Influence of wheel size on muscle activity and tri-axial accelerations during Cross-Country mountain biking

Howard Thomas Hurst[1], Jonathan Sinclair[1], Stephen Atkins[1], Lee Rylands[2], John Metcalfe[1].

[1]Division of Sport, Exercise and Nutritional Sciences, University of Central Lancashire.

[2]College of Life and Natural Sciences, University of Derby.

Abstract

This study aimed to investigate the influence of different mountain bike wheel diameters on muscle activity and vibrations. Nine male competitive mountain bikers (age 34.7 ± 10.7 yrs; stature 177.7 ± 5.6 cm; body mass 73.2 ± 8.6 kg) participated in the study. Riders performed one lap at race pace on 26", 27.5" and 29" wheeled mountain bikes. sEMG and acceleration (RMS) were recorded for the whole lap and during ascent and descent phases at the gastrocnemius, vastus lateralis, biceps brachii and triceps brachii. No significant main effects were found by wheel size for each of the four muscle groups for sEMG or acceleration during the whole lap and for ascent and descent ($p > .05$). When data were analysed between muscle groups, significant differences were found between biceps brachii and triceps brachii ($p < .05$) for all wheel sizes and all phases of the lap with the exception of for the 26" wheel during the descent. Findings suggest wheel diameter has no influence on muscle activity and vibration during mountain biking. However, more activity was observed in the biceps brachii during 26" wheel descending. This is possibly due to an increased need to manoeuvre the front wheel over obstacles.

Introduction

The physiological demands of cross-country (XCO) mountain biking (MTB) have been well reported over recent years (MacRae, Hise, & Allen, 2000; Lee, Martin, Anson, Grundy, & Hahn, 2002; Stapelfeldt, Schwirtz, Schumacher, & Hillebrecht, 2004; Impellizzeri, Rampinini, Sassi, Mognoni, & Marcora, 2005; Prins, Treblanche, & Myburgh, 2007). These studies focused primarily on aerobic and anaerobic contributions to the activity. However, few studies have investigated muscle activity during MTB. Hurst and Atkins (2006) proposed MTB riders utilised a high level of isometric muscular contractions during racing to aid postural control and control of the bicycle over obstacles.

Several studies have used surface electromyography (sEMG) to analyse muscle activity in road cyclists (Egaña, Ryan, Warmington, & Green, 2010; Matsuura, Arimitsu, Yuncki, & Yano, 2011; Blake, Champoux, & Wakeling, 2012). However, these studies focused on lower limb muscle activity and were primarily laboratory based. Duc, Bertucci, Pernin, and Grappe (2008) investigated the influence of hand grip position, on the handlebar drops compared to the tops, during uphill cycling on upper body muscle activity. However, the activity observed does not reflect those used in MTB due to the more dynamic nature of upper body movements in MTB. Hurst et al. (2012) investigated the influence of course terrain on upper body sEMG activity during downhill (DHI) riding in elite DHI and XCO cyclist. They found significant differences in the muscles recruited between the groups, with DHI riders exhibiting greatest triceps brachii activity, whilst XCO riders showed greater activity in the brachioradialis muscle. Their study concluded that the differences in bicycle design between DHI and XCO bicycles may in part have influenced the differences observed.

