The effect of mountain bike wheel size on Cross-Country performance

Running head: Mountain bike wheel size and performance

Keywords: Power output, velocity, cadence, mountain biking,

Abstract

The purpose of this study was to determine the influence of different wheel size diameters on indicators of cross-country mountain bike time trial performance. Nine competitive male mountain bikers (age 34.7 ± 10.7 yrs; stature 177.7 ± 5.6 cm; body mass 73.2 ± 8.6 kg) performed one lap of a 3.48 km mountain bike course as fast as possible on 26”, 27.5” and 29” wheeled mountain bikes. Time (s), mean power (W), cadence ($revs \cdot min^{-1}$) and velocity ($km.h^{-1}$) were recorded for the whole lap and during ascent and descent sections. One-way repeated measure ANOVA were used to determine significant differences. Results revealed no significant main effects for any variables by wheel size during all trials, with the exception of cadence during the descent ($F_{(2, 16)} = 8.96$; $p = .002$; $p^2 = .53$). Post hoc comparisons revealed differences lay between the 26” and 29” wheels ($p = .02$). The findings indicate that wheel size does not significantly influence performance during cross-country when ridden by trained mountain bikers, and that wheel choice is likely due to personal choice or sponsorship commitments.

Introduction

Cross-country Mountain biking has been a recognised Olympic discipline since the 1996 Atlanta Games, and requires riders to negotiate varied terrain and obstacles (Wilber, Zawadzki, Kearney, Shannon & Davis, 1997). The physiological responses to cross-country mountain biking have been extensively researched (Warner, Shaw, & Dalsky, 2002; Stapelfeldt, Schwirtz, Schumacher, & Hillebrecht, 2004; Impellizzeri, Rampinini, Sassi, Mognoni, & Marcora, 2005; Impellezzeri & Marcora, 2007; Gregory, Johns, & Walls, 2007). These studies have reported an exercise intensity during elite level racing equivalent to ~80 % of maximal oxygen uptake and ~90 % of maximal heart rate, with over 80 percent of race duration being performed at or above the lactate threshold. In addition, mean power output during cross-country racing has been reported to be approximately 240-250 W or ~3.5 $W.kg^{-1}$ in elite male racers (Stapelfeldt et al., 2004; Macdermid & Stannard, 2012). Macdermid et al. (2012) also reported a mean cadence of 76 $revs \cdot min^{-1}$ during cross-country riding at self-selected race pace.

Several studies have also investigated the influence of mountain bike design, specifically the use of suspension systems, on performance (Seifert, Luetkemeier, Spencer, Miler, & Burke, 1997; MacRae, Hise, & Allen, 2000; Nishii, Umemura, & Kitagawa, 2004; Levy & Smith, 2005). These studies have shown that power output is generally higher when suspension is used than without, most likely the result of energy losses through the systems requiring greater effort to maintain propulsion. However, few studies have investigated to influence of different wheel diameters on mountain biking performance.

Since the inception of mountain biking the standard wheel diameter has been 26”. However, more recently manufacturers have developed and promoted 27.5” and 29” wheel diameter mountain bikes. Much subjective debate has occurred regarding the potential advantages and disadvantages of each of the three options. The vast majority of the debate has revolved around anecdotal evidence of improved speed and performance with the larger wheel size, with scant information being derived from empirical studies. Macdermid, Fink, and Stannard (2014) reported that at the 2012 Olympic Games the split between 26”, 27.5” and 29” wheel bikes was 5, 25 and 70 % respectively, with the men’s gold and bronze medals being won on a 29” wheel bike, with silver being won on a 27.5” wheel. In the women’s race gold, silver and bronze medals were won on 26”, 27.5” and 29” wheeled bikes respectively. Macdermid et al. (2014) investigate the performance characteristics when riding a 26” and 29” wheeled mountain bike. They found that no significant differences existed between the two wheel sizes in mean power output over a single lap at race pace, or during ascent and descent sections. Despite this, they did report significant differences in lap duration, with the 29” wheel diameter bike being significantly quicker than the 26” version (mean lap times 635 s and 616 s, respectively). However, their study didn’t report cadence data or values for the increasingly popular 27.5” wheel standard. Many mountain bike manufacturers are gradually phasing out of 26” diameter wheels in favour of the 27.5” diameter. However, there remains no scientific evidence to support this trend, or the proposed benefits of the 27.5” diameter wheel for MTB performance, other than anecdotal.

