height*, and *Quad bike driving experience* combined to explain 38% (R^2 = 0.376) of the variance in *$1hrVDV_Z$*, however only *Body mass* (p = 0.0004) demonstrated statistical significance.

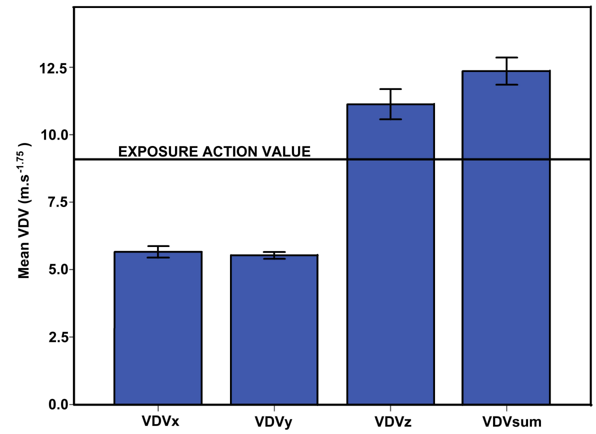
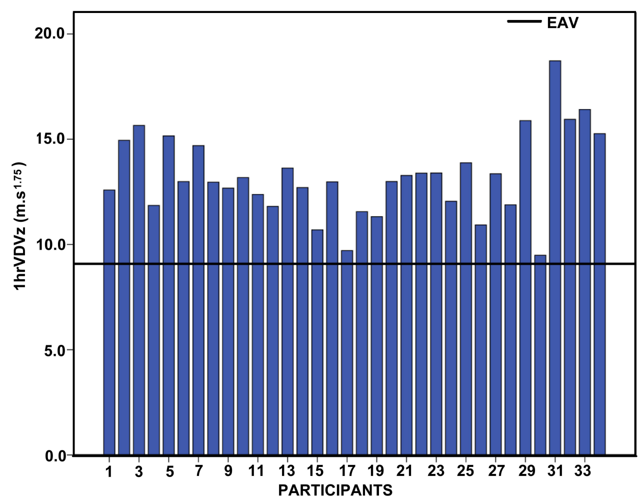


Fig. (2). Mean VDV $_{X, Y, Z \text{ and sum}}$ (m/s$^{1.75}$) (error bars represent 95% confidence intervals).



EAV = Exposure Action value: 9.1 m/s$^{1.75}$

Fig. (3). $1hrVDV_Z$ of the 34 participants.

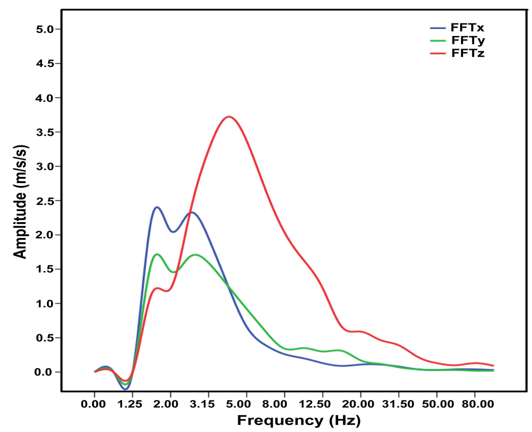


Fig. (4). FFT vibration spectrum.

Table 4. Uni and Multivariate Regression Analysis for $1hrVDV_Z$ Exposure

Univariate	$1hrVDV_Z$				
	β	**Lower Bound**	**Upper Bound**	**p Value**	R^2
Age	0.197	-0.030	0.105	0.263	0.039
Body Mass	-0.583	-0.123	-0.041	0.0003	0.340
Body height	-0.198	-13.570	3.829	0.262	0.039
BMI	-0.581	-0.488	-0.161	0.0003	0.337
Quad bike experience	-0.039	-0.108	0.087	0.828	0.001
Multivariate					
Body mass	-0.721	-0.153	-0.050	0.0004	0.340
Body height	0.231	-3.466	14.827	0.214	0.035
Quad bike experience	-0.020	-0.086	0.075	0.891	0.001
Combined model					0.376