Since the mountain bike was first introduced in the late 1980s, the standard wheel diameter has been 26". However, in the past 10 years two more wheel size standards have been introduced, 29" and more recently 27.5". The rationale for the 29" wheel has been that the larger diameter wheel improves roll over small trail bumps and therefore improves contact with the ground and subsequent velocity. In addition, it has been proposed by the cycling industry that the larger wheel will also reduce trail vibrations observed in MTB (Levy & Smith, 2005; Faiss, Praz, Meichtry, Gobelet, & Deriaz, 2007) being transmitted to the rider. Mester, Spitzenfeil, Schwarzer, & Seifriz (1999) found that these vibrations lead to increased muscle activity to aid dampening of trail shocks, resulting in reduced exercise efficiency. Justification for the newer 27.5" wheel standard has been that it potentially provides a balance between the better handling characteristics of the 26" wheel and the improved rolling properties of the 29" wheel. However, few academic studies exist determining the merits of these different wheel diameters on performance. Macdermid, Fink, and Stannard (2014) present one of the few studies to investigate differences in 3D acceleration between different wheel sizes. They looked at differences between 26" and 29" wheels and reported that 29" wheeled mountain bikes resulted in significantly greater vibrations than the 26" wheel during a typical lap of an XCO course, possibly due to the increase in velocity observed. However, Macdermid and co-workers also point out that a key limitation of their study was that they used the same 29" bicycle fitted with 26" wheels, and thus this may have influenced their findings, as frame geometry may not have been optimised for the smaller wheel size. In addition, they did not investigate the influence of the 27.5" wheel standard. Therefore, the aims of this study were to investigate the influence of the 3 primary wheel standards on tri-axial accelerations and muscle activity in upper and lower limbs during XCO mountain biking. It was hypothesised that the larger wheel diameters would

significantly attenuate the muscle activity and vibrations experienced by the riders more than the 26" wheel.

Materials and methods

Participants

Nine male competitive mountain bikers (age 34.7 ± 10.7 yrs; stature 177.7 ± 5.6 cm; body mass 73.2 ± 8.6 kg) participated in the study. All riders had a minimum of 5 years racing experience and competed at a National level in their respective age category. Ethical approval was granted by the University of Central Lancashire Ethics Committee and in accordance with the Declaration of Helsinki. Participants were informed both verbally and in writing of the test procedures and written informed consent was obtained.

Course Profile

All testing was completed on a purpose build cross-country (XCO) mountain bike course at the British National Cycle Centre (Clayton Vale, Manchester). The course was typically representative of the terrain encountered during a UK XCO race and composed of undulating technical sections climbs and descents. The course also featured one major climb and descent, for which data were analysed for these sections as well as the whole lap. Figure 1 shows a GPS trace of the course and profile. A Garmin Edge 810 GPS computer was used to gain a representative schematic of the course and was also used to record lap times and temperature. However, due to the level of tree cover and the inherent inaccuracies of GPS under tree cover, actual distances for the whole lap and its component sections were recorded with a calibrated trundle wheel. Distances of each section highlighted in figure 1 were; Start to 1 = 1.72 km; 1 to 2 = 0.38 km (Climb); 2 to 3 = 0.47 km; 3 to 4 = 0.66 km (Descent); and 4 to Finish = 0.25 km; total lap distance = 3.48 km. Based on Ordinance Survey maps, the average gradient of

the climb was 5.8 ± 0.3 %, whilst the descent gradient was -6.1 ± 0.4 %. Testing took place over a four week period between the months of June and July. Mean temperature was 18.46 ± 1.52 °C, with all test sessions being performed in sunny dry conditions. Therefore, course conditions were consistent for all trials.

Figure 1 near here

Surface EMG and Acceleration Analyses

Surface electromyography (sEMG) data were recorded using a mobile wireless sensor system (Trigno Mobile, Delsys, USA) at 1926 Hz from the gastrocnemius, vastus lateralis, biceps brachii and triceps brachii. The sensors used two parallel bar electrodes with a 1 cm spacing between electrodes. This method has been shown to significantly reduce the cross-talk between muscles when compared to the use of disc electrodes (De Luca, Kuznetsoc, Gilmore, & Roy, 2012). All recordings were taken from the left hand side of the body. Prior to sensor placement, the skin was prepared by shaving the area, lightly abrading and cleaning with alcohol wipes in order to minimise skin impedance. Sensors were positioned longitudinally in parallel to the muscle fibres on the medial aspect of each muscle. Placement of the sensors was in accordance with the Surface EMG for Non-Invasive Assessment of Muscles project (SENIAM) recommendations. Once positioned on the muscles, sensors were secured in place using elasticated bandages. Following data collection, sEMG data were full-wave rectified then filtered at 20 Hz using a second order low pass Butterworth filter. Data were processed using EMGWorks Version 4.0 (Delsys Inc., Boston, USA) prior to later statistical analyses.

