Journal of Science & Cycling
Breakthroughs in Cycling & Triathlon Sciences

OPEN ACCESS

Original article

Prediction of track performance in competitive BMX riders using laboratory measures

Amin Daneshfar [1]*, Carl R. Petersen [1], Brad Miles [1], Daniel E. Gahreman [2]

[1] School of Health Sciences, University of Canterbury, New Zealand
[2] College of Health & Human Sciences, Charles Darwin University, Australia

* Correspondence: Amin Daneshfar. amin.daneshfar@pg.canterbury.ac.nz

Received: 7 October 2019; Accepted: 31 March 2020; Published: 30 June 2020

Abstract: Identifying key physiological factors is essential in cycling; however, the unique nature of BMX decreases the validity and transferability of research findings from other cycling disciplines. Therefore, this study highlighted the physical and physiological characteristics of BMX riders that could influence track performance. Fifteen sub-elite BMX riders (male n = 12; age 18.3 ± 3.3 and female n = 3; 17.7 ± 5.7 years) undertook a battery of laboratory tests on three different occasions, including body composition, upper and lower body strength, flexibility, sprint and aerobic capacity measures. On a separate day, participants completed three full lap sprints on an outdoor BMX track. Correlation and multiple linear regression analyses were performed to develop predictive models of performance across the laboratory tests and race time. The final model indicated power to weight ratio, relative back-leg-chest strength and arm span explained ~87% of the variability in finish time (adjusted R2 = 0.87, p < .01). These findings highlighted the importance of a multidimensional approach for developing BMX race performance. Coaches should prioritise these variables in their training programs and selection of future talents. However, further physiological and biomechanical investigation is needed to validate current findings, particularly among elite riders.

Keywords: Peak Power, BMX Time Trial, Physiological Demand, Anthropometry

1. Introduction

Bicycle Motocross (BMX) is a relatively new Olympic sport since 2008, which is built on the premise of fast racing around off-road tracks on a bicycle smaller and lighter than a road bike or mountain bike. A BMX race over a 300-400m dirt track begins with the drop of the starting gate, after which up to eight riders pedal down a 5-8m slope. Riders then face several large jumps, banked turns, and smaller jumps in quick succession. In a BMX race, riders combine the cycling periods with technical non-pedaling periods known as manualling and pumping in which the upper body manoeuvres the bike. It is believed that both physiological and technical proficiency of riders contribute to race performance and riders' success (Rylands et al., 2017a).

Given the high technical and physical demands of BMX, previous research highlighted the importance of gaining the front position of the race group by the end of the first jump. This gives riders a distinct advantage to best navigate the upcoming obstacles and contribute with a faster finish time (Cowell et al., 2012b). To gain the front position, BMX riders attempt to apply a maximum power effort using the leverage and strength of their upper and lower body (Herman et al., 2009; Mateo et al., 2011; Rylands et al., 2014). Factors that could affect power output such as gear ratio (Rylands et al., 2017b), optimal cadence (Rylands et al., 2017c), and the maximal torque and cadence relationship (Debraux et al., 2013; Gardner et al., 2007) have also been investigated. Despite this, research of physiological demands and performance predictors are scarce, and BMX coaches require specific data (Rylands et al., 2019).

Identifying key performance indicators is considered an important step to increase the efficacy of training programs. Bertucci et al. (2011) evaluated the relationship between laboratory measures, including Counter Movement Jump (CMJ), Squat Jump (SJ), seated and standing 30 second Wingate sprints, with subsequent race performance. Their results demonstrated a moderate relationship between power output and 80m sprint from a stationary start on levelled ground. However, this research was suffering from ecological validity. For instance, the race performance was measured only to the end of the first straight section (75m) and not over the whole track, therefore, some findings may be missed by negating the rest of the race distance. In addition, with BMX being an intermittent cycling activity, where only 30-40% is devoted to pedalling, a continuous 30 second Wingate test may not be a good predictor of BMX performance (Cowell et al., 2011). Furthermore, while the lower body power output significantly associated with overall performance, success in BMX racing might also be influenced by factors other than just lower body power. For instance, riders' anthropometry (Grigg et al., 2017), muscular strength (Cowell et al., 2012b), and aerobic capacity (Louis et al., 2013).

BMX race analysis showed that between ~ 70% of the race time is spent jumping, coasting, or pumping (Cowell et al., 2011). Rylands et al. (2017a) showed that upper body pumping technique could improve the finish time by 20% compared to the non-pumping technique. Furthermore, Baker et al. (2001) stated that upper body strength significantly contributes to cycling peak power. Their study demonstrated that the intensity of the electrical activity recorded for the forearm musculature during sprint cycling was similar to that recorded during a maximum voluntary hand grip contraction. By pulling the handlebar, the centre of body mass is maintained at a constant vertical level, so that leg extension can be directed to pushing down on the pedals and facilitate the acceleration phase of performance (Dore et al., 2006).