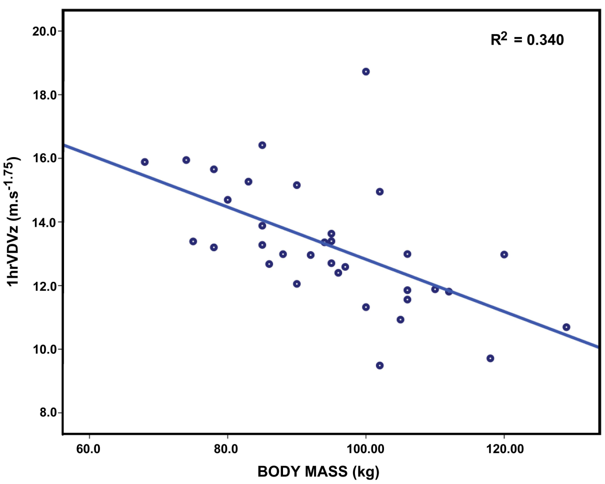


Fig. (5). Strength of association: Body mass (kg) and $1hrVDV_Z$ ($m/s^{1.75}$).

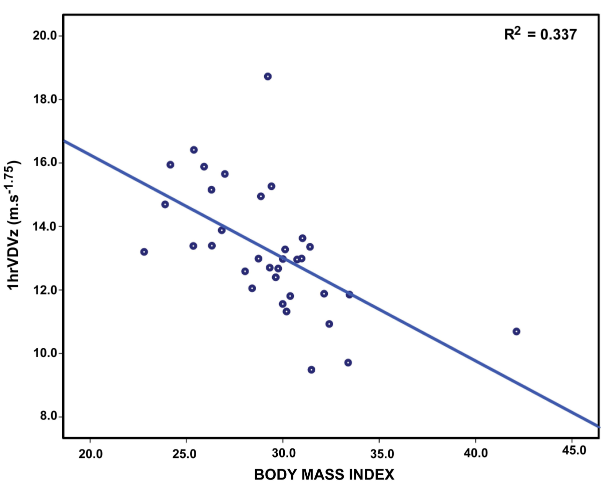


Fig. (6). Strength of association: BMI (kg/m^2) and $1hrVDV_Z$ ($m/s^{1.75}$).

4. DISCUSSION

The aim of this field study was to explore the relationship between body mass and WBV exposure in a group of New Zealand rural workers who use quad bikes. The results demonstrate a significant negative association (R^2 = 0.34) between body mass and $1hrVDV_Z$ (Fig. **5**). Consistent with other quad bike vibration research [8-10], this study has demonstrated high levels of vibration exposure in the Z direction exceeding the EAV of $9.1m/s^{1.75}$ [11] when driving for a mean 30 minutes of exposure. As vibration exposure was considerably lower than the EAV (< $9.1m/s^{1.75}$) in the X and Y directions these results primarily discuss risk and modulation associated with vibration in the Z direction. Although body height and quad bike experience strengthened a multivariate model slightly (R^2 = 0.376) the effect was only minor and non-significant. Furthermore, body mass alone presented a univariate model (R^2 = 0.340) similar to BMI (R^2 = 0.337). Thus the predominant effect in this controlled fieldwork experiment (same track, same vehicle, same distance, same tyre pressure, similar riding time) was the influence of increased body mass in attenuating a significant percentage of vibration exposure in the Z direction.

The FFT analysis also demonstrated the presence of Z-axis resonant frequencies peaking at 3.72 m/s^2 and 4.0Hz as well as lower amplitude peak accelerations detected in the X and Y axis in the lower frequency of 2.50Hz. These frequencies have been described as spinal resonant frequencies associated with injury risk as well as subjective discomfort in the vertical, fore-and-aft and lateral directions [34-36] particularly when the worker is exposed to these resonant frequencies for longer daily exposure periods.

