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ORIGINAL INVESTIGATION

Determinant physiological factors of simulated BMX race

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Abstract
Evaluating the physiological demands of BMX cycling on a track provides coaches with the information required to prescribe more effective training programmes. To determine the relative importance of physiological factors during simulated BMX race, 12 male riders (age 19.2 ± 3.5 years, height 1.76 ± 0.06 m, mass 68.5 ± 4.3 kg) completed a maximum aerobic capacity ($\dot{V}O_{2max}$) test in a laboratory, and a week later, completed six laps on a BMX track interspersed by 15 min passive recovery. Peak power, immediate post-lap $\dot{V}O_{2peak}$, blood lactate, and heart rate were measured in each lap. Peak power to weight ratio was significantly correlated with lap time, however, the strength of this association decreased in each subsequent lap. Mean $\dot{V}O_{2peak}$ was greater than 80% of laboratory-measured $\dot{V}O_{2max}$ in every lap, indicating a strong contribution of the aerobic energy system during BMX racing. This study also identified that mean blood lactate was significantly associated with lap time, which showed the importance of the anaerobic energy system contribution to BMX race. Despite the short period of pedalling during BMX racing, both aerobic and anaerobic energy systems are important contributors to lap performance. Coaches should consider maximising both anaerobic power and aerobic capacity to improve riders' overall performance in multiple laps.

Keywords: *Peak power, $\dot{V}O_{2peak}$, blood lactate, cycling performance*

Highlights

- BMX is considered an intermittent sport and includes repeated high-intensity cycling sprints followed by non-pedalling periods.
- A better understanding of the physiological demands of BMX cycling on the race condition, provides coaches with data required to prescribe more effective training programs.
- The ability to repeatedly perform anaerobic efforts is an important determinant of maximal anaerobic performance.
- Oxidative metabolism can improve performance by increasing PCr resynthesize between multiple sprints.
- An effective training program should aim to enhance power to weight ratio as well as maximum aerobic capacity. Both these factors appear to affect BMX racing overall performance.

Introduction

Understanding the physio-metabolic requirements of a sport enables coaches to prescribe targeted training programmes to maximise performance. Using laboratory assessments relative to field-based workloads, researchers have identified several performance indicators in Bicycle Motocross (BMX) (Bertucci & Hourde, 2011; Daneshfar, Petersen, Miles, & Gahreman, 2020; Rylands, Roberts, & Hurst, 2015). However, laboratory measures have poor correlations with BMX race performed on a track, and this poor relationship between laboratory assessments and field performance limits the transferability of the results (Daneshfar, Petersen, Koozehchian, & Gahreman, 2020; Rylands & Roberts, 2019). Better understanding the physiological demands of BMX during a race will assist coaches to focus on the key factors that have the potential to enhance field performance.

A BMX competition usually involves qualification series, quarterfinals, semi-finals, and the final. Riders who are eliminated in the qualification series perform a minimum of three laps, while those who progress to the final complete six laps or more depending on the number of riders (Zabala et al., 2011). Each lap

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typically lasts between 30–40 s followed by 15–30 min recovery between laps, in which up to eight riders line up behind an electronic start gate awaiting the starting signal to start the next lap (Zabala et al., 2011). The start gate drops after the signal and riders pedal from a standing position down a 5–8 m ramp (UCI cycling regulations, 2019), then navigate a series of four straights with jumps separated by berms (u-bend corners).

BMX is considered an intermittent sport and includes repeated high-intensity cycling sprints (Zabala et al., 2008) followed by non-pedalling periods. The ability to perform repeated sprints is closely related to the contribution of aerobic and anaerobic energy systems (Tomlin & Wenger, 2001). Due to a significant contribution of the anaerobic energy system in high-intensity cycling sprints, a significant increase in blood lactate concentration has been reported (Zabala et al., 2011). This increase in lactic acid concentration may also lead to reduced power output and increased finish time in the latter laps.

Maintaining performance across repeated sprints requires greater ability to reduce blood lactate, regulate pH, and importantly, replenish phosphocreatine (PC) stores (Porter, Fenton, & Reed, 2019). Considering BMX racing as a repeated sprint event, data is limited regarding the relative importance of metabolic pathways and the consistency of power output over successive laps. To the authors' knowledge, only one study has examined the metabolic response of simulated BMX race with elite riders (Louis et al., 2013), and reported that high $\dot{V}O_{2peak}$ (94 ± 1% of $\dot{V}O_{2max}$) could be responsible for 54% of the variation in lap performance. This relatively high contribution is possibly due to the carryover from initial high anaerobic demands of an explosive start, technical movements, and the isometric work of the upper limbs throughout the lap. Louis et al. (2013) did not investigate the correlations between performance variables of lap time, peak power, $\dot{V}O_{2peak}$, and blood lactate. Consequently, the relationship between these factors and BMX performance remained unknown.

Currently, there is a lack of empirical data on the metabolic pathways and physiological demands of repeated BMX laps. This information will assist with the development of more effective training programmes and better monitoring of riders' progress. Accordingly, this study aimed to identify the physio-metabolic factors of BMX race in sub-elite riders. It was hypothesised that lap time would significantly correlate with the peak power output and lap $\dot{V}O_{2peak}$. Furthermore, blood lactate responses would positively associate with peak power production and post laps $\dot{V}O_{2peak}$.

Methods

Participants

Twelve nationally competitive male BMX riders participated in this study. Mean ± standard deviation (SD) of subjects' demographic data were: age 19.2 ± 3.5 years, height 1.76 ± 0.06 m, body mass 68.5 ± 4.3 kg. Subjects received written and verbal instruction regarding the risks and nature of the procedure and were asked to complete a training history questionnaire developed by the author, which identified that all had been actively involved in BMX for 5.0 ± 1.5 years. The average BMX track training time was 4.5 ± 1.5 h each week. This study was approved by the University of Canterbury's Human Ethics Committee (approval number: HEC 2018/83) and was carried out in accordance with the Declaration of Helsinki. Before commencement, all subjects completed the Physical Activity Readiness Questionnaire (PAR-Q) and provided their written consent. Parental written consent was obtained for subjects under 18 years old.

Experimental design

For testing the hypothesis, the correlations between $\dot{V}O_{2max}$, BMX lap $\dot{V}O_{2peak}$, lap time and power production were examined. To measure $\dot{V}O_{2max}$, a laboratory-based incremental intensity bike test to exhaustion was performed. This was followed a week later by simulated BMX race on a track, which included six laps interspersed by 15 min passive recoveries between each successive lap. Subjects were familiarised with the equipment and testing protocols before completing experimental testing sessions (Figure 1).

Anthropometric assessment

Stature was measured to the nearest centimetre with a wall-mounted stadiometer (Seca 213 stadiometer, Birmingham, UK) and mass was determined to within ± 0.1 kg with a digital weighing scale (Seca Quadra 808 digital scales, Birmingham, UK).

Maximum aerobic capacity ($\dot{V}O_{2max}$)

An incremental maximal cycle test was carried out on a Watt Bike Pro (Giant 2015, Nottingham, UK) which was calibrated according to the manufacturers' guidelines. The subjects performed a 6-minute warm-up at 100 W, power was then increased by 30 W per minute until volitional exhaustion occurred. The cadence and air resistance were set

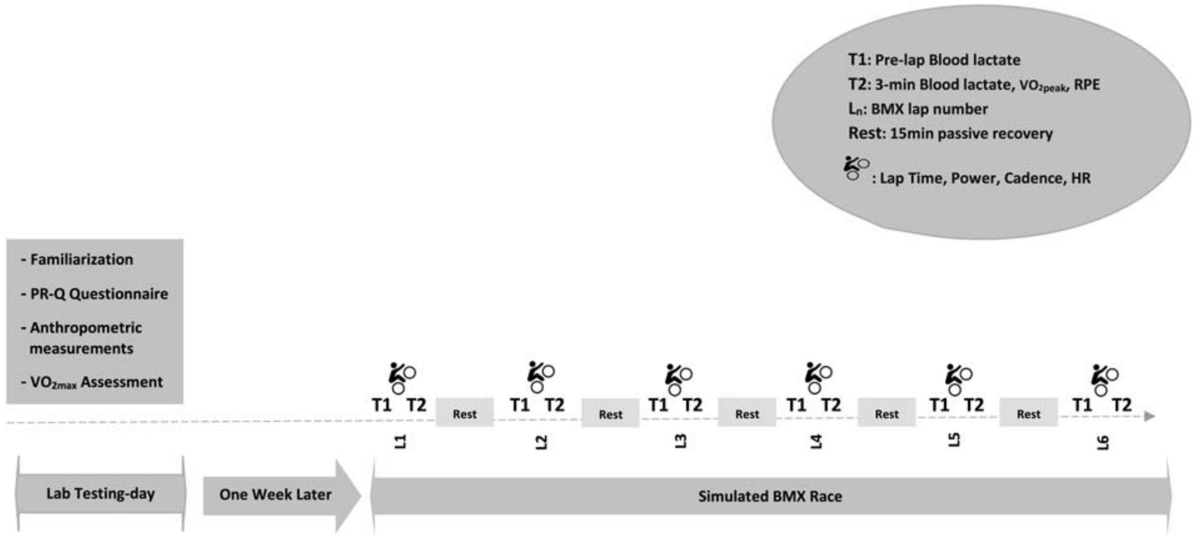

Figure 1. Simulated BMX race study design.

for each individual based on the manufacturer's guidelines for a maximal ramp test (Maximal Ramp Test, 2019). Heart rate (HR) was monitored using a GarminTM (Garmin®, Olathe, USA). Metabolic data were obtained during the test using a previously validated portable telemetric metabolimeter system Cosmed K5 (Cosmed, Rome, Italy), which was pre-calibrated following manufacturer's instructions. Before each test, the gas analyser was calibrated using a high-precision gas mixture (5.06% CO_2 and 16.02% O_2) and the spirometer with a 3-litre syringe (Hans Rudolf, Kansas City, MO, United States). Subjects were assumed to have achieved $\dot{V}O_{2max}$ if the following three criteria were met: (1) a plateau in $\dot{V}O_2$ despite an increase in power output, (2) a Respiratory Exchange Ratio (RER) above 1.1, and (3) > 90% of HR_{max} achieved during the test (Howley, Bassett, & Welch, 1995). $\dot{V}O_{2max}$ was considered to be the highest average 30 s of oxygen uptake. The peak power output was considered as the average cycling power recorded over the one minute period equating with $\dot{V}O_{2max}$ (Gastin & Lawson, 1994; Howley et al., 1995).

Simulated BMX race

The simulated race was carried out one week after the laboratory session on an outdoor track (342-meter and 28° gradient ramp), with three berms, four straights, and several technical jumps on each straight section. The simulated race was conducted in summer at a temperature of 19°C, the humidity of ~45%, and side wind speed of ~5 km/hr. Subjects were instructed to perform a warm-up to their preferences, consisting of 4–6 standing short sprints. They were then asked to complete six full laps as fast as possible from a 5-meter high start ramp using a standard electronic start gate. All subjects rode the same BMX bike (gear ratio of 43/16) fitted with a SRM BMX power meter crank (Schoberer Rad Messtechnik, Welldorf, Germany). The power meter had an eight strain gauge and a 175 mm crank arm. Prior to each test, the power meter was configured in combination with the SRM instructions. Data were downloaded using Power Control8 software (PC8DeviceAgent). To factor out the effect of body mass on power production, peak power to weight ratio (PWR) was calculated.

During the lap, HR was continuously monitored by the Garmin HR chest strap. The percentage of maximum HR obtained in the laboratory test was used for data analysis. Subjects undertook a 15-minute passive recovery between each lap as they typically undertaken in BMX race. The percentage lap time (LT) decrement (%Dec) was calculated using the following formula:

$$\%\mathrm{Dec} = \left(\frac{(\mathrm{LT}_{\mathrm{mean}} - \mathrm{LT}_{\mathrm{best}})}{\mathrm{LT}_{\mathrm{best}}}\right) \times 100,$$

where LT_{mean} = mean lap time and LT_{best} = fastest lap time of the 6 BMX laps (Oliver, 2009). Lap time was measured using two sets of photocells (NEOtm Swift Performance, Queensland, Australia) positioned at the start gate and on the finish line.

Oxygen uptake

The expired gases were analysed immediately after each lap using a Cosmed K5. A mask was fitted on each subject's face covering both their nose and mouth as soon as they crossed the finish line within the first 5 s post laps. Data were recorded during the first minute of recovery. The oxygen recovery curve was measured during the first 20 s to predict peak oxygen uptake ($\dot{V}O_{2peak}$) reached during the lap (Jalab, Enea, Delpech, & Bernard, 2011; Louis et al., 2013). Afterwards, the subjects' rating of perceived exertion (RPE) was recorded using the 0–10 Borg scale ranging from very very light (0) to exhaustion (10) (Borg, 1998).

Blood lactate

Blood lactate concentration ($mmol\,L^{-1}$) was measured using a Lactate Pro2 analyser (Arkray, Kyoