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RESEARCH ARTICLE **Open Access**

Elite mountain bike enduro competition: a study of rider hand-arm vibration exposure

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Abstract
Limited information is currently available regarding the hand-arm vibration (HAV) exposure for professional off-road cyclists. Previous reports have suggested that commuting and recreational cyclists are at risk of exceeding exposure limit values (ELV) in a single ride. Therefore, further investigation of HAV exposure in competitive mountain biking is warranted. Partial and total eight hour exposure data ($A_i(8)$, $A(8)$, ms^{-2}) were computed for a national level mountain bike enduro competitions. Hand-arm vibrations were measured using a tri-axial accelerometer recording at a frequency of 3.2 kHz mounted on the handlebar and accelerations were quantified after frequency weighting filters were applied (W_h). The data presented shows that HAV exposure during one day of competitive enduro mountain bike racing exceeds ELV (mean race exposure = 5.84 ms^{-2}, minimum = 5.47ms^{-2}, maximum = 6.61ms^{-2}) and is greater than the HAV exposure observed in recreational cycling. This suggests that further work is required to determine the exposure associated with changes in equipment, technique and international racing events in professional athletes.

Keywords: Enduro mountain bike, competition, hand-arm vibration exposure.

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Introduction
Exposure to hand-arm vibration in the workplace is tightly controlled due to evidence linking excessive exposure to musculoskeletal, neuromuscular, vascular and other types of pathologies. Hand-arm vibration syndrome (HAVS) is a recognised industrial disease induced by excessive exposure to vibration through occupational tasks involving vibrating machinery (Bovenzi 1998). HAVS is a progressive and irreversible condition comprising a range of disorders affecting the peripheral circulatory system, peripheral nervous system and muscular skeletal system of the hand and arm. Therefore, the ability to predict a rate of progression of HAVS and take timely preventative action through exposure reduction or complete elimination of hazardous exposure is highly desirable. Despite strict enforcement of vibration exposure guidelines in the work place, professional sports have received less attention in this context despite evidence of potentially harmful vibration exposure. However, vibration data has been considered in relation to overuse injury prevention in sports (Spörri et al. 2017). There have also been significant competitive wins where increased performance has been associated with vibration management. These include Gilbert Duclos-Lassalle's Paris-Roubaix win in 1992 and more recently, Peter Sagan's win at the same race in 2018. Both bicycles were fitted with shock absorbing devices in the front fork designed to reduce vibration transferred to the handlebar induced from the cobbles encountered throughout this race.

Previous research has assessed the relative difference of bicycle components on the vibration induced in the hands and body of cyclists. Lépine, Champoux and Drouet (2015) assessed the relative contribution of vibration through measurement in three locations. These included the vibration transmitted through the handlebars, saddle and brake hoods. Results showed that the handlebar and fork were the main contributors of vibration induced at the hands, whilst the frame and wheels were the main components associated with vibration induced at the buttocks of the cyclist (Lépine et al. 2015). Gomes and Savionek (2014) conducted hand-arm vibration exposure assessment on a range of pavement surfaces including asphalt, precast concrete and interlocking concrete blocks. Using an accelerometer attached to the handle bars, they determined the daily vibration exposure using a two-hour duration to represent the average time of a commuter cyclist's journey. Terrain was shown to be a key factor of vibration exposure with interlocking concrete blocks presenting significantly higher values than asphalt or precast concrete. Parkin and Eugenie Sainte (2014) provided a study of comfort and health factors including the nature of vibration from riding in different circumstances in the City of London. Several cyclists reported having discomfort or pain after cycling, proposed to be related to vibration exposure during cycling, inappropriate body position while cycling or a combination of both factors (Capitani and Beer, 2002).

Munera et al. (2014) summarised the different standards and guidelines associated with the evaluation of vibration and exposure limits whilst cycling. Focussing on performance athletes, they considered the application of European Directive 2002/44/EC (EC 2002) in defining the limits of exposure and action 'triggers' for safe exposure management in sport with particular reference to the exposure action value (EAV; 2.5 ms^{-2}) and the exposure limit value (ELV; 5.0 ms^{-2}). In a limited number of studies on road cycling, harmful levels of hand-arm vibration have been reported when riding on cobbled surfaces where exposure limit values (ELV) values are exceeded in less than 20 minutes (Chiementin et al. 2013; Duc et al. 2016; Taylor et al. 2018). This is particularly concerning as riders competing in races such as the Paris-Roubaix spend ~90 minutes riding on cobblestones and are therefore subjected to harmful levels of hand-arm vibration.

Despite the broad range of research concerning road or commuter cycling, to the authors' knowledge, there has been no attention given to the hand-arm and hand-transmitted vibration that mountain bike enduro athletes are exposed to. Additionally, studies that have explored magnitude of vibration experienced by downhill (Hurst et al. 2013) and cross-country riders (Macdermid et al. 2014, 2015) were limited by the fact that they did not meet the analysis requirements of hand-arm vibration exposure in compliance with of the international standard BS EN ISO 5349-1:2001. In particular, there has been limited attention to measurement of the appropriate frequency range and the application of the appropriate weighting filters within the previous work.

Enduro mountain bike races are composed of a series of timed, predominantly downhill race stages on challenging downhill terrain linked by non-competitive, primarily uphill, transition sections (Enduro World Series 2018). The physiological demands of elite enduro competition requires a large aerobic capacity with intermittent anaerobic contribution coupled with the ability to navigate technical terrain at high speed (Hassenfratz et al. 2012; Kirkwood et al. 2017). This latter study also demonstrated that faster riders experienced greater vibration exposure values (r.m.s. ms^{-2}) over the duration of an international enduro race stage, though no detailed vibration analysis was presented. The extreme terrain, high velocities and prolonged duration warrant further investigation of hand-arm vibration in enduro mountain bike competition. Therefore, the aim of the present study was to assess the hand-arm vibration exposure associated with enduro mountain bike competition.

Methods

Participants

Two male elite enduro athletes (athlete no. 1 age = 24 years; athlete no. 2 age = 31 years) who were either currently or recently professional athletes and previously placed in the top 10 overall positions at an Enduro World Series race were recruited for this study. Ethical approval for this study was granted by the [organisation name withheld for purposes of blind review] ethics committee in accordance with the World Medical Association Declaration of Helsinki (World Medical Association 2001). Written and verbal consent was obtained from both participants prior to commencement of data collection.

Table 1. Distance, elevation and gradient details for SES race event.

Section	Distance (km)	ΔElevation (m)	Gradient (%)
Entire course	33.8	1579	-
Stage 1	1.12	-297	-26.5
Stage 2	1.05	-221	-21.1
Stage 3	1.58	-198	-12.6
Stage 4	2.52	-308	-12.2
Stage 5	1.43	-331	-23.1

Table 2. Summary of distance, elevation and gradient for BC race event.

Section	Distance (km)	ΔElevation (m)	Gradient (%)
Entire course	52.2	1493	-
Stage 1	0.99	-157	-15.9
Stage 2	1.38	-298	-21.5
Stage 3	1.40	-292	-20.9
Stage 4	0.72	-215	-29.9
Stage 5	0.76	-153	-20.2
Stage 6	0.60	-114	-19.1

Assessment of vibration: track and bicycle details

Vibration exposure data was collected during two national level enduro races; a round of the Scottish Enduro Series (SES) and the British Enduro Championship Race from the same year (BC). Elevation and distance profiles of each race event are provided in Figures 1 and 2. Data concerning the elevation, distances covered and gradients for the BC and SES stages are provided in Tables 1 and 2. The athletes rode their own bicycles (all size large) which were set up to personal preference as detailed in Table 3. Athlete 1 (A1) rode a bicycle with 584mm outer diameter rims (650b) front and rear in both events while athlete 2 (A2) rode a 650b bicycle during SES and a bicycle with 622mm outer diameter rims (29er) front and rear during BC. The SES race consisted of five race stages over a distance of 33.8km with a total elevation gain of 1579m. The BC race consisted of six race stages within a 52.2km course featuring 1493m elevation gain.

Assessment of vibration: accelerometer and mounting position

A proprietary three-axis accelerometer and data logger (Axivity AX-3) was selected as a robust and compact measurement device with suitable overall dimensions and data storage capability. The device sample rate was 3.2 kHz with a range of ±16g.

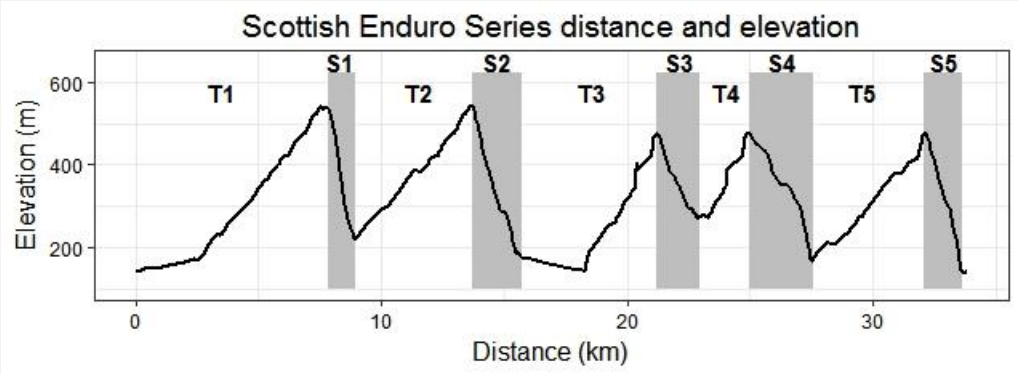

Figure 1. SES stage summary showing transitions, stages, and elevation.

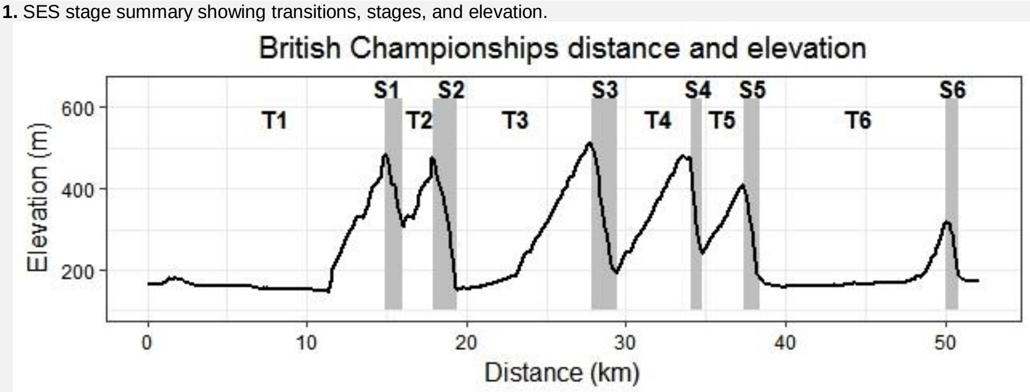

Figure 2. BC Stage summary showing transitions, stages, and elevation.

It is essential that human vibration exposure is quantified by the vibration conditions at the interface between the environment and the human body: not by the vibration at any other arbitrary position on the body or in the vibration environment (Griffin 1990). However, due to the need to avoid potential interference with the riders hand grip and control ergonomics under racing conditions, a compact, lightweight and generic handle bar mount adaptor was utilised. Due to the low mass of the combined mount and accelerometer (26.432g < 5% of the handle bar, refer to BS EN ISO 5349-2:2001, Clause 6.1.5), it was deemed not to affect the vibration characteristics of the handlebars. The accelerometer mount was positioned in close proximity to the handlebar grip. The bespoke accelerometer mount was constructed from a stereolithography file using a 3D printer (Makerbot Replicator 2) and was printed from acrylonitrile butadiene styrene (ABS) thermoplastic

Table 3. Details of participants, bicycle components and set-up. Note: Total mass (kg) refers to the mass of the athlete wearing cycling equipment and total cycling mass (kg) refers to the combined weight of athlete wearing cycling equipment and the bicycle.

	Scottish Enduro Series		British Championships	
Participant	1	2	1	2
Height (cm)	181	182.3	181	2
Total mass (kg)	78.9	80.4	77.5	182.3
Bike mass (kg)	15.2	15.5	14.8	81.5
Total cycling mass (kg)	94.1	95.9	92.3	15.9
Tyre pressure (front/rear; psi)	22/27	18/20	22/26	97.4
Fork pressure (psi)	75	77	75	20/20
Fork suspension travel (mm)	170	160	170	70
Wheelsize	650b	650b	650b	160
Frame	Ibis Mojo HD4	Ibis Mojo HD4	Ibis Mojo HD4	29
Fork	Fox 36	Fox 36	Fox 36	Ibis RipMo
Shock	Fox Float X2	Fox Float X2	Fox Float X2	Fox 36
Handlebars	Joystick Analog Carbon	Joystick Analog Carbon	Joystick Analog Carbon	Fox Float X2
Stem	Joystick Analog 50mm	Joystick Analog 50mm	Joystick Analog 50mm	Joystick Analog Carbon

polymer. Figure 3 shows the adaptor dimensions. Figure 4 shows the position of the accelerometer mount on the handlebar.