In order to minimise for extrinsic factors such as vehicle type, track conditions and tyre pressure [10, 37, 38] all participants drove the same quad bike with a pre-set tyre pressure on the same test route. Although previous literature has reported relationships between driving experience, age of the driver, and vibration exposure [6, 10], there was no statistically significant evidence for this in this study. Thus the standardized test route and driving instructions are likely to have reduced behavioral effects associated with age and driving experience [39]. While this association between body mass and VDV_Z is moderately strong and explains close to 34% of the variance for this vertical vibration measure it must also be recognized that 66% of vibration exposure is not explained by weight. Interestingly previous research indicates body mass had little effect on vibration exposure in the uni and multi-variate models when the rural workers were free to use their own vehicles, in their normal farm environment, undertaking their own daily chores, choosing their own vehicle and driving paths and driving at their own self-selected speed [9, 10]. This shows that a substantial number of factors can potentially influence statistical models for quad bike vibration exposure and that body mass is but one of these factors. Where choice is associated with vibration exposure (e.g. choice of driving path, tasks, and/or velocity) and where the demands of farm productivity can force the worker into making difficult task and time allocation choices, it is likely that behavioral factors will also have a strong influence on vibration exposure [39].

This research is consistent with previous *laboratory* results which demonstrate negative relationships between body mass, transmission coefficient and seat effective amplitude transmissibility [19, 20, 22] as well as the positive relationships seen between body mass and vibration measures of total absorbed power, mechanical impedance and apparent mass [21-26]. These laboratory results thus support a negative relationship between body mass and vibration exposure. Two previous (albeit non-farming) field studies are contradictory, with one (taxi drivers) demonstrating a negative relationship and the other (fork-lift trucks) showing no relationship [19, 29]. However, these were conducted under different test conditions, routes and vehicles; with markedly different sample sizes which will likely have influenced vibration record and outcomes. A further small number of field studies (small samples) using a standardized test vehicle (bus drivers/fork-lift trucks) and test route also found contradictory effect for body mass on vibration exposure [30, 31]. In contrast to the majority of these other studies the current research used a larger sample size and standardized for possible effects of extrinsic confounding factors such as: test farm, test route, vehicle (quad bike) as well as minimizing for driving speed, and thus attempted to isolate for the influence of personal, anthropometric and work experience variables.

The literature suggests occupational WBV, body mass or BMI are individual risk factors in the development of low back disorders [2, 15, 40]. Surprisingly recent evidence has found no association between WBV, BMI and low back pain in professional drivers [18]. It is possible that this recent finding could be explained in part, by the results of the current study, where increased body mass is significantly and negatively associated with vibration exposure at least in light-weight quad bikes in on-farm conditions.

The strengths of this study include: controlling for intrinsic and extrinsic factors such as driving instructions, standardized vehicle, validity of farm terrain, and adequate standardized exposure period. The limitations include a modest sample size (n=34) thus reducing generalisability to the larger work force, the use of surveyed self-reported measures (including body mass, body height, driving experience) where evidence for reliability, validity and accuracy of self reported anthropometric measures are equivocal [41-44], as well as the use of a pragmatic and single sex (males) sample. Further research with a larger sample will be required to clarify these issues.

5. CONCLUSION

Body mass is significantly associated with quad bike induced WBV (expressed as $1hrVDV_Z$) in a group of New Zealand rural workers. Other intrinsic factors such as body height, age and quad bike experience were not associated with vibration exposure. These results for body mass should be considered by others undertaking WBV research on small vehicle vibration exposures. Reduction of vibration exposures is considered an ergonomic intervention of importance in drivers of commercial vehicles. Attenuation of vibration by body mass alone may need to be factored into design of seating and suspension systems for small on-farm vehicles.

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