Therefore, the purpose of the present study was to ascertain the influence of the three different wheel sizes on indicators of mountain bike performance during an off-road time trial. It was hypothesised that the 29” wheel would significantly improve performance during the time trials, when compared to the two smaller wheel sizes.

Materials and methods

Participants

Ethical approval for this study was granted by the University of Central Lancashire Ethics Committee and in accordance with the Declaration of Helsinki. Nine male competitive mountain bikers (age 34.7 ± 10.7 yrs; stature 177.7 ± 5.6 cm; body mass 73.2 ± 8.6 kg) took part in the study. All riders were sub-elite, though competed at National level in their respective age categories, and had at least 5 years racing experience. Participants were informed both verbally and in writing of the test procedures, and written informed consent was obtained. Prior to testing, it was determined that all participants had previous experience of riding both 26" and 29" wheel diameter bicycles, but none reported riding a 27.5" variant.

Course Profile

Testing took place on three days over a four week period between June and July on a purpose build cross-country mountain bike course at the British National Cycle Centre (Clayton Vale, Manchester). Mean ambient temperature over the testing sessions was 18.5 ± 1.5 °C, 50.9 ± 3.7 % humidity and sunny. Track conditions were dry for all test sessions. As a result, course conditions were comparable for all riders. The course was typically representative of the terrain riders would encounter during a UK cross-country race, and is itself used for regional races. The course profile presented in figure 1 was recorded using a Garmin Edge 810 GPS cycle computer. However, due to tree cover on the course and the impact this has on GPS accuracy, GPS data was not used during analysis for the determination of distance and velocity. Instead, accurate distances were recorded in metres using a calibrated trundle wheel and subsequently mean velocity ($km.h^{-1}$) was manually calculated.

Therefore, the GPS system was used purely to provide a representative schematic of the course (figure 1). 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 the mean GPS data from all laps, the average gradient of the climb was 5.8 ± 0.3 %, whilst the descent gradient was -6.1 ± 0.4 %. Though the accuracy of this may be debated, it was not possible to gain the gradient information via another method.

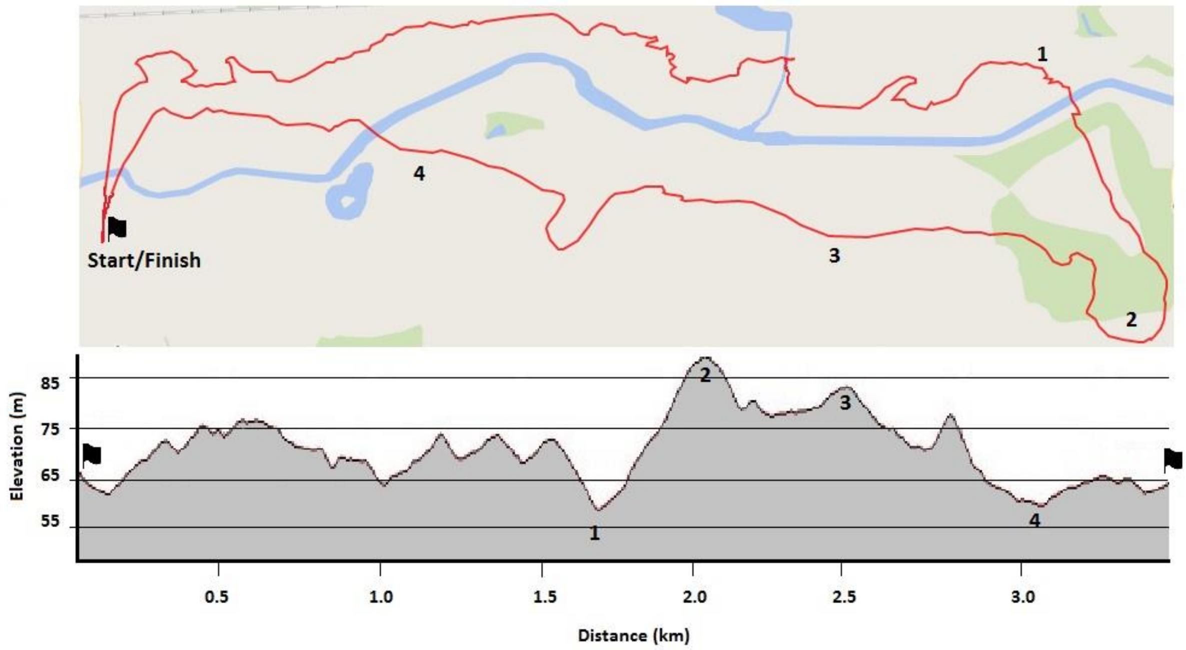

Figure 1. Schematic and GPS map of MTB course. Numbers refer to each section of the course.

