Original Works

Title: Effect of gear ratio on peak power and time to peak power in BMX Cyclists

Abstract

The aim of this study was to ascertain if gear ratio selection would have an effect on peak power and time to peak power production in elite BMX cyclists. Eight male elite BMX riders volunteered for the study. Each rider performed three, 10 second maximal sprints on an Olympic standard indoor BMX track. The riders' bicycles were fitted with a portable SRM power meter. Each rider performed the three sprints using gear ratios of 41/16, 43/16, 45/16 tooth. The results from the 41/16 and 45/16 gear ratios were compared to the current standard 43/16 gear ratio. Statistically significant differences were found between the gear ratios for peak power ($F(2,14) = 6.448$; $p = 0.010$) and peak torque ($F(2,14) = 4.777$; $p = 0.026$), but no significant difference was found for time to peak power ($F(2,14) = 0.200$; $p = 0.821$). When comparing gear ratios, the results showed a 45/16 gear ratio elicited the highest peak power,1658 ± 221 W, compared to 1436 ± 129 W and 1380 ± 56 W, for the 43/16 and 41/16 ratios, respectively. The time to peak power showed a 41/16 tooth gear ratio attained peak power in -0.01 s and a 45/16 in 0.22 s compared to the 43/16. The findings of this study suggest that gear ratio choice has a significant effect on peak power production, though time to peak power output is not significantly affected. Therefore, selecting a higher gear ratio results in riders attaining higher power outputs without reducing their start time.

Keywords: Bicycle motocross, gear ratio, peak power, time to peak power, torque.

Introduction

The start of a Bicycle Motocross (BMX) race is a crucial aspect of performance, as it has been shown to have a direct correlation to a rider's final finishing position (Rylands & Roberts, 2014). There are a number of reported physiological considerations that contribute towards an optimum start, including peak power, rate of force produced and torque (Rylands, Roberts, Hurst & Bentley, 2015b; Bertucci & Hourde, 2011). A BMX rider applies all of these forces to their bike during a race, but crucially does not apply them in a linear or constant pattern. This is in contrast to other cycling disciplines, such as road time trials or individual track pursuit (Wells, Atkinson & Marwood, 2013; De Koning, Bobbert & Foster, 1999). Forces applied by a BMX rider fluctuate as the profile of the BMX track varies considerably. For instance, as a rider performs a static standing start the cadence will be lower, but greater torque and power can be applied to the bicycle by the rider. This is in contrast to the mid-point of a race where higher cadences have been recorded along with lower power output (Cowell, McGuigan & Cronin, 2012).

In addition to the profile of the track, forces applied to the bike by a rider can be regulated by changing the gear ratio on the bike (Mognoni & Prampero, 2003). However, unlike other cycling disciplines, such as MTB, Road or Cyclo-cross, BMX bikes are not equipped with a gear shifter system. The world governing body of cycling does not prevent the use of gear shifter systems in BMX racing (UCI rule book), simply, riders elect to use a single speed system. Based on unpublished interview data, elite BMX riders in the United Kingdom (UK) stated the two major reasons for not adopting a gear shifter system were 1) increased risk of the chain falling off the chain ring and 2) insufficient opportunity to change gear during a race. This would therefore suggest gear ratio selection prior to a race is important, as the single speed ratio selected must be optimal for producing peak power and reducing time to peak power production.

There are a number of factors to be considered when choosing the optimal gear ratio. According to Gardner et al (2007) larger inertial loads require a longer duration to accelerate. Therefore, increasing a gear ratio (inertial load) could increase the time to peak power and have a negative effect on the start of a race.

A manipulation of inertial loads (gear ratio) has been reported to increase or decrease the power output of a rider at a given cadence (Mognoni & Prampero, 2003). A rider's ability to increase their power can result in greater velocity production, and as a result increase the possibility of winning a race (Kohler & Boutellier, 2005). Therefore, gear ratio selection is vital, as a higher inertial load can elicit great power outputs, but might result in an increase in the time required to achieve peak power. Many riders use a gear ratio of 43/16 which has been highlighted as a standard race gear ratio (Rylands et al, (2013). Bertucci and Hourde (2011) noted that the optimisation of biomechanical variables, such as gear ratio, have an effect on BMX cycling performance. However, to the author's knowledge no research has been undertaken to ascertain the optimal gear ratio in BMX cycling.