Intuitively, based on race movement pattern, it could be argued that overall muscular strength and the anthropometric profile of riders could improve leverage and offer functional advantages to BMX riders. Given the limited data available on physiological demands of BMX racing, a holistic approach to identifying contributing factors to riders' performance seems most appropriate. This information could assist coaches in prioritising specific components of training for annual periodization and selecting future talents. Therefore, the purpose of the present study was to investigate the relationship between anthropometrical features and laboratory-based assessments of strength and power, with track performance.

2. Methods

Participants

Fifteen sub-elite BMX riders (12 males and 3 females; age: 18.3 ± 3.3, 17.7 ± 5.7 years; height 177 ± 5.8, 164 ± 3.6 cm; mass 69.2 ± 6.4, 67.8 ± 13.9 kg; body fat percentage (BF%) 13.3 ± 4.4, 26 ± 7.5; muscle mass 34.4 ± 3.2, 28.8 ± 1.6 kg; training experience 7.5 ± 2.5, 6.4 ± 2 years for males and females respectively) volunteered to participate in this study. All participants were informed about the study protocol and potential risks and provided written consent by the Declaration of Helsinki. Parental consent was also obtained for participants under the age of 18. This study was approved by the Human Ethics Committee of the University of Canterbury.

Design

In this cross-sectional study, the relationships between laboratory results and track performance were investigated using multivariate analysis over three different occasions. Firstly, participants had a familiarisation session of all laboratory testing procedures, as well as anthropometric measurement. The following day, in the second laboratory session, maximal strength and cycling sprints were measured. Finally, 48 hours later, participants' aerobic capacity was tested. The track performance was measured one week later and described as the time taken to complete three all-out efforts on a 342m outdoor BMX track.

Anthropometric assessment

Body mass (Seca Quadra 808 digital scales, Birmingham, UK), height (Seca 213 stadiometer, Birmingham, UK), arm span, hand dimensions (Lufkin W606PM anthropometric tape, SPARK, USA), and sum of seven skinfolds including triceps, subscapular, biceps, supraspinale, abdominal, thigh and medial calf (Harpenden Callipers Holtain, Crymych, UK) were assessed by a level two anthropometrist following the International Society for the Advancement of Kinanthropometry (ISAK) testing protocols (Marfell-Jones et al., 2012).

Muscle mass and BF% were determined using Bio-electrical Impedance (Inbody 230, Seoul, Korea), which its validity and reliability have been approved by Von Hurst et al. (2016). The somatotypes of participants were assessed according to the Heath-Carter method (Carter et al., 1990) using the Somatotype 1.2.6 program (MER Goulding Software Development, Geeveston, Australia).

Strength assessment

Handgrip strength (HGS) was measured using a digital dynamometer (Jamar Plus Digital-Dynamometer, Chicago, USA) according to the American Society of Hand Therapists (Fess et al., 1981). Participants held a dynamometer in their hand with the arm held straight and maximally squeezed for three seconds. The maximum strength of the three attempts for each hand was recorded (Mathiowetz et al., 1984).

Back-leg-chest strength

A calibrated Back-Leg-Chest (BLC) strength dynamometer (Mentone, Victoria, Australia) was used to assess isometric muscle strength. The length of the chain was adjusted according to the participants' height with their knees and hips flexed slightly and with their lower back in an appropriate lordotic curve. Participants lifted in a vertical direction with a continuous isometric contraction of the extensors of the knees, hips, and lower back. After demonstration and familiarization, three attempts were performed, each followed by a 30-second rest period. The best of the three attempts was recorded (Ten Hoor et al., 2016).

Maximal leg press, leg extension and bench pull strength tests (1-RM)

A one repetition maximum test (1-RM) was used to estimate the maximal strength of bench pull, leg press and leg extension using a cable machine. Prior to testing, a warm-up of 6 to 10 repetitions at approximately 50% of the participants estimated strength was undertaken. The 1-RM test was initiated two minutes post-warm-up. Using the protocol employed by Brzycki (1993), participants attempted to lift each weight a maximum of 10 times. If 10 repetitions were achieved, a higher weight was tested following a 5-minute recovery. Whereas when a participant was only able to complete less than 10 repetitions, this number was entered into the maximum repetition calculations.

$$1\text{-RM} = 100 * \text{load rep} / (102.78 - 2.78 * \text{Rep})$$

Where: load rep = workload value of repetitions performance in kg.

Rep = number of repetitions performed.

Leg power tests

The correct technique for SJ and CMJ were demonstrated and explained to each participant by a qualified biomechanist. The SJ tests were performed in an upright standing position with hands on the hips and flexed knees. This position was maintained for three seconds before participants jumped as high as possible, without any counter-movement action. The CMJ started with an upright standing position with hands unrestricted. The participants were encouraged to bend their knees to approximately 90◦ and use their arm to achieve the maximum height with no delay at their lowest position (Daneshfar et al., 2018). After a standardized warm-up of 2-3 repetitions of both SJ and CMJ, participants were asked to perform three jumps with a passive recovery of 1-min in between each jump. The highest jump of the three attempts was recorded. Participants were instructed to repeat any incorrectly performed jumps.

Laboratory leg power assessment

Each participant performed three 10-second standing cycle sprints on a Wattbike Pro (Giant 2015, Nottingham, UK) which was calibrated according to the manufacturers' guidelines. The air and magnet resistance was set at level 1. Through the use of a load cell, the Wattbike calculates the force that the cyclist applies through the cranks onto the chain at 100Hz. Power output is then calculated as the sum of all of the force applied to the chain. The highest peak power of the three attempts was recorded, as well as the average 10-second power, max cadence, time to peak power, minimal power, and fatigue index. The bar height and stem length were adjusted to each participant's preferred position, while the seat was set at the lowest position so it would not interfere when performing each sprint. Each participant performed their usual warm-up which included both seated and standing short cycling sprints. Participant were encouraged to reach maximal power as fast as possible while performing each sprint from a standing stationary position using their preferred leg in the lead position. A rest period of 10 minutes was employed between each sprint (Gardner et al., 2007).

Maximum Aerobic Capacity (VO2max)

An incremental intensity bike test, undertaken to exhaustion, was used to determine VO2max. Following a 6-min warm-up at 100 W, power was increased by 30 W per minute until volitional exhaustion occurred, with participants choosing their preferred cadence. During the test, oxygen uptake (VO2), minute ventilation (VE), and respiratory exchange ratio (RER) were continuously measured breath-by-breath with a gas exchange analyzer (K5, Cosmed, Italy) which was pre-calibrated in accordance with the manufacturer's instructions. To determine VO2max, these three conditions were required: a plateau in VO2 despite an increase in power output, a RER above 1.1, and a heart rate (HR) above 90% of the participants' age-predicted maximal HR. Peak VO2max was taken as the highest sampled average of the 30 second reading (Howley et al., 1995).

On track sprint assessment

Two weeks after completing their laboratory testing, participants were tested at the Christchurch BMX track, in New Zealand. Prior to testing, they performed a structured self-paced warm-up consisting of 4-6 standing short sprints. Three full lap races were then undertaken using the same BMX bike (gear ratio of 43/16). The track included a 5m high start ramp and a standard electronic start gate was employed. Lap time was recorded using two pairs of photocells (NEOtm Swift Performance, Queensland, Australia) positioned at the start gate and on the finish line. A 15-minute passive recovery was undertaken between each of the three races, and the fastest finish time of three races was recorded.

Blood Lactate

Blood lactate concentration (mmol.L-1) was measured using a Lactate Pro2 analyzer (Arkray, Koyoto, Japan) while a finger prick was taken before warm-up (baseline value) and 3 min after the sprint tests (Tanner et al., 2010).

Statistical Analyses

Data were analysed using SPSS 25 (SPSS, An IBM Company, Amarouk, NY) and presented in mean ± SD. All variables were assessed for normality using the Shapiro-Wilk test. The Pearson's correlation coefficients and simple linear regression models were used to assess the relationship between the physical and physiological lab measures (independent variable) with the BMX finish time (dependent variable), as well as to screen for independent variables to be included in the multiple linear regression model (Table 1). Forward stepwise multiple linear regression was conducted to identify the best model. In addition, the typical error of estimate and 95% Confidence Limits (CL) were used to describe predictive accuracy.

Table 1. Dependent and selected independent variables

Dependent Variable	
Time to finish	**time to completion of the race (s)**
Selected independent variables	
Arm span	distance between the middle finger of each hand while the arms are outstretched (cm)
BF%	percentage of whole-body fat component (%)
Muscle mass	muscle mass (kg)
Relative leg press 1RM	one repetition maximum ($kg.kg^{-1}$)
Relative bench pull 1RM	one repetition maximum ($kg.kg^{-1}$)
BLC strength 1RM	one repetition maximum (kg)
Maximal HGS	hand grip strength (kg)
SJ	squat jump
Power to weight ratio	power to weight ratio ($W.kg^{-1}$)
Maximum cadence	cadence at peak power ($revs \cdot min^{-1}$)
VO_2max	maximum oxygen capacity ($ml.kg^{-1}\ min^{-1}$)

3. Results

Variables were normally distributed and descriptive data for lab and track performance is presented in Table 2 separated by gender. Pearson's correlation coefficients were significant between finish time and BF% (-0.727), endomorphic value (0.763), relative back strength (0.725), SJ (-0.730), and maximum cadence (-0.756), respectively (Table 3).

Following the identification of collinear variables, those variables (e.g. height, sit and reach, relative leg extension) that could not be retained in any models were omitted from the results. Forward multiple regression was performed for finish time with anthropometrical, and physiological variables. No violations of the assumption of linearity,

homoscedasticity, and outliers were observed (Table 4).

The strongest model to predict the BMX race performance displayed a good fit (adjusted R2 = 0.867; p < .001). This model utilised three independent variables: arm span, relative BLC strength and power to weight ratio which, when taken together, were responsible for 87% F(3, 11) of the explained variability in the finish time of the race (Table 5).

Table 2. Descriptive statistics of the lab and BMX track (mean ± SD)

	(Male, N=12)	(Female, N=3)
Somatotype and Anthropometric		
Endomorph	2.6 ± 0.4	5.3 ± 1.8
Mesomorph	4.9 ± 1.1	4.4 ± 1.7
Ectomorph	2.5 ± 0.8	1.6 ± 1.0
Arm span (cm)	178.7 ± 8.4	161.0 ± 5.8
Maximal hand dimension (cm)	22.4 ± 1.2	19.3 ± 2.1
Flexibility and Laboratory Strength		
Sit and reach (cm)	14.8 ± 5.8	18 ± 1
Leg extension 1RM (kg)	117.2 ± 13.0	83 ± 24
1RM relative leg extension ($kg \cdot kg^{-1}$)	1.7 ± 0.1	1.2 ± 0.2
1RM bench pull (kg)	62 ± 12.5	36 ± 9.9
1RM relative bench pull ($kg \cdot kg^{-1}$)	0.9 ± 0.1	0.5 ± 0.1
1RM leg press (kg)	177. 6 ± 30	125.7 ± 87.0
1RM relative leg press ($kg \cdot kg^{-1}$)	2.5 ± 0.3	1.7 ± 1.1
Maximal HGS (kg)	46.4 ± 5.6	31.3 ± 4.7
BLC strength (kg)	145.7 ± 20.0	101 ± 10
Relative BLC strength ($n \cdot kg^{-1}$)	2.1 ± 0.2	1.5 ± 0.2
CMJ (cm)	54.7 ± 10.7	32.3 ± 0.7
SJ (cm)	40.3 ± 6.3	24.67 ± 0.6
Laboratory Bike Test		
Peak power (W)	1220 ± 177	837 ± 138
Power to weight ratio ($W \cdot kg^{-1}$)	17.6 ± 1.8	12.5 ± 1.2
Average power (W)	1071 ± 165	718 ± 109
Relative average power ($W \cdot kg^{-1}$)	15.5 ± 1.9	10.7 ± 1.4
Maximum cadence ($revs \cdot min^{-1}$)	152 ± 10	125 ± 8
Time to peak power (s)	0.8 ± 0.6	0.7 ± 0.3
Minimal power (W)	948 ± 143	649 ± 60
Relative minimal power ($W \cdot kg^{-1}$)	13.7 ± 1.6	9.8 ± 1.7
Fatigue Index (a.u)	27.2 ± 7.5	18.8 ± 8.8
VO_{2max} ($ml \cdot kg^{-1}\ min^{-1}$)	43.3 ± 5.8	35.0 ± 5.3
RPE	9.7 ± 0.4	8.7 ± 0.6
Resting blood lactate ($mmol \cdot L^{-1}$)	2.2 ± 0.5	2.5 ± 0.7
Post 3 min blood lactate ($mmol \cdot L^{-1}$)	10.9 ± 2.7	9.5 ± 1.1
BMX Track Performance		
Finish time (s)	36.39 ± 0.70	40.71 ± 0.80
HR on the track (% of HR Max)	88.5 ± 3.9	85.2 ± 3.7