Equipment

All bicycles were full suspension cross-country mountain bikes with 100 mm of rear suspension travel and 120 mm front suspension (Superlight, Santa Cruz Bicycles, USA). The bicycles were 2014 models and were new and unused prior to testing. Each bicycle was the same model and fitted with identical components with the exception of wheel size. All frames geometries were designed to optimise the bicycles for their respective wheel sizes by the manufacturer. All three bicycles had a size medium frame. Top tube lengths were 590, 602 and 613 mm for the 26", 27.5" and 29" wheels respectively, whilst bottom bracket heights were 319, 326 and 337 mm, respectively. To accommodate differences in rider stature a choice of two different stem lengths were offered (90 and 110 mm). Saddle setback was also adjusted to ensure best fit. In addition, riders were allowed to use their own pedals.

Bicycle mass differed due to the differences in wheel diameter and wheel mass (13.69 kg, 13.93 kg and 14.15 kg for the 26", 27.5" and 29" wheeled bicycles respectively). Mass of the bicycles is inclusive of powermeter and GPS head unit. Therefore, as the focus of the study was on the influence of wheel size on performance and not differences in bicycle/wheel mass, the mass was standardised to the heaviest bicycle (29" wheeled) by adding small weights to the lower downtube of the 26" and 27.5" wheeled bicycles. Suspension shocks were set up according to the manufacturers' recommendations for each rider's individual body mass to allow 10 percent sag in the travel, whilst shock leverage ratios were optimised by Santa Cruz for each frame geometry. Tyre pressure was run at 35 psi for all trials to ensure consistency. Prior to each trial bicycles were fitted with the same SRM Shimano XT 2 x 10 mountain bike powermeter chainset (SRM, Jüllich, Germany). The powermeter consisted of eight strain gauges housed within the inner bolt circle. To ensure accurate data collection, the SRM powermeter was calibrated through the Garmin Edge 810 head unit prior to each trial. SRM powermeters have previously been shown to have high reliability by several studies (Jones & Passfield, 1998; Martin, Milliken, Cobb, McFadden, & Coggan, 1998; Lawton, Martin, & Lee, 1999). Power output data were also used to determine differences in mechanical work performed during each section and over the duration of the lap using equation 1.

$$\text{Mechanical Work (Kj)} = \text{Power } (W) \times \text{Time } (s) \div 1000 \qquad \text{(Equation 1).}$$

Whilst the Garmin Edge 810 was not used to record distance or velocity, it was paired via ANT+ wireless protocol to the SRM and used to record time (s), mean power output (W) and mean cadence ($revs\cdot min^{-1}$) throughout each lap and during selected ascent and descent sections. Data were sampled at 1 s intervals. As GPS data were not used, riders were instructed to press the ‘lap’ button on the handlebar mounted GPS computer when they passed the start and end points of the designated ascent and descent sections of the course. These sections were clearly signposted on the course with coloured tape attached to trees. This allowed us to analyse data for these sections in isolation, along with the whole lap based on the distances measured with the trundle wheel and the lap times recorded.

Protocols

Participants were required to ride one lap of the course on each of the three test bicycles in a randomised order, with each lap being performed as fast as possible. Riders performed each of their three laps on the same day, with thirty minutes passive rest between laps to allow sufficient recovery time. Each lap was then preceded by a 10 min re-warm, consisting of low intensity cycling. All riders had previous experience of riding the course with the exception of one participant. All riders were allowed 1 hour to familiarise themselves with the course and the bicycles.

Statistical Analyses

Data were first downloaded from the GPS head unit to the Garmin Connect online database. Data were subsequently exported to Microsoft Excel before being analysed using the SPSS statistical software (SPSS Inc., version 20.0, Chicago, Illinois, USA). Data were confirmed to be normally distributed by means of a Shapiro-Wilk test. Differences in overall, ascent and descent time (s), mean velocity, power, cadence and work done were analysed using one-way repeated measures analysis of variance (ANOVA). In order to control for type I errors, Bonferroni corrections were employed during post hoc analyses. Effect sizes were calculated using a partial Eta^2 (η^2). The influence of stature on performance indicators was determine using Pearson Product Moment Correlations. Significance was accepted at the $p \leq 0.05$ level (Sinclair et al. 2013) and descriptive data were presented as mean ± standard deviation.

Results

Table 1. Mean ± standard deviation for mean performance variables recorded during the full lap and during the selected ascent and descent phases.

	Wheel Size (inches)	**Overall**	**Ascent**	**Descent**
Time (s)	26	916.11 ± 54.45	100.89 ± 10.97	173.11 ± 9.79
	27.5	923.78 ± 52.94	107.33 ± 8.40	177.44 ± 15.25
	29	904.22 ± 54.77	98.67 ± 16.42	176.67 ± 19.72
Velocity (km.h^{-1})	26	13.72 ± .77	13.70 ± 1.42	13.77 ± .80
	27.5	13.61 ± .76	12.81 ± .95	13.48 ± 1.13
	29	13.91 ± .84	14.20 ± 2.32	13.62 ± 1.70
Absolute Power (W)	26	211.06 ± 28.16	250.47 ± 52.90	205.23 ± 48.08
	27.5	211.50 ± 31.71	243.85 ± 60.75	179.57 ± 28.42
	29	220.93 ± 30.43	237.91 ± 27.61	195.81 ± 31.57
Cadence (revs·min^{-1})	26	65 ± 6	74 ± 5	55 ± 8*
	27.5	67 ± 7	72 ± 8	59 ± 9
	29	68 ± 6	71 ± 5	65 ± 7
Work done (Kj)	26	193.00 ± 25.03	25.33 ± 6.43	35.38 ± 7.82
	27.5	195.20 ± 29.31	26.02 ± 5.84	31.75 ± 4.67
	29	199.70 ± 29.14	23.64 ± 5.54	34.48 ± 6.49

* Significantly different to 29” wheel ($p < .05$).

When performance parameters were analysed over the duration of the full lap, no significant main effects for wheel size were found for time ($F_{(2, 16)}$ = .70; p = .51; η^2 = .08); velocity ($F_{(2, 16)}$ = .70; p = .45; η^2 = .08); absolute power ($F_{(2, 16)}$ = 2.98; p = .96; η^2 = .27); work done ($F_{(2, 16)}$ = .68; p = .52; η^2 = .08) or cadence ($F_{(2, 16)}$ = 3.53; p = .06; η^2 = .31). When data were analysed for the selected ascent, no significant main effects were again found for time ($F_{(2, 16)}$ = 1.05; p = .37; η^2 = .12); velocity ($F_{(2, 16)}$ = 1.42; p = .27; η^2 = .15); absolute power ($F_{(2, 16)}$ = .19; p = .83; η^2 = .02); work done ($F_{(2, 16)}$ = .48; p = .66; η^2 = .05) or cadence ($F_{(2, 16)}$ = .84; p = .45; η^2 = .10). Similarly, no significant main effects were found during the descent section; time ($F_{(2, 16)}$ = .20; p = .72; η^2 = .02); velocity ($F_{(2, 16)}$ = .48; p = .55; η^2 = .06); work done ($F_{(2, 16)}$ = .79; p = .47; η^2 = .09) or absolute power ($F_{(2, 16)}$ = 1.17; p = .34; η^2 = .13). However, a significant main effect was found for cadence during the descent ($F_{(2, 16)}$ = 8.96; p = .002; η^2 = .53). Post hoc comparisons revealed that cadence was significantly lower (p = .02) when riding with the 26” when compared to the 29” wheel. Table 1 presents the mean ± standard deviation values for all performance parameters during each phase of testing.

The same size frames with a selection of stem lengths were used to accommodate the differences in participant stature. Therefore, data were analysed to determine whether these differences in stature had any influence of performance variables between wheel sizes, despite the same size frame for each bicycle. No significant relationships were found between stature and any of the performance variables recorded. Table 2 presents the Pearson Product Moment correlation results.

Table 2. Pearson Product Moment Correlation coefficient (*r*) between stature and performance variables for each wheel diameter (*N= 9*).