Assessment of vibration: signal processing and analysis

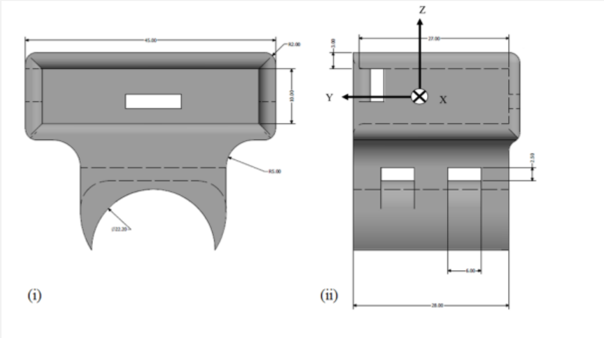

Figure 3. (i) Front and (ii) end elevation of handle bar accelerometer mount showing apertures for fixing ties and orientation of measurement axes.

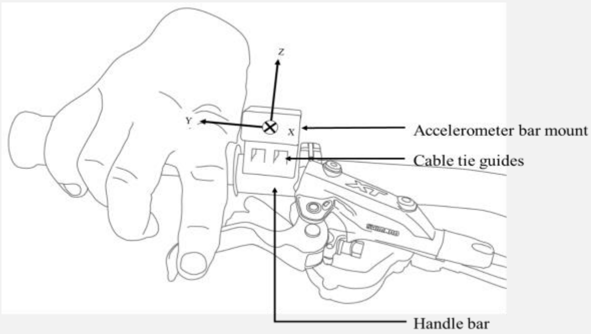

Figure 4. In-situ handle bar accelerometer mount showing proximity to hand grip.

Digital signal processing was undertaken using Matlab 2018b. Toolbox add-ons included the Control System Toolbox (Version 10.2), Digital Signal Toolbox (Version 9.4) and Signal Processing Toolbox (Version 7.4). Digital filters (W_h) were constructed in accordance with ISO 5349 (BSI 2001) using continuous time transfer functions. The current research considers the application of European Directive 2002/44/EC (EC 2002) to mountain bike enduro race events. Therefore, daily vibration exposure is considered in the present study with reference to the exposure action value (EAV = 2.5 ms^{-2}) and the exposure limit value (ELV = 5.0 ms^{-2}).

Each racing stage of the race was considered as a discrete operation and as a partial vibration exposure ($A_i(8)$). Transition stages were not included in the present analysis. However, despite riders not racing, these stages may also contribute to additional partial vibration exposure over the duration of the race. The r.m.s. acceleration values (Equation 1) were calculated for each rider on each race stage (Scottish Enduro Series, Stage 1-5 and British Championship Stage 1-6).

The r.m.s. acceleration value was calculated using:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2}$$

Equation 1

where a_{hv} is the total vibration value (frequency-weighted acceleration sum), a_{hwx}, a_{hwy} and ah_{wz} are the single axes acceleration values for the axes denoted x, y and z.

Amplitude analysis was conducted using the mean value, standard deviation, root-mean-square (r.m.s.) and root-mean-quad (r.m.q.). For the time series sampled for a period of time, Ts, at fs samples per second with a total of N samples data values x(i), where i = 1 to N, the mean value (x′) is calculated as:

$$x' = \frac{1}{N}\sum_{i=1}^{i=N} x(i)$$

Equation 2

The standard deviation is calculated as:

$$\sigma = \left\{\frac{1}{N}\sum_{i=1}^{i=N}[x(i) - x']^2\right\}^{1/2}$$

Equation 3

The root-mean-square (r.m.s.) value, is calculated as:

$$r.m.s. = \left[\frac{1}{N}\sum x^2(i)\right]^{1/2}$$

Equation 4

The root mean quad (*r.m.q.*) considers the *r.m.s.* acceleration raised to the fourth power and ensures that consideration is given to the peaks in the acceleration levels. The authors propose the use of the r.m.q., alternatively known as the vibration dose value (VDV) and commonly used in whole body vibration analyses, as an indicator of the peak vibrations (or shock) experienced by the rider. The root-mean-quad is calculated as:

$$r.m.q. = \left[\frac{1}{N}\sum x^4(i)\right]^{1/4}$$

Equation 5

The exposure time for each stage was calculated in accordance with the official event times provided by the race organiser. The partial exposure time for each race stage (Equation 2) was then combined to calculate the 8-hour energy equivalent vibration total value (Equation 3). This value can then be considered to be the race vibration exposure value. To facilitate comparison between the different stages and evaluate the individual contribution, each stage was considered as a partial stage vibration exposure calculated as:

$$A_{i,stage}(8) = a_{hvi}\sqrt{\frac{T_i}{T_0}}$$

Equation 6

The race exposure (considering racing stages only) has been calculated in the similar manner to the calculation of a daily vibration (BSI 2015) considering the summation of the partial exposure values as:

$$A_{race}(8) = \sqrt{\sum_{i=1}^{n} A_i^2(8)}$$

Equation 7

The daily vibration exposure for the rider would include all race stages, transition stages and all riding throughout the entire day. Due to the data storage requirements of recording a rider's entire daily vibration exposure, race stage vibration exposure has been considered for the present study. Frequency-weighted partial vibration exposure values (r.m.s., ms^{-2}) are calculated by applying the W_h weighting filter (BSI 2001). The human sensitivity to vibration depends on (i) the frequency, (ii) the direction of vibration, both translational and rotational and (iii) the posture of the human (Giubilato & Petrone 2012). Frequency weighting curves consider these aspects of human sensitivity. The frequency-weighting and band-limiting filter reflected the assumed importance of the different frequencies in causing injury to the hand and arms. Band-limiting high-pass and low-pass filters are used to restrict the measured value of vibration frequencies. These filters were realised using digital methods and applied using a Matlab 2018b programme. The characteristics of the W_h filter are provided in Annex A of BS EN 5349-1:2001 (BSI 2001).

Results

The athletes successfully finished both race events and provided complete data sets. Both athletes finished in the top 10 overall positions at both race events, highlighting the elite status of these athletes. The athletes provided permission for these details to be included as it is realised that they could potentially be identifiable from these data. Details of overall race and individual stage performance are provided in Table 4.

Table 5 provides the overall stage time (*r.m.s*). vibration exposure for the duration of the stage including the mean (x'), standard deviation (σ), root-mean-quad (*r.m.q.*) and partial vibration exposure ($A_{i,stage}$ *(8)*). The race vibration exposure for both athletes in both the British Championship and Enduro Series races was in excess of the ELV (5.0 ms^{-2}) in accordance with EC Directive 2002/44/EC.

Both athletes experienced lower vibration exposure at BC compared to SES. The faster rider (A1) also presented larger stage and overall race vibration exposure values throughout both races and all stages with the exception of BC stage 2. The greatest race vibration exposure value was experienced by A1 at SES ($A_{race}(8)$ = 6.97 ms^{-2}) while the lowest vibration exposure was A2 at BC ($A_{race}(8)$ = 5.47 ms^{-2}). Figure 5 and Figure 6 show the time domain data for the maximum and minimum partial vibration (stage)

Table 5. Summary of vibration analysis results from British championship (BC) and Scottish Enduro Series (SES). S = stage, A1 = athlete 1, A2 = athlete 2.

Athlete/ race		**t**	**x'**	**σ**	***r.m.s.***	***r.m.q.***	**$A_i(8)$**	**$A_i^2(8)$**
		(s)	**(ms^{-2})**	**(ms^{-2})**	**(ms^{-2})**	**($ms^{-1.75}$)**	**(ms^{-2})**	**(ms^{-2})**
A1 BC	S1	138.90	27.05	17.73	32.34	42.35	2.25	5.04
	S2	186.80	21.87	18.32	30.61	43.18	2.46	6.08
	S3	242.17	25.82	17.51	31.20	41.38	2.86	8.18
	S4	141.11	26.61	17.51	31.85	41.55	2.23	4.97
	S5	127.44	26.72	17.19	31.77	41.29	2.11	4.47
	S6	92.08	26.48	17.25	31.60	41.07	1.79	3.19
Total race		-	-	-	-	-	-	**5.65**
A2 BC	S1	159.91	23.28	15.55	27.99	36.85	2.09	4.35
	S2	214.58	25.51	17.16	30.75	40.38	2.65	7.04
	S3	266.98	23.22	16.10	28.25	37.76	2.72	7.40
	S4	158.21	23.62	15.71	28.37	37.46	2.10	4.42
	S5	140.44	23.78	15.73	28.51	37.15	1.99	3.96
	S6	100.84	23.37	15.54	28.06	37.12	1.66	2.76
Total race		-	-	-	-	-	-	**5.47**
A1 SES	S1	195.47	26.24	17.87	31.75	41.79	2.62	6.84
	S2	266.35	23.56	16.52	28.77	38.98	2.77	7.66
	S3	259.95	27.75	18.59	33.40	43.57	3.17	10.07
	S4	455.26	24.79	16.35	29.69	39.18	3.17	10.03
	S5	233.33	27.38	19.20	33.44	44.43	3.01	9.06
Total race		-	-	-	-	-	-	**6.61**
A2 SES	S1	202.27	22.86	15.87	27.83	36.99	2.33	5.44
	S2	273.32	20.42	14.16	24.85	33.37	2.42	5.86
	S3	270.20	22.99	15.32	27.63	36.20	2.68	7.16
	S4	485.55	20.58	13.44	24.58	32.30	2.62	6.87
	S5	245.58	23.08	15.66	27.89	36.85	2.58	6.63
Total race		-	-	-	-	-	-	**5.65**