Table 3. Pearson correlation coefficient matrix

	TTF	AS	BF%	MMS	RBP	RLP	DHG	RBLC	SJ	PWR	MCad	VO2max
AS	-0.676 †	-										
BF%	0.727 †	-0.472	-									
MMS	0.629*	0.783 †	-0.536	-								
RBP	-0.645 †	0.435	-0.525 *	0.657 †	-							
RLP	-0.543 *	0.583*	-0.065	0.388	0.529*	-						
DHG	-0.699 †	0653 †	-0.264	0.510	0.607 *	0.808 †	-					
RBLCS	-0.725†	0.303	-0.681 †	0.561 *	0.592 *	0.191	0.516 *	-				
SJ	-0.730 †	0.434	-0.464	0.522	0.678†	0.487	0.536*	0.544*	-			
PWR	-0.868 †	0.459	-0.636 *	0.568 *	0.749 †	0.395	0.475	0.644 †	0.786 †	-		
MCad	-0.756 *	0.767	-0.515 *	0.680 †	0.567 *	0.518	0.585 *	0.603 *	0.541 *	0.642 †	-	
VO2max	-0.647 †	0.304	-0.264	0.463	0.463	0.404	0.593 *	0.672 †	0.522 *	0.655 *	0.534 *	-

TTF: Time to Finish; AS: Arm Span; BF%: Body Fat Percentage; MMS: Muscle Mass; RBP: Relative Bench Pull; RLP: Relative Leg Press; DHG: Dominant Hand Grip; RBLC: Relative Back-Leg-Chest Strength; SJ: Squat Jump; PWR: Power to Weight Ratio; Mcad: Max Cadence; VO2max: maximum oxygen uptake normalized by body mass (ml.min-1.kg-1); *Significant at 0.05; † significant at 0.01

Table 4. Multiple regression model to predict time to finish of the simulate BMX race

Anthropometric Variables				
Coefficient				
	B [95%CI]	(β)	sr^2	
Predictor Variable				
Arm Span	-0.161 [0.177, 0.055]	-0.334	0.039	
Body Fat%	0.136 [-0.016, 0.256]	0.502	0.183	
Model Summary				
Observation	R^2	*Adjusted* R^2	*F(3, 11)*	*p*
15	0.676	0.588	5.22	.005
Strength Variables				
Coefficient				
Predictor Variable	B [95%CI]	(β)	sr^2	
Relative Bench Pull	2.748 [-6.555, 4.756]	0.106	0.372	
Relative leg press	1.012 [-3.491, 1.606]	-0.165	0.021	
Relative BLC Strength	1.361 [-6.443, 0.170]	-0.466	0.133	
Maximal HGS	0.076 [-0.231, 0.168]	-0.200	0.004	
Model Summary				
Observation	R^2	*Adjusted* R^2	*F(4, 10)*	*p*
15	0.702	0.583	5.90	.011
Physiological Laboratory Variables				
Coefficient				
Predictor Variable	B [95%CI]	(β)	sr2	
SJ	0.048 [-0.127, 0.086]	-0.092	0.003	
Power to Weight Ratio	0.176 [-0.777, 0.010]	-0.537	0.081	
Maximum Cadence	0.023 [-0.091, 0.10]	-0.312	0.054	
VO2max	0.051 [-0141, 0.088]	-0.091	0.005	
Model Summary				
Observation	R^2	Adjusted R^2	F(4, 10)	p
15	0.828	0.759	12.01	.001

Unstandardised (B), and Standardised (β) Regression Coefficients, and Squared Semi-Partial correlations (sr^2) for each predictor in a regression model.

Table 5. Final Predictors

Coefficient				
Predictor Variable	B [95%CI]	(β)	sr^2	
Arm Span	0.020 [-0.591, 0.162]	-0.349	0.096	
Power to Weight Ratio	0.079 [-0.106, -0.019]	-0.528	0.144	
Relative BLC Strength	0.726 [-3.190, -0.007]	-0.349	0.045	
Model Summary				
Observation	R^2	*Adjusted* R^2	*F(3, 11)*	*p*
15	0.896	0.867	31.55	.001

4. Discussion

To predict BMX race performance, we applied a multidimensional approach using laboratory-based measures. Notably, our findings displayed that across all the anthropometric, strength, and physiological categories, 87% of BMX race performance variation could be explained by power to weight ratio, relative BLC strength, and arm span. Coaches and cyclists can benefit from these findings as they demonstrate the factors that may influence BMX race result and could also be considered in talent identification processes.

The ability to generate maximum power in the first few seconds is vital for success in a BMX race. Rylands et al. (2014) analysed the 2012 UCI BMX World Cup series data and showed a strong correlation between the riders' position in the first 8–10 s of the race and their eventual finish line placing. In the current study, we applied a 10 s laboratory cycle sprint test to measure power. The strong correlation found between 10 s power to weight ratio and finish time in our study supported the importance of power on the rider's final position.

Power to weight ratio is a method of comparing one athlete's ability to produce power to another (Rylands et al., 2013). Riders with a large power to weight ratio can generate a substantial amount of force when the gate drops in the BMX race. Specifically, having a higher rate of force development (RFD) allows riders to reach a higher level of force in the early phase of muscle contraction (Debraux et al., 2011). This ability, when combined with quick reaction time, potentially assists a rider to have a greater chance of gaining the front position, which is a key factor for success in BMX racing.

Rylands et al. (2013) reported power to weight ratio of 21.29 ± 0.8 W.kg-1 and 16.65 W.kg-1 in 5 male and 1 female elite British BMX cyclists respectively, which was measured on a 50m track sprint test. The authors concluded that power to weight ratio might affect BMX riders' velocity, flight time, and distance travelled in the air while competing on the BMX track. The male BMX riders in the current study had a mean power to weight ratio of 17.6 ± 1.8 W.kg-1, in contrast with the female riders 12.5 ± 1.2 W.kg-1 for the three laboratory sprint tests. The highest laboratory correlation with finish time on the BMX track belonged to power to weight ratio ($r = 0.87$; $p < .01$) and this was higher than the correlation ($r > 0.70$) found by Bertucci et al. (2011). In addition, the absolute male peak power value in our study was 123 W and 748 W lower than Spanish and French elite riders (1343 ± 68 W and 1968 ± 210 W) respectively (Bertucci et al., 2011; Mateo et al., 2011). The lower peak power output in our study may be related to a younger rider age or differences in testing procedures. It could also be explained by lower (regional) competitive level as previous research has found power of national-level riders is 28% higher compared to regional riders (Bertucci et al., 2007).

There was a significant negative correlation between finish time and BF% ($r = -0.73$, $p < .01$). Additionally, BF% was significantly correlated with power to weight ratio ($r = -0.64$, $p < .05$). Milašius et al. (2012) reported that BF% of the elite female BMX cyclist was ~23%, which was higher than elite track cyclists. In the current study, female riders had 26 ± 7.5 BF%, which was higher than both elite BMX rider and track cyclists. The excess fat component could negatively affect power to weight ratio and influence race performance. Considering these findings, riders and conditioning coaches should monitor and maintain an optimal BF% to maximise power to weight ratio.

Generally, our findings were aligned with previous research that reported lower limb power (power to weight ratio) is an important factor in BMX (Cowell et al., 2012a; Debraux et al., 2013; Rylands et al., 2017b; Rylands et al., 2017c). Additionally, Debraux et al. (2011) reported that results of CMJ, 8 seconds seated sprint cycle test, and 30 second Wingate were three performance-related factors ($R2 = 41$ to 66%) during the 5 to 75 m of initial straightaway of the BMX track. Given that multiple factors explain BMX performance, we found a combination of riders' lower limb power, strength and anthropometric characteristics could have a stronger prediction (adjusted $R2 = 0.87$; $p < .001$) of the variability of BMX race performance. These results are essential for BMX coaches and practitioners while planning conditioning training to improve riders' performance.

Skeletal muscle strength is fundamental in many sports and exercise activities. The BLC strength test has been reported as a reliable measure for overall muscular strength (Ten Hoor et al., 2016). There are similarities between the BLC test, BMX movement patterns, and muscular recruitment across the entire race. In particular, at the start of a race before initiating any movement, the riders' body posture is almost identical to the BLC strength test where they draw their hips towards the handlebars to keep their balance (Kalichová et al., 2013). Movement patterns during a BMX race demand high muscular strength in both the leg and back muscles. This can assist riders to have a powerful start, as well as the ability to stabilize the bike during technical movements such as pumping, jumping and facing obstacles in the entire race (Rylands et al., 2017a). In our study, relative BLC strength had the highest correlation ($r = -0.73$, $p < .01$) with BMX performance compared to other strength tests and hence, it was presented in the final model. Having higher relative BLC strength allows riders to apply their upper body forces on the bike to generate more speed. It is worth noting that we examined the influence of different physiological measurements on BMX performance. However, further physiological and biomechanical investigation is needed to validate current findings, particularly among elite riders.

Arm span was significantly correlated with the finish time ($r = - 0.68$; $p < .01$) and appeared in our final model. The correlation between arm span and athletic performance has been investigated before. Lockie et al. (2018b) reported that individuals with a longer arm span and a shorter leg length were able to reach the peak power and velocity sooner during the deadlift. In a BMX race, riders with longer arms might be able to apply the upper body force on the bike more efficiently compared to riders with shorter arms. It can also be assumed that riders with longer arms can pump a further distance and generate more speed during the pumping technique where riders are neither pedalling nor jumping to increase their speed. However, another study reported that having a longer arm span resulted in more work during a bench press as they need to move the bar further (Lockie et al., 2018a). Therefore, in a BMX race performing more work could potentially create more fatigue and negatively influence race performance. Riders' physique varies between different cycling disciplines, for instance, sprint cyclists are significantly heavier, and have larger chest, arm, thigh and calf girths than endurance cyclists (Craig et al., 2001). As the BMX bike dimensions do not vary, riders' height and arm span could affect mechanical efficiency and subsequently overall race performance. Further physiological and biomechanical investigation is required on the impact of arm span on power development and race performance in BMX to validate its actual influence. If confirmed, this finding could be considered by coaches and practitioners during the talent identification process, as arm span is dependent on genetics.