Therefore, the aim of this study was to investigate the relationships between gear ratio, peak power and time to peak power. By establishing the optimal gear ratio that elicits peak power and reduces the time to peak power riders might gain an advantage at the start of a race and increase velocity during a race.

Methods

Subjects

Eight elite male BMX riders participated in the study. The participants mean ± standard deviation age was 21 ± 2 years, stature 170 ± 6 cm and body mass 69 ± 3 kg. A description of the test protocol was given to the participants prior to the test day and the protocol was explained to each rider on the day of the testing. The riders in this study were in their competition phase of training and had not raced for a minimum of three days prior to testing. Based on their British Cycling competition licence, all riders were classified as elite cyclists. To maintain hydration each rider ensured they had consumed fluids throughout the day. The riders had also eaten one hour prior to testing. They were informed of the benefits and risks of the investigation prior to signing a PARQ health check questionnaire and consent form. Any rider whom identified they had an injury or health related issue that may be exacerbated by the trials was excluded from the study. The study was approved by the University Ethics Committee and met the requirements of the Declaration of Helsinki for research on humans.

Experimental Design

The study was conducted at the British National Indoors BMX Centre, Manchester, UK
The participants all had previous experience of racing on this track and were familiar with the electronic start gate used in the study (Pro-Gate, Rockford, Illinois, USA). Prior to testing each rider completed a 10 minute familiarisation session and self-paced warm up. Specifically, each rider carried out their standard pre-competition routine, which included seated cycling, and a series of short standing sprints (Rylands, Roberts & Hurst 2015a). Participants performed the warm up using the standard race gear ratio (43/16) on their own bikes. Gear ratios of 41/16, 43/16 or 45/16 tooth were then fitted to the riders' bike, with test ordering being randomised. The theoretical distance travelled by each gear ratio for a single revolution was calculated using the following equation:

Wheel circumference = wheel size (20" or 0.508cm) x π

Distance travelled = (wheel circumference (1.59m) x Number of teeth in front chain ring)/ Number of teeth in rear cog

Following a randomised allocation of gear ratio, riders performed three sets of 10 second sprints from the 5-metre start ramp using the electronic start gate. Riders were given a 10-minute recovery period between each gear ratio to help limit fatigue between the sprints. This was based on a study conducted by Soderlund & Hultman (1991) in which they identified that muscle phosphate creatine level are almost completely recovered after 5 minutes of recovery following high intensity muscle activation.

The riders' bikes were fitted with a Schoberer Rad Messtechnik (SRM) 8 strain gauge crank. The riders' peak power, torque, cadence at peak power and time to peak power were recorded for all three gear ratios and downloaded to proprietary software (SRMWin version 7) for later analyses. The SRM power meter was calibrated at 1000 Watts closer to the predicted values of the BMX riders in this study. Although various studies such as Jones and Passfield (1998) have noted a 95% linear regression in power outputs using an SRM power meter the relationship has been ascertained at lower powers (90-625 W). The utilization of this higher load reduced the assumption that the load frequency relationship was linear at higher outputs. The SRM power meter was a BMX specific power meter (DXR) with a sampling rate of 5 Hz. A zero-offset calibration was performed after each sprint for the SRM power meter (version VII power control) in accordance with the manufacturer guidelines (Wooles, Robinson & Keen, 2005).

Power and cadence data from the SRM power meter were used to calculate the riders' peak torque (T), using the equation:

$T\ (Nm) = P\ (w)/(R\ (rev \bullet min^{-1}) \times \pi/30)$,

Where: P is power in watts; T is torque and R is cadence in $rev \bullet min^{-1}$ (Gardner, Martin, Martin, Barratt, & Jenkins, 2007).

Finally, peak power and time to peak power was used to determine differences in mechanical work performed between the gear ratio using the equation below.