According to Sinclair, Brooks, Edmundson, & Hobbs (2012), due to the nature of field-based testing, normalisation of sEMG signals to a maximal voluntary isometric contraction (MVIC)

are not possible or appropriate, though their study looked at running. This was due to the dynamic muscular activity involved. Therefore, they proposed that sEMG data should be normalised to a dynamic peak task (DPT), that being the peak amplitude recorded during the field-based trials. As cycling is also dynamic in nature, sEMG data in the present study are presented as a percentage of the DPT for the whole lap and the ascent and descent sections.

In addition to sEMG, the Delsys Trigno sensors also recorded wireless tri-axial acceleration in accordance to the International Standards (ISO 2631-1) for measurement of vibrations (ISO 1997). The placement of accelerometers on soft tissue to monitor vibrations has previously been validated (Lafortune et al. 1995; Coza et al 2010). Data were sampled at 148 Hz and analysed for total (XYZ) accelerations. Root mean squares of the resultant XYZ data were determined to analyse the vibrations experienced by the riders (ISO 1997). Similar methods have been used in earlier studies of MTB vibrations (Macdermind et al., 2014).

Protocols

Following placement of the sensors participants were shown the course and allowed 1 hour to familiarise themselves with the route. With the exception of one rider, all had previous experience of racing or riding on the course. Participants were required to complete one lap of the course at self-determined race pace on each of the three wheel sizes. Thirty minutes passive rest was given between trials to allow adequate recovery, this was then followed by a 10 minute re-warm, which consistent of low intensity cycling prior to the next trial. The test bicycles were Santa Cruz Superlight full suspension mountain bikes (Santa Cruz Bicycles, USA) with 120 mm and 100 mm of front and rear suspension respectively. All bicycles were fitted with identical components and differed only in wheel size, those being 26", 27.5" and 29" diameter.

Suspension systems were set up according to the manufacturers' recommendations for each rider's individual weight and to allow for 10 percent sag in the travel. Both front and rear suspension were run in fully open mode.

Immediately prior to each trial participants lined up on the start line and were instructed to perform a maximal vertical jump to provide a marker on the accelerometer data. This was used to synchronise the accelerometer and sEMG data. Participants were then set off 10 s post vertical jump. All sEMG and accelerometer data pre and 10 s post jump were discarded from the analysis. The time the participants crossed the finish line was noted and all data after this time was also discarded from the results. In the absence of a trigger system to help identify where the climb and descents started and ended on the sEMG and accelerometer traces, data were synchronised with the time date on the GPS unit attached to the handlebars. The start and end of the main climb and descent were marked with signposts. Riders were instructed to press the 'lap' button on the GPS at the start and end of these sections. This then enabled the identification these sections on the sEMG and accelerometer traces by means of the time stamps. Trials were randomised for all participants.

Statistical Analyses

Normality of data were first confirmed by means of a Shaprio-Wilk test. Differences in muscle activity and accelerations between wheel sizes and between muscle groups within each wheel size were determined using within groups one-way repeated measures ANOVA's. Bonferroni corrections were used during post hoc analyses to control for type I errors. Where the homogeneity assumption was violated, the degrees of freedom were adjusted using the

Greenhouse Geisser correction. Effect sizes were calculated using partial Eta^2 (p^2). Significance was accepted at the p≤0.05 level (Sinclair, Taylor, & Hobbs, 2013) and data are presented as mean ± standard deviation. All statistical procedures were conducted using SPSS 20.0 (SPSS Inc., Chicago, IL, USA).