	Wheel Size (inches)		
Correlation Between	**26**	**27.5**	**29**
Stature and Absolute Power (W)	*r* = .56, p = .12	*r* = .63, p = .06	*r* = .71, p = .08
Stature and Velocity (km.h^{-1})	*r* = .43, p = .25	*r* = .14, p = .73	*r* = .13, p = .73
Stature and Cadence (revs.min^{-1})	*r* = .45, p = .22	*r* = .29, p = .45	*r* = .40, p = .29
Stature and Relative Power (W.Kg^{-1})	*r* = .38, p = .31	*r* = .59, p = .09	*r* = .69, p = .06

Discussion

This study aimed to determine the effect of different mountain bike wheel diameters on performance indicators, during an off-road time trial. To the authors' knowledge, this represents the first study to investigate the influence of all three current MTB wheel size standards, 26", 27.5" and 29". The key findings were that no significant differences were observed in relation to time, power, velocity, cadence or work done when analysed for the full lap, ascent and descent. The only exception to this was the significant difference in cadence between the 26" and 29" during the selected descent phase. Subsequently, the hypothesis that the 29" wheel would statistically improve performance over the smaller wheels has to be rejected.

Mean power output for the full lap was lower than that reported previously for XCO-MTB racing (Stapelfeldt et al., 2004; Impellezzeri et al., 2007; Macdermid et al., 2014), irrespective of wheel size. This is likely to be due to the sub-elite level of the riders in the present study compared to elite riders in the aforementioned studies. In addition, the lower mean power output may also have been influenced by the relatively technical and twisty nature of the course used in the present study, as this would determine when and how long riders could apply power for. Previous research by Hurst and Atkins (2006) alluded to how differences in terrain affected power production. Cadence was also lower than that reported in previous studies (Macdermid et al., 2012). This again may be attributable to difference in course terrain and the opportunity to pedal. Though not significantly different, power output and cadence were greater for the 29" wheel when compared to the smaller diameter wheels. Effect sizes revealed approximately 27% and 31% of the variance in mean power and cadence over the full lap was attributable to the experimental conditions. Though around two thirds of the variance was likely due to random errors, the remaining variance may have been influenced by greater contact time between the ground and tyres, and the ability of the larger wheel diameter to roll over small bumps in the trail more effectively. This would potentially enable the rider to produce power and maintain cadence more consistently throughout the lap, leading to the slightly higher values observed. Indeed, increased ground contact and 'rollover' ability is one of the key benefits of 29" wheels promoted by manufacturers, whilst reduced vibrations have also been reported with larger wheels (Wilson, 2004). However, contrary to this Macdermid et al (2014), found hardtail 29" wheels actually increased vibrations over 26" a wheeled hardtail. However, some of the differences between studies could again be influenced by differences in course terrain.

Differences in overall lap times did not reach a level of significant difference, whilst effect size revealed only approximately 8% of the variances in lap times could be attributed to the experimental design. Despite this, and accepting the relatively small sample size, the 29" wheel was on average 1.3 % quicker than the 26" and 2.1 % quicker than the 27.5" wheels over the duration of the full lap. Interestingly, Macdermid et al. (2014) reported similar, though significant, gains in time between 29” and 26” wheels during an cross-country mountain bike time trials. Though only ~1-2% quicker and non-significant, like Macdermid et al. (2014), results were collected from a single lap time trail. Despite this the results from the 29” wheel are interesting nonetheless, and over a full race distance with multiple laps, indicate 29” wheels may potentially offer a greater advantage over smaller wheel sizes. Further research under full race conditions is warranted.

Based on the proposed improved rolling properties of larger wheels, the 27.5” wheel should in theory have also been quicker than the 26” diameter wheel bicycle. However, in order to optimise the bicycles’ performance for each wheel size, geometry did differ between frames, which may have contributed to the results. The wheelbase length of the 27.5” was longer by almost 10 mm than the other two wheel sizes, with the difference between the 26” and 29” being only 1.6 mm. As a result, the longer wheelbase may have negatively affected handling of the 27.5” wheel on the relatively technical course used in the present study, leading to the slowest overall lap times observed. Macdermid et al. (2014) reported using a 26” wheel in a frame designed for a 29” diameter wheel, though claimed the observed difference of 10 mm in mechanical trail, a key determinant of a bicycles’ handling properties, would not affect the bicycles performance. However, the findings of the present study would seem to refute this.