5. Practical Applications.

This study has demonstrated that various factors can potentially explain BMX race performance. Our results suggest that coaches and practitioners should consider multiple characteristics when planning a training program. Namely, they should focus on short sprint power production, as this was the key component of the regression model for BMX finish time. In the current study we only discussed the final and strongest predictive model, but other variables are still important. Factors including SJ, pull strength, and VO2max could also be trained as they demonstrated a high correlation with finish time. It is apparent that individual body size could also be an important factor with a significant effect on BMX performance, and could assist the riders' selection and talent identification processes. In summary, our data presents specific aspects of BMX riders that should be targeted to maximise performance. We recommend that additional studies with more elite-level riders are undertaken to provide validity around these findings.

6. Limitations

There are several limitations which should be noted. The population of high-level BMX riders in the South Island is very limited, and including more elite level riders would increase the validity of the results. In addition to this, using more female riders in the study could provide comparative information around gender effects on BMX performance. Furthermore, using a specific BMX power meter on a real track will help to find the correlation between power produced in the lab condition and a simulated BMX race.

7. Conclusion

In conclusion, this study showed that power to weight ratio, relative BLC strength, and arm span explained 87% of the variability in BMX performance. We used a multidimensional approach to identifying contributing factors to BMX performance. This information can assist BMX coaches in prioritising specific components of training for annual periodization, as well as new riders selection process.

8. Conflict of interest

The authors report no conflict of interest.

References

1. Baker, Gal, Davies, Bailey, et al. (2001). Power output of legs during high intensity cycle ergometry: influence of hand grip. *Journal of Science and Medicine in Sport, 4*(1), 10-18 doi:10.1016/s1440-2440(01)80003-7
2. Bertucci, & Hourde. (2011). Laboratory Testing and Field Performance in BMX Riders. *Journal of Sports Science & Medicine, 10*(2), 417-419.
3. Bertucci, Hourde, Manolova, & Vettoretti. (2007). Mechanical performance factors of the BMX acceleration phase in trained riders. *Science & Sports, 22*, 179-181 (In French: English abstract).
4. Brzycki. (1993). Strength Testing Predicting a One-Rep Max from Reps-to-Fatigue. *Journal of Physical Education, Recreation & Dance, 64*(1), 88-90 doi:10.1080/07303084.1993.10606684
5. Carter, & Heath. (1990). *Somatotyping: development and applications* (Vol. 5): Cambridge university press.
6. Cowell, Cronin, & Mcguigan. (2011). Time motion analysis of supercross BMX racing. *Journal of Sports Science & Medicine, 10*(2), 420.
7. Cowell, Mcguigan, & Cronin. (2012a). Movement and skill analysis of supercross bicycle motocross. *Journal of Strength and Conditioning Research, 26*(6), 1688-1694 doi:10.1519/JSC.0b013e318234eb22
8. Cowell, Mcguigan, & Cronin. (2012b). Strength training considerations for the bicycle Motocross athlete. *Strength & Conditioning Journal, 34*(1), 1-7.
9. Craig, & Norton. (2001). Characteristics of track cycling. *Sports medicine, 31*(7), 457-468.
10. Daneshfar, Gahreman, Koozehchian, Amani Shalamzari, et al. (2018). Multi Directional Repeated Sprint Is a Valid and Reliable Test for Assessment of Junior Handball Players. *Frontiers in Physiology, 9*, 317 doi:10.3389/fphys.2018.00317
11. Debraux, & Bertucci. (2011). Muscular determinants of performance in BMX during exercises of maximal intensity. *Computer Methods in Biomechanics and Biomedical Engineering, 14*(sup1), 49-51 doi:10.1080/10255842.2011.591637
12. Debraux, Manolova, Soudain-Pineau, Hourde, et al. (2013). Maximal torque and power pedaling rate relationships for high level BMX riders in field tests. *Journal of Science and Cycling, 2*(1), 51-57.
13. Dore, Baker, Jammes, Graham, et al. (2006). Upper body contribution during leg cycling peak power in teenage boys and girls. *Research in Sports Medicine, 14*(4), 245-257 doi:10.1080/15438620600985829
14. Fess, & Moran. (1981). *American Society of Hand Therapists Clinical Assessment Recommendations* (1th ed.): American Society of Hand Therapists.
15. Gardner, Martin, Martin, Barras, et al. (2007). Maximal torque-and power-pedaling rate relationships for elite sprint cyclists in laboratory and field tests. *European Journal of Applied Physiology, 101*(3), 287-292.
16. Grigg, Haakonssen, Orr, & Keogh. (2017). Literature Review: Kinematics of the BMX SX Gate Start. *Journal of Science and Cycling, 6*(1), 3-10.
17. Herman, Mcgregor, Allen, & Bollt. (2009). Power Capabilities Of Elite Bicycle Motocross (BMX) Racers During Field Testing In Preparation For 2008 Olympics. *Medicine and Science in Sports and Exercise, 41*(5), 306-307.
18. Howley, Bassett, & Welch. (1995). Criteria for maximal oxygen uptake: review and commentary. *Medicine and Science in Sports and Exercise, 27*(9), 1292-1301.
19. Kalichová, Hřebíčková, Labounková, Hedbávný, et al. (2013). Biomechanics analysis of bicross start. *International Journal of Medical, Health, Pharmaceutical and Biomedical Engineering, 7*, 361-369.
20. Lockie, Callaghan, Orjalo, & Moreno. (2018a). Relationships Between Arm Span And The Mechanics Of The One-Repetition Maximum Traditional And Close-Grip Bench Press. *Facta Universitatis, Series: Physical Education and Sport*, 271-280.
21. Lockie, Moreno, Orjalo, Lazar, et al. (2018b). Relationships Between Height, Arm Length, and Leg Length on the Mechanics of the Conventional and High-Handle Hexagonal Bar Deadlift. *Journal of Strength and Conditioning Research, 32*(11), 3011-3019 doi:10.1519/jsc.0000000000002256

22. Louis, Billaut, Bernad, Vettoretti, et al. (2013). Physiological demands of a simulated BMX competition. *International Journal of Sports Medicine, 34*(6), 491-496 doi:10.1055/s-0032-1327657
23. Marfell-Jones, Stewart, & De Ridder. (2012). *International standards for anthropometric assessment*.
24. Mateo, Blasco-Lafarga, & Zabala. (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.
25. Mathiowetz, Weber, Volland, & Kashman. (1984). Reliability and validity of grip and pinch strength evaluations. *Journal of Hand Surgery, 9*(2), 222-226.
26. Milašius, Dadelienė, Tubelis, & Skernevičius. (2012). Alternation of physical and functional powers of high performance female BMX cyclist during yearly training cycle. *Baltic Journal of Sport and Health Sciences, 1 (84)*, 36-41.
27. Rylands, Hurst, Roberts, & Graydon. (2017a). The Effect of "Pumping" and "Nonpumping" Techniques on Velocity Production and Muscle Activity During Field-Based BMX Cycling. *Journal of Strength and Conditioning Research, 31*(2), 445-450 doi:10.1519/jsc.0000000000001499
28. Rylands, & Roberts. (2014). Relationship between starting and finishing position in World Cup BMX racing. *International Journal of Performance Analysis in Sport, 14*(1), 14-23.
29. Rylands, & Roberts. (2019). Performance Characteristics in BMX Racing: A Scoping Review. *Journal of Science and Cycling, 8 (1)*, 3-10.
30. Rylands, Roberts, Cheetham, & Baker. (2013). Velocity production in elite BMX riders: a field based study using a SRM power meter. *Journal of Exercise Physiology Online*.
31. Rylands, Roberts, & Hurst. (2017b). Effect of gear ratio on peak power and time to peak power in BMX cyclists. *European Journal of Sport Science, 17*(2), 127-131 doi:10.1080/17461391.2016.1210237 Rylands, Roberts, Hurst, & Bentley. (2017c). Effect of cadence selection on peak power and time of power production in elite BMX riders: A laboratory based study. *Journal of Sports Sciences, 35*(14), 1372-1376 doi:10.1080/02640414.2016.1215491
32. Tanner, Fuller, & Ross. (2010). Evaluation of three portable blood lactate analysers: Lactate Pro, Lactate Scout and Lactate Plus. *European Journal of Applied Physiology, 109*(3), 551-559.
33. Ten Hoor, Musch, Meijer, & Plasqui. (2016). Test-retest reproducibility and validity of the back-leg-chest strength measurements. *Isokinetics and Exercise Science, 24*(3), 209-216.
34. Von Hurst, Walsh, Conlon, Ingram, et al. (2016). Validity and reliability of bioelectrical impedance analysis to estimate body fat percentage against air displacement plethysmography and dual-energy X-ray absorptiometry. *Nutrition & Dietetics, 73*(2), 197-204.