Results

Surface electromyography data

Analysis of sEMG data revealed no significant main effects for wheel size when analysed over the whole lap for the gastrocnemius ($F_{(2,16)}$ = .29; p = .75; p^2 = .04), vastus lateralis ($F_{(2,16)}$ = 1.42; p = .27; p^2 = .15), biceps brachii ($F_{(2,16)}$ = .83; p = .40; p^2 = .09) or triceps brachii ($F_{(2,16)}$ = .12; p = .89; p^2 = .02). When data were analysed for the climb alone, no significant main effect was again reported for any muscle group by wheel size; gastrocnemius ($F_{(2,16)}$ = .39; p = .69; p^2 = .05), vastus lateralis ($F_{(2,16)}$ = .95; p = .41; p^2 = .11), biceps brachii ($F_{(2,16)}$ = .44; p = .65; p^2 = .05) and triceps brachii ($F_{(2,16)}$ = .43; p = .66; p^2 = .05) respectively. Analysis of descent sEMG also found no significant main effect for wheel size; gastrocnemius ($F_{(2,16)}$ = .23; p = .80; p^2 = .03), vastus lateralis ($F_{(2,16)}$ = 1.64; p = .23; p^2 = .17), biceps brachii ($F_{(2,16)}$ = .94; p = .37; p^2 = .11) or triceps brachii ($F_{(2,16)}$ = .13; p = .88; p^2 = .02). Figure 2 shows the mean values for sEMG as a percentage of DPT. When muscles were compared against each other within wheel sizes, significant differences (p < .05) were found between the antagonistic muscles of the biceps brachii and triceps brachii within all wheel sizes when analysed over the whole lap and the climb. However, during the descent section significant differences (p < .05) were only reported between biceps brachii and triceps brachii within the 27.5" and 29" wheel sizes.

Figure 2 near here

Acceleration Data

Analysis of total XYZ acceleration amplitude (RMS) over the complete lap revealed no significant main effect for wheel sizes in the gastrocnemius ($F_{(2,16)}$ = 1.42; p = .27; p^2 = .15), vastus lateralis ($F_{(2,16)}$ = .48; p = .63; p^2 = .06), biceps brachii ($F_{(2,16)}$ = .85; p = .45; p^2 = .10) or triceps brachii ($F_{(2,16)}$ = .70; p = .51; p^2 = .08). Data from the climbing section also showed no significant main effect for wheel size; gastrocnemius ($F_{(2,16)}$ = .87; p = .44; p^2 = .10), vastus lateralis ($F_{(2,16)}$ = 2.73; p = .10; p^2 = .25), biceps brachii ($F_{(2,16)}$ = 1.50; p = .25; p^2 = .16) or triceps brachii ($F_{(2,16)}$ = .90; p = .43; p^2 = .10). Similarly, no significant main effects were found for wheel size during the main descent section of the lap; gastrocnemius ($F_{(2,16)}$ = 1.94; p = .18; p^2 = .20), vastus lateralis ($F_{(2,16)}$ = .68; p = .52; p^2 = .08), biceps brachii ($F_{(2,16)}$ = .47; p = .64; p^2 = .06) or triceps brachii ($F_{(2,16)}$ = .51; p = .61; p^2 = .06). When total acceleration was analysed between muscle groups for each wheel size overall and during climb and descent sections, significant differences existed (p < .001) between the gastrocnemius and vastus lateralis as expected. However, no significant differences were found between the biceps brachii and triceps brachii. Figure 3 shows the mean total acceleration amplitude (RMS) for each muscle and wheel size.

Figure 3 near here

Discussion

The purpose of this study was to determine the influence of three different MTB wheel diameters on muscle activity and vibrations at different muscle sites during a typical XCO lap at race pace. The key findings were that no significant differences were observed in muscle activity between the 26", 27.5" and 29" wheeled bicycles when analysed for the whole lap and during the highlighted ascent and descent sections. Similarly, no significant differences were found in accelerations at the four different muscle sites between the three wheel sizes. Therefore, the hypothesis that larger wheels reduce muscle activity and vibrations is rejected.