Differences during the ascent and descent sections were again non-significant between wheel sizes for all variables except descent cadence, with effects sizes revealing a relatively small amount of variance (range 2-15 %) for each parameter could be attributable to the experimental conditions. During the climb the 29” was only marginally quicker than the 26”, though was around 10 seconds faster than the 27.5” over the 380 m long climb. However, velocity was 3.5 % and 9.8 % higher for the 29” than the 26” and 27.5”, respectively, for power output that was 5.1 % and 2.4 % lower than the 26” and 27.5” wheels respectively. Again, though not to a level of significance, this may, to a small extent, be influenced by the proposed better rolling qualities of the larger 29” wheel, resulting in less effort being required to maintain forward propulsion and therefore velocity. This supposition, is in part supported by the lower work done, as indicated by the lower kilojoules observed during the ascent section for the 29” wheel over the other two sizes. Though this too did not reach a level of significance, the 29” required on average 6.7 % less work to ascend than the 26” wheel, and 9.2 % less than the 27.5” wheel. However, this does not explain why the 27.5” wheel proved to be the slowest over the ascent. This wheel size is relatively new and has been promoted as a ‘best of both’ option between the better manoeuvrability of the 26” and the better rolling properties of the 29” wheel, yet the results of the present study do not support this logic. Despite this, it would be unfair to label the 27.5” as the worst performing bicycle tested. Reported differences were not significantly different to the other two wheel diameters, as such any differences may simply have been due either to random errors.

During the descent section the 26” diameter wheel was approximately 2 % quicker than the 27.5” and 29” diameter wheels. Though these differences were again not significant, some of the variance could have been the result of improved stability and therefore control during the tighter more technical sections of the descent compare to the 29”, resulting from the lower bottom bracket height (319.7 mm and 337.6 mm, for 26” and 29”, respectively). However, this does not explain why the 27.5” wheel was slower, as this too had a lower bottom bracket height than the 29” wheel. The slower times of the 27.5” wheel during the descent may again have been due to the longer wheelbase compromising handling on the tight, twisty sections of the descent. This may have led to participants slowing more into corners to get round them, whilst the higher cadence seen during descending for the 27.5” and 29” trials may have been the result of riders having pedal faster out of corners to get back up to speed.

Limitations

Possible limitations to the present study are the lack of physiological measures such as heart rate and oxygen uptake. However, given the rapid changes in effort associated with cross-country mountain biking and the lag time in heart rate response to changes in intensity, it was anticipated that heart rate would change little in response to the different wheel sizes and therefore yield little benefit to the study. In addition, previous studies have shown heart rate to be remarkably consistent throughout mountain bike races, potentially due to increased isometric muscular activity over that observed in road cycling (Hurst & Atkins, 2006), and as a result of possible increases in adrenaline levels and subsequent stimulation of the sympathetic nervous system (Sperlich, Achtzehn, Buhr, Zinner, Zelle, & Holmberg, 2012). Oxygen uptake, was not monitored during the present study despite being used in previous research (MacRae et al., 2000; Macdermid et al., 2012). The authors of the present study felt that although this may have been of interest, the increased mass of the equipment and the intrusive nature of wearing a facemask may have influenced the natural riding dynamics of the participants, thus compromising the ecological efficacy of the investigation. Indeed, feedback from riders during pilot testing reported the gas analyser and facemask restricted movement and increased discomforted due to sweat build up in the facemask. Therefore, the decision was made not to monitor this variable.

Though participants were given time to familiarise themselves with the course and the bicycles, this may not have been sufficient to learn the full capabilities of the relatively newer 27.5" wheel size. It is also accepted that multiple timed laps on different courses are need to fully determine the extent of any differences between wheel sizes. However, the current findings are still of interest nonetheless. Finally, though riders were not 'blinded' to the data on the GPS unit, it is unlikely that this would have led to changes in pacing strategies, are riders were more likely to be focusing on the trail ahead than looking at the handlebar mounted unit, particularly given the relatively technical nature of the course used.

Conclusions

To summarise, the present study revealed no statistically significant differences for all recorded parameters between the three wheel sizes, with the exception of cadence during the downhill section. However, further research over a full race distance is warranted to determine if the small but non-significant differences observed over a one lap time trial in the present study lead to significant benefits or drawbacks over the course of a race. In addition, it is important to note that the findings of the present study only relate to the particular course used, and as alluded to by previous research, results may differ depending upon terrain.

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