Mechanical Work (Kj) = Power (W) × Time (s) ÷ 1000

Statistical analysis

A Shapiro-Wilk test was used to test for normality due to the relatively low sample size, and data were found to be normally distributed. To determine any statistical differences between the gear ratios, data were subjected to a within groups repeated measures analysis of variance (ANOVA). Where a significant ANOVA test was observed, Bonferroni pairwise comparisons were used to determine where the differences lay and to control for type I errors. Effect size was calculated using Partial eta squared (η^2), with 0 - 0.1 representing a weak effect, 0.1 - 0.3 a modest effect, 0.3 - 0.5 a moderate effect and >0.5 a strong effect (Tolmie, Muijs & McAteer, 2011). IBM Statistical Package for the Social Sciences statistical (SPSS) version 19 was used for all statistical analyses (IBM inc., Chicago IL) and a $p \leq 0.05$ was accepted as the level of significance.

Results

The results of the ANOVA indicated a significant main effect existed between the gear ratios for peak power ($F(2,14) = 6.448$; $p = 0.010$). A significant main effect was also found on peak torque ($F(2,14) = 4.777$; $p = 0.026$). However, there was no significant main effect on time to peak power ($F(2,14) = 0.200$; $p = 0.821$).
The theoretical distance each gear ratio can travel was also calculated for a single revolution. The 45/16 ratio travelled 4.47 m, the standard race gear ratio (43/16) travelled 4.27 m and the lowest ratio 41/16 ratio travelled 4.07 m. Furthermore the mean theoretical mechanical work done during the time to peak power was calculated for each of the gear ratios: 45/16 = 1.65 Kj, 43/16 = 1.23 Kj, 41/16 = 1.26 Kj. The results showed no significant difference between the mechanical work for each of the gear ratio ($F(2,14) = 1.73$: $p = 0.172$.

Table 1

Riders mean results

	Peak Power	Compared Results	Peak Torque	Compared Results	Time to Peak Power	Compared Results	Cadence at peak Power	Compared Results
41/16 Gear Ratio	1381 W ± 199 W	- 56 W (η^2 = 0.989)	87 Nm ±19 Nm	- 23 Nm (η^2 = 0.993)	0.88 s ±0.52 s	0.00 s (η^2 = 0.006)	158 rev•min^{-1} ± 28 rev•min^{-1}	+ 28 rev•min^{-1} (η^2 = 1.00)
43/16 Gear Ratio	1437 W ± 205 W		109 Nm ±23 Nm		0.88 s ±0.44 s		129 rev•min^{-1} ± 25 rev•min^{-1}	
45/16 Gear Ratio	1658 W ± 201 W	+ 221 W (η^2 = 1.00)	112 Nm ±16 Nm	+ 3.00 Nm (η^2 = 1.00)	1.00 s ±0.53 s	+ 0.22 s (η^2 = 0.394)	142 rev•min^{-1} ± 18 rev•min^{-1}	+ 13 rev•min^{-1} (η^2 = 0.782)

Table 1 shows the mean and standard deviation results for peak power, torque and time to peak power using a 41/16, 43/16 and 45/16 gear ratio. The table also shows the results of a 41/16 and a 45/16 chain ring compared to a standard 43/16 chain ring.

Discussion

The purpose of the current study was to determine if a non-standard gear ratio could elicit a significant increase in peak power whilst reducing the time to peak power. The results showed a 41/16 and a 45/16 ratio compared to a standard 43/16 ratio has several significant differences. The main findings were that riders attained lower peak power and an increased time to peak power comparing the 41/16 to the 43/16. Whilst the larger 45/16 gear ratio enabled riders to produce a higher peak power in a similar time to the trials using a 43/16 gear ratio (see table 1). The standard gear ratio for a BMX bike is 43 tooth front chain ring and a 16 tooth rear cog, more commonly referred to as a 43/16 (Rylands, Roberts, Cheetham & Baker, 2013).