The present study found significantly lower sEMG values than those reported by Hurst et al. (2012) in elite XCO and DHI riders. Although the riders in the present study were not performing at an elite level, the differences between these studies are less likely the result of differences in athletic ability and more likely due to the limitation of normalising muscle activity during dynamic tasks to a maximal voluntary isometric contraction. Mountain biking involves numerous eccentric muscular contractions as a result of riding off drops to aid dampening and control of the bicycle. This most likely resulted in the greater then MVIC values reported previously by Hurst et al. (2012). However, the present study normalised on course muscle activity to the peak dynamic task (PDT) values elicited across all trials in accordance the methods previously reported (Sinclair et al., 2012). Results showed that irrespective of wheel size mean muscle activity over the whole lap, ascent and descent were not significantly different and represented a very low percentage of DPT, approximately 2-6 %. This low percentage may potentially be skewed somewhat due to high peak values occurring when riding off drops to help control the bicycle. The course used contained several drops of approximately 1 m in height.

Though values did not reach a level of significance, the results show that biceps brachii activity was generally higher during all phases of the lap for the 26" wheel when compared to the 27.5" and 29" wheels. This may be the result of riders having to pull more on the handle bars increasing elbow flexion to lift the front wheel of the 26" wheel over obstacles and small gaps. As a result of the larger wheel diameter, both the 27.5" and 29" wheels would potentially roll over such obstacles more efficiently and would not drop into small gaps as easily, thereby reducing muscle activity. This supposition would appear to be supported when data were analysed between muscle groups. Significant differences were found between the antagonistic muscles of the biceps brachii and triceps brachii over the whole lap and the main climbing section for all wheel sizes. However, during the descent section, only significant differences were found between these two muscle groups when riding the 27.5" and 29" wheeled bicycles. The non-significant difference between biceps brachii and triceps brachii during downhill on the 26" wheel bicycles again potentially indicates a greater demand on the biceps to manoeuvre the bicycle over and around obstacles. However, it is important to note the relatively large standard deviations reported for the sEMG data. This may reflect differences in riding styles of the participants, as some riders may have actively pumped the suspension systems with the arms and legs more than others during non-pedalling phases to aid the maintenance of velocity.

Previous research has tried to evaluate the external load imposed on riders during MTB (Hurst, Swarén, Hébert-Losier, Ericsson, Sinclair, Atkins, & Holmberg, 2013). Their study used a tri-axial accelerometer positioned between the scapulae. However, they reported values as a global index of load/vibration on the whole body, which did not reflect the vibrations exerted on specific muscle groups. As such, the present study analysed total acceleration (XYZ) (RMS) as an indicator of vibrations imposed on muscles in the upper and lower limbs. Other than the expected differences in vibrations between the gastrocnemius and vastus lateralis, due to the

different locations from the body/bicycle interface, no significant differences were found for muscles between wheel sizes or within muscle groups. This is contrast to the findings of Macdermid et al. (2014) who found the 29" wheel resulted in significantly greater vibrations than the 26" wheeled mountain bike. In addition, data for vibrations presented in the current study are approximately double the magnitude of those reported by Macdermid and co. This may be the result of differences in sensor placement, as Macdermid et al. (2014) positioned their accelerometers on the bony processes of the wrist and ankle, whilst sensors in the present study were positioned on soft tissue on the medial aspects of the muscles to be analysed. Research by Lafortune, Hening, and Valiant (1995) and Coza, Nigg, and Fliri (2010) previously validated the use accelerometers placed on soft tissue to monitor vibrations on human muscle. However, Lafortune et al. (1995) reported values approximately double the amplitude of those recorded by accelerometers placed on the bone. This may in part account for some of the differences in results between the current study and those of Macdermid et al (2014). Arpinar-Avsar, Birlik, Sezgin, and Soylu (2013) sought to quantify the vibrations imposed on the forearm of the rider when riding a mountain bike. They reported RMS values for acceleration again approximately half those reported in the present study. However, their study only involved riders riding over rough road for a distance of 250 m and not terrain representative of off-road cycling. This most likely contributed to the lower values reported.