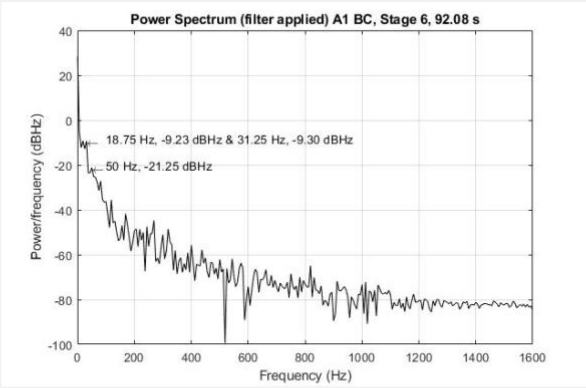

Figure 9. Power spectral analysis for SES A1, Stage 4.

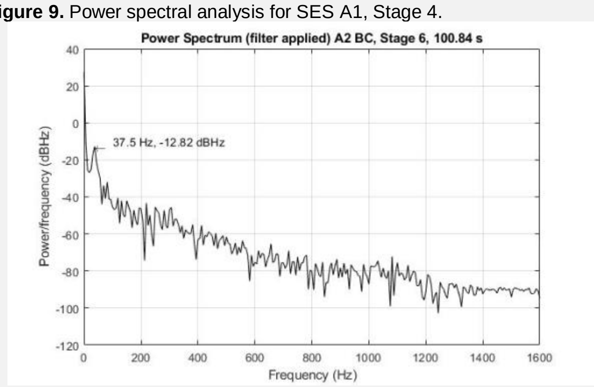

Figure 10. Power spectral analysis for BC A2, Stage 6.

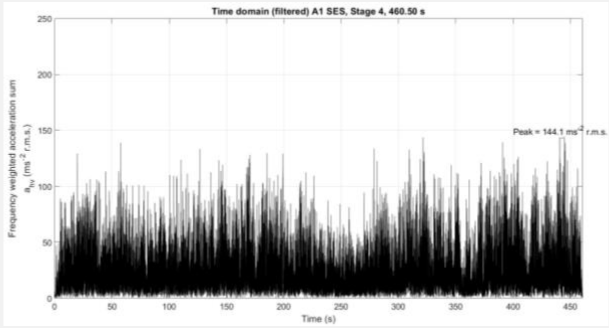

Figure 5. Time domain data showing maximum partial vibration exposure (Ai(8) = 3.87 ms-2, SES A1, Stage 4).

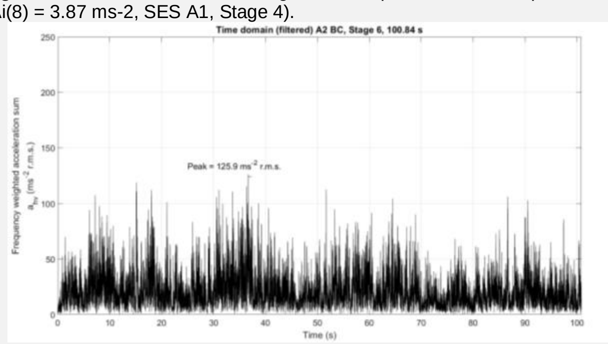

Figure 6. Time domain data minimum partial stage vibration exposure (Ai(8) = 1.66 ms-2, BC A2, Stage 6).

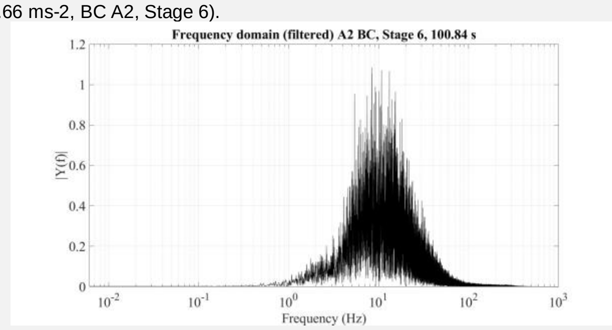

Figure 3. Frequency domain data showing the dominant frequencies and magnitudes (SES A1, Stage 4).

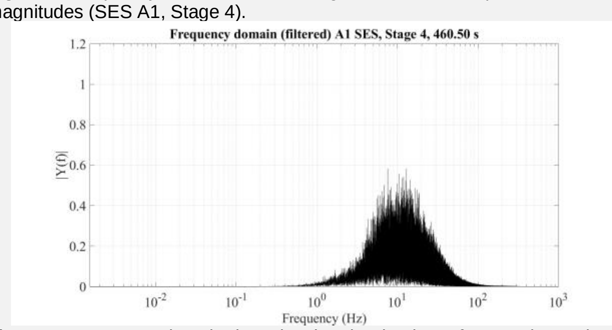

Figure 4. Frequency domain data showing the dominant frequencies and magnitudes (BC A2, Stage 6).

exposures. Figure 5 shows a peak value of the total vibration (frequency-weighted acceleration sum) of 144.14 ms^{-2}. Figure 6 shows a peak value of the total vibration (a_{hv}) of 126.15 ms^{-2}. Interestingly, the r.m.q. results for BC A1 Stage 2 show that the course has more peak acceleration values despite the r.m.s. value being lower than the other stages in the race. Furthermore, BC Stage 6 also shows a considerable amount of shock impacts with high VDV of 37.12 ms$^{-1.75}$ in comparison with the other stages in race.

Figure 7 and Figure 8 show the frequency domain data for the two stages in the SES and BC races. The race stage (A1, SES, Stage 4) with the higher partial stage vibration exposure shows a reduced magnitude of vibration in comparison with the lower partial stage vibration exposure (A2, BS, Stage 5). Power spectral density has been used to compare the power in each of the example vibration signals.

The power spectral analysis are shown in Figure 9 and 10 for the British Championship Stage 6. They show how power of the vibration signal is distributed over frequency by constructing a power spectral density. Figure 9 shows the spectral analysis for rider A1 on Stage 6 (t = 92.08 s). Considering the power from 6.3 Hz to 1259 Hz, the total power in the vibration was 22.33 dBHz. Considering a range of 6 Hz to 80 Hz, the total power in the vibration 22.29 dBHz. Three peak frequencies were identified at 18.75 Hz (-9.23 dBHz), 31.25 Hz (-9.30 dBHz) and 50 Hz (-21.25 dBHz). Figure 10 shows the spectral analysis for rider A2 on Stage 6 (t = 100.84 s). Considering the power from 6.3 Hz to 1259 Hz, the total power in the vibration was 21.13 dBHz. Considering a range of 6 Hz to 80 Hz, the total power in the vibration 21.10 dBHz. A peak frequency was identified at 37.50 Hz (-12.82 dBHz). Power spectral analysis may provide insights into the performance of the suspension and rider in relation to monitoring power and peak frequencies. These may contribute to assessing the overall physical impact of the stage (or race) on the hand-arm system and provide understanding of how vibration analysis may contribute to reducing the potential for harm and improving performance. Monitoring hand-arm vibration exposure may contribute to a riders' ability to sustain competitive performance.

Discussion

The results presented in this study suggest that elite enduro mountain bike athletes are exposed to potentially harmful levels of hand-arm vibration during the race stages of an enduro event. As the total race vibration exposure (A(8)) is exceeded at each event for both athletes, prolonged or repeated exposure to such levels of vibration could potentially lead to the development of vibration related pathologies such as ulnar nerve compression (Patterson et al. 2003) or HAVS (Bovenzi, 1998). Under the control of vibration at work regulations adopted in industrial sectors, employers have an obligation to ensure they take immediate action to reduce exposure to below the limit value. Furthermore, they should introduce a programme of controls or new equipment to eliminate risk, or to reduce exposure to as low as reasonably practicable.

As the competitive season spans March to November and athletes potentially train on similar terrain at similar velocities it appears that prolonged exposure is a likely scenario, however more work is required to investigate this suggestion. The findings of this paper are aligned with those of (Duc et al. 2016) who showed that ELV for hand arm vibration was exceeded during a cobbled road cycling event. However, the vibration exposure values presented here are significantly greater than those observed in cycling on a range of surfaces on a commuting bicycle (Taylor et al. 2018). This suggests that mountain bike athletes are at an increased risk of exposure to potentially harmful levels of hand arm vibration, particularly when taking a longer-term view of chronic exposure.

As the addition of vibration to cycling at fixed power output reduces time to exhaustion and increases oxygen uptake (Rønnestad et al. 2018; Samuelson et al. 1989a), these findings suggest that vibration exposure is a key component of physiological workload during elite enduro mountain bike racing. The findings presented here also support previous work suggesting that faster riders encounter greater exposure to hand arm vibration (Duc et al. 2016; Kirkwood et al. 2017). The only exception observed in this study is the lower partial vibration exposure reported by the faster rider during BS stage 2. The cause of this result is not clear, though may be related to line choice, mechanical malfunction or rider error. Prolonged vibration exposure reduces motor output during maximal voluntary contractions (Bongiovanni et al. 1990) and further reduces endurance of maximal isometric contraction (Samuelson et al. 1989b). Therefore, the data presented here may also offer an explanation for previous findings of ~30% reductions in grip strength during downhill mountain biking dependant on the number of impacts experienced by the rider on the day before (Florida-James et al. 2010). This may have negative implications for performance both by reducing the riders grip on the handlebar which may result in loss of control and reduced ability to operate the brakes. Effective braking is an essential component of performance, as shown by experienced riders producing more braking power for shorter periods of time than inexperienced riders (Lopes & McCormack 2017; Miller et al. 2018). Therefore, it is likely that reductions in grip strength due to vibration may compromise this ability meaning the athlete has to reduce velocity during the technical terrain typically associated with race stages in enduro, resulting in reduced performance and potentially resulting in what is commonly called '*arm pump*' by mountain bike racers. The stage with the highest partial vibration exposure returned vibration amplitude values lower than those of the stage featuring the lowest partial vibration exposure. This suggests that the cumulative effect of accelerations caused by smaller impacts such as braking bumps has a larger contribution to vibration exposure than accelerations caused by larger impacts such as jumps and drop offs. This may be influenced by equipment set up such as suspension setting or tyre pressure. Accordingly, athletes often experiencing '*arm pump'* may benefit from utilising equipment settings aiming to improve the damping of accelerations induced by smaller impacts. Unfortunately, little information is available regarding the optimisation of bicycle equipment to reduce vibration exposure to the rider, thus further research is warranted to potentially improve performance. Overall, it appears than employing strategies to mitigate vibration exposure during enduro mountain biking will benefit performance.

Previous studies have shown different components, frames and tyre pressure to have different vibration transmission properties (Lépine et al. 2015; Macdermid et al. 2015). Therefore, further work is required to explore the vibration transmission of different components with the aim to find means to reduce vibration exposure in mountain biking. Additionally, due to the rising popularity of mountain biking as a recreational sport, future studies should assess the vibration exposure in recreational settings. Many of the vibration exposure values for the race stages analysed here exceed the EAV level suggesting further investigation in downhill mountain biking (one timed race run) are warranted. Furthermore, the races analysed in the present study have a shorter duration (~16-25 minutes overall) when compared to EWS events (up to 60 minutes for winning rider) thus suggesting further investigation is required to measure vibration exposure during international competition.

Conclusions

In conclusion, elite enduro mountain bike athletes are exposed to potentially harmful vibration exposure values during the race stages of national enduro events. Further work is required to explore the extent of potential long-term health effects and the influence of vibration exposure on performance, physiological load and recovery from racing and training in enduro mountain biking. Consideration must be given to the use of wearable devices to monitor hand-arm and human transmitted vibration exposure during training and competition. Monitoring hand-arm vibration exposure during training sessions may offer greater insight to rider fatigue and further contribute to improved event performance.

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Conflict of Interest

None

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