The gear ratios are termed higher or lower based on the number of teeth on the combined gear ratio. A gear ratio determines the distance a bike will travel for every pedal revolution. For instance, the bikes in this study used a 175 cm crank length and 0.508 m wheels diameter. Based on the gear ratios used in this study for a single revolution of a crank arm the following distance will be travel by a bicycle 41/16 = 4.07m, 43/16 = 4.27m, 45/16 = 4.47m (see methods section for calculation).
This concept has an impact on cycling performance as increasing the cadence or the size of the gear ratio will result in a greater distance being covered by a rider.

However, it has also been shown that an increase in the gear ratio increases the inertial load at a set cadence (Fregly, Zajac & Dairaghi, 2000; Hansen, Jørgensen, Jensen, Fregly & Sjøgaard, 2002). Therefore, if cadence can be increased, or maintained with an increase in inertial load (gear ratio), peak power will increase and as a result, so will the riders velocity on the track. Within the current study the authors found an increase in cadence occurred (η^2 = 1.00, + 28 revs·min^{-1}) when comparing the lower (41/16) gear ratio to the standard 43/16 ratio and a reduction in peak power (η^2 = 0.989, - 56 W). A probable cause of this is due to the reduction in inertial load associated with lower gear ratio. Furthermore, the study found the 41/16 resulted in a lower mean torque of 87 Nm compared to the 43/16 (109 Nm) and the 45/16 (112 Nm). A possible cause of this is the reduction in resistive force (inertial load), limiting the riders' ability to produce power.

Conversely, the higher gear ratio (45/16) elicited the relatively greatest power outputs (η^2 = 1.00, + 221 W) and an increase in cadence above that of the smaller and standard gear ratios (η^2 = 0.782, + 13 revs·min^{-1}). The increase in power might be due to the increase in resistive force associated with greater torque and inertial load. Whilst an increase in cadence might be due to the riders gaining greater velocity on the start ramp due to the increased power applied to the bicycle. Moreover, as there was no reduction in cadence, and an increase in power using a 45/16 gear ratio, theoretically the participants could use a higher gear ratio than a 45/16, but more research is required to determine the optimum gear ratio threshold for increasing power and the reduction of cadence.

Previous studies have confirmed that peak power alone is not the single contributing factor to BMX race performance (Mateo, Blasco-Lafarga & Zabala, 2011). Bertucci and Houde (2011) analysed the power characteristics of 17 elite and national standard BMX riders. One of the observations in their study was that the rate of force applied to the pedals was crucial as it had a direct effect on the start phase of a BMX race. The importance of the start of a BMX race on the overall race outcome was noted by Rylands and Roberts (2014). The authors analysed four UCI world cup events in 2012 using data from 348 riders across 175 elite BMX races. The results from the study identified that the first 8-12 seconds of the race had a direct correlation to the finish line placing's for both male (t = 0.581, $P<0.01$) and female elite riders (t = 0.571, $P<0.01$). Therefore, the optimisation of time to peak power through gear selection could have an effect on race outcome. The results from the current study identified that the lower 41/16 gear ratio had no effect on time to peak power (η^2 = 0.006, 0.00 s) compared to the 43/16 gear ratio. Whilst the higher gear ratio (45/16) demonstrated an increase in time to peak power over the 10 seconds sprint of + 0.22 s (see table 1), albeit a weak to modest effect size of η^2 = 0.394. The results of the mechanical work done between the gear ratios revealed no statistical differences (p = 0.172). Consequently, if the larger gear ratio (45/16) can produce higher peak power in a similar time as the lower gear ratio, with similar mechanical work, then coaches and riders may find this information useful when selecting a gear ratio.

Conclusion

As BMX bicycles have a single gear ratio and are unable to change gear during a race choosing the optimal ratio prior to a race is essential. The results from the study infer that there is a trade-off as a result of gear selection between peak power and the time to peak power. The findings from this study suggests that a higher gear ratio could be used by riders to elicit a higher peak power. Whilst, the time to peak power would be increased minimally as a consequence. These findings have implications for individual riders when choosing a gear ratio specific to their strengths and weaknesses. For example, if a rider is losing races due to their reaction time at a start gate, the larger gear ration would be an ineffective choice, as it would exacerbate the poor start. Gear selection is therefore a crucial consideration when racing, due to its significant impact on performance.

Reference list

Bertucci, W., & Hourde, C. (2011). Laboratory testing and field performance in BMX riders. *Journal of Sports Science and Medicine,* 10: 417-419.

Cowell, J. F., McGuigan, M. R., & Cronin, J. B. (2012). Movement and skill analysis of Supercross BMX. *The Journal of Strength & Conditioning Research,* 226(6): 1688-1694.

De Koning, J. J., Bobbert, M. F., & Foster, C. (1999). Determination of optimal pacing strategy in track cycling with an energy flow model. *Journal of Science and Medicine in Sport,* 2(3): 266-277.

Fregly, B. J., Zajac, F. E., & Dairaghi, C. A. (2000). Bicycle drive system dynamics: theory and experimental validation. *Journal of Biomechanical Engineering, 122*(4): 446-452.

Gardner, S. A., Martin, J. C., Martin, D. T., Barrat, M., & Jenkins, D. G. (2007). Maximal torque- and power-pedaling rate relationships for elite sprint cyclists in laboratory and field tests. *European Journal of Applied Physiology,* 101: 287–292.

Hansen, E. A., Jørgensen, L. V., Jensen, K., Fregly, B. J., & Sjøgaard, G. (2002). Crank inertial load affects freely chosen pedal rate during cycling. *Journal of Biomechanics,* 35(2): 277-285.

Jones, S. Passfield, L. (1998). The dynamic calibration of bicycle power measuring cranks. *The Engineering of Sport.* 265-274.

Kohler, G., & Boutellier, U. (2005). The generalized force–velocity relationship explains why the preferred pedalling rate of cyclists exceeds the most efficient one. *European Journal of Applied Physiology*, 94(1): 188-195.

Mateo, M., Blasco-Lafarga, C., & Zabala, M. (2011). Pedaling power and speed production vs. technical factors and track difficulty in bicycle motocross cycling. *The Journal of Strength & Conditioning Research*, *25*(12), 3248-3256.

Mognoni, P., & Prampero, P. E. (2003). Gear, inertial work and road slopes as determinants of biomechanics in cycling. *European Journal of Applied Physiology*, 90(3): 372-376.

Rylands, L. P., Roberts, S. J., Hurst, H. T. (2015a). Variability in laboratory versus field-testing of peak power, torque and time of peak power production amongst elite BMX cyclists. *Journal of Strength and Conditioning Research*, 29 (9): 2635–2640.

Rylands, L. P., Roberts, S. J., Hurst. H. T., & Bently. I. (2016). Effect of cadence selection on peak power and time of power production in elite BMX riders: a laboratory based study. *Journal of Sports Sciences*, In press.

Rylands, L., Roberts, S. J. (2014). Relationship between starting and finishing position in World Cup BMX racing. *International Journal of Performance Analysis in Sport*, 14(1): 14-23.

Rylands, L., Roberts, S. J., Cheetham, M., & Baker, A. (2013). Velocity Production in Elite BMX Riders: A Field Based Study Using a SRM Power Meter. *Journal of Exercise Physiology Online,* 16(3).

Soderlund, K., & Hultman, E. R. I. C. (1991). ATP and phosphocreatine changes in single human muscle fibers after intense electrical stimulation. *American Journal of Physiology-Endocrinology and Metabolism*, *261*(6).

Tolmie, A., Muijs, D., & McAteer, E. (2011). Quantitative methods in educational and social research using SPSS. Berkshire, England: *Open University Press*.

UCI rule book (4.04.14). Part 6 BMX. Cranks, pedals and gears, 6.1.069.

Wells, M., Atkinson, G., & Marwood, S. (2013). Effects of magnitude and frequency of variations in external power output on simulated cycling time-trial performance. *Journal of Sports Sciences,* 31(15): 1639-1646.

Wooles, A. L., Robinson, A. J., & Keen, P. S. (2005). A static method for obtaining a calibration factor for SRM bicycle power cranks. *Sports Engineering,* 8: 137-144.