Differences may also be attributed to the fact that full suspension bicycles were used in the present study compared to the rigid hard tail mountain bike used by Macdermid et al. (2014). As a consequence, this may have influenced riding dynamics. It is possible that the lower accelerations observed by Macdermid et al. (2014) may have resulted from greater flexion of the arms and legs to absorb trail shocks more effectively, whilst in the present study riders may have relied more on the bicycle's suspension to absorb the shocks. However, this potentially

could have led to participants riding with straighter arms and legs and unknowingly increasing the vibrations transmitted to the muscles, possibly during the shocks rebound phase. This idea may be supported by Hurst et al. (2012) who found DHI riders had a smaller degree of elbow flexion compared to XCO rider as a result of the greater level of suspension travel used on DHI bicycles.

The non-significant differences in vibrations between the three wheel sizes in the present study may again be due to the effects of the suspension systems effectively reducing trail shock. In addition to the lack of rear suspension on the bicycle used in the Macdermid study, they also fitted the 26" wheels to a frame designed for 29" wheels. This may have altered the handling characteristics of the bicycle, as the bottom bracket and crank arms would have been lower to the ground than when using frames designed specifically for the respective wheel sizes.

Limitations

One potential limitation of the present study was the lack of gyroscopic and magnetometer sensors within the sensor units used. The inclusion of such sensors could have aided in more accurate determination of the directionality of the acceleration forces experienced by the riders. Such information could have helped identify differences in riding styles between wheel sizes and whether riders were required use greater lateral, vertical or horizontal efforts to manoeuvre the bicycles through different sections of the course.

Conclusions and practical implications

In conclusion, this study revealed that larger wheel diameters did not significantly reduce muscle activity or vibrations more so than the long standing traditional 26" wheel on the particular course used. However, there appeared to be a trend for slightly greater biceps brachii activity in the 26" wheel, possible due to the need to lift the front wheel over small obstacles more. That said the study did find relatively large variance in values that may reflect differences in riding styles or adaptations to riding the different wheeled bicycles. Ultimately, the lack of statistical differences between the measured parameters suggests that when ridden by trained mountain bike riders all three wheel sizes are just as effective at controlling trail induced shocks and that bicycle choice is largely a matter of personal preference.

References

Arpinar-Avsar, P., Birlik, G., Sezgin, Ö.C., & Soylu, A.R. (2013) The effects of surface-induced loads on forearm muscle activity during steering a bicycle. *Journal of Sports Science and Medicine*, 12, 512-520.

Blake, O.M., Champoux, Y., & Wakeling, J.M. (2012) Muscle Coordination Patterns for Efficient Cycling. *Medicine and Science in Sports and Exercise*, 44, 926-938.

Coza, A., Nigg, B.M., & Fliri, L. (2010) Quantification of soft-tissue vibrations in running: accelerometry versus high-speed motion capture. *Journal of Applied Biomechanics*, 26, 367-373.

De Luca, C.J., Kuznetsoc, M., Gilmore, L.D., & Roy, S.H. (2012) Inter-electrode spacing of surface EMG sensors: Reduction of crosstalk contamination during voluntary contractions. *Journal of Biomechanics*, 45, 555-561.

Duc, S., Bertucci, W., Pernin, J.N., & Grappe, F. (2008) Muscular activity during uphill cycling: Effect of slope, posture, hand grip position and constrained bicycle lateral sways. *Journal of Electromyography and Kinesiology*, 18, 116-127.

Egaña, M., Ryan, K., Warmington, S.A., & Green, S. (2010) Effect of body tilt angle on fatigue and EMG activities in lower limbs during cycling. *European Journal of Applied Physiology*. 108, 649–656.

Faiss, R., Praz, M., Meichtry, A., Gobelet, C., & Deriaz, O. (2007) The effect of mountain bike suspensions on vibrations and off-road uphill performance. *Journal of Sports Medicine and Physical Fitness*, 47, 151-158.

Hurst, H.T., & Atkins, S. (2006) Power output of field-based downhill mountain biking. *Journal of Sports Sciences*, 24(10), 1047-1053.

Hurst, H.T., Swarén, M., Hébert-Losier, K., Ericsson, F., Sinclair, J., Atkins, A., & Holmberg, HC. (2012) Influence of course type on upper body muscle activity in elite cross-country and downhill mountain bikers during off road downhill cycling. *Journal of Science and Cycling*, 1(2), 2-9.

Hurst, H.T., Swarén, M., Hébert-Losier, K., Ericsson, F., Sinclair, J., Atkins, A., & Holmberg, HC. (2013) GPS-based evaluation of activity profiles in elite downhill mountain biking and the influence of course type. *Journal of Science and Cycling*, 2(1), 25-32.

Impellizzeri, F.M., Rampinini, E., Sassi, A., Mognoni, P., & Marcora, S. (2005) Physiological correlates to off-road cycling performance. *Journal of Sports Sciences*, 23, 41-47.

ISO-International Organisation for Standardization. (1997) Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General Requirements. Geneva.

Lafortune, M.A., Hennig, E., & Valiant, G.A. (1995). Tibial shock measured with bone and skin mounted transducers. *Journal of Biomechanics*, 28, 989-993.

Lee, H., Martin, D.T., Anson, J.M., Grundy, D., & Hahn, A.G. (2002) Physiological characteristics of successful mountain bikers and professional road cyclists. *Journal of Sports Sciences*, 20, 1001-1008.

Levy, M., & Smith, G. (2005) Effectiveness of vibration damping with bicycle suspension systems. *Sports Engineering*, 8, 99-106.

Macdermid, P.W., Fink, P.W., & Stannard R. (2014) Transference of 3D accelerations during cross country mountain biking. *Journal of Biomechanics*, 47, 1829-1827.

MacRae, H.S-H., Hise, K.J., & Allen, P.J. (2000) Effects of Front and Dual Suspension Mountain Bike Systems on Uphill Cycling Performance. *Medicine and Science in Sports and Exercise*, Vol. 32, 1276-1280.

Matsuura, R., Arimitsu, T., Yuncki, T., & Yuno, T. (2011) Effects of resistive load on performance and surface EMG activity during repeated cycling sprints on a non-isokinetic cycle ergometer. *British Journal of Sports Medicine*. 45, 820-824.

Mester, J., Spitzenfeil, P., Schwarzer, J., & Seifriz, F. (1999) Biological reaction to vibration – implications for sport. *Journal of Science and Medicine in Sport*, 2, 211-226.

Prins, L., Terblanche, E., & Myburgh, K.H. (2007) Field and laboratory correlates of performance in competitive cross-country mountain bikers. *Journal of Sports Sciences*, 25, 927 – 935.

Sinclair, J., Brooks, D., Edmundson, C.J., & Hobbs S.J. (2012) The efficacy of EMG MVC normalisation techniques for running analyses. *Journal of Biomechanics*, 45(1), 623.

Sinclair, J., Taylor, P.J., & Hobbs, S.J. (2013) Alpha level adjustments for multiple dependent variable analyses and their applicability – A review. *International Journal of Sport Science and Engineering*, 7, 17-20.

Stapelfeldt, B., Schwirtz, A., Schumacher, Y.O., & Hillebrecht, M. (2004) Workload demands in mountain bike racing. *International Journal of Sports Medicine*, 25, 294-300.

Figure 1. GPS profile of course. Numbers indicate the different sections of the course.

Figure 2. Mean ± standard deviation of mean sEMG amplitude as a percentage of dynamic peak task (DPT) for different wheel size during (A) whole lap; (B) climb; and (C) descent. *Significantly different to triceps brachii (26"); + significantly different to triceps brachii (27.5"); ¥ significantly different to triceps brachii (29").

Figure 3. Mean ± standard deviation of mean acceleration amplitude (RMS) for different wheel size during (A) whole lap; (B) climb; and (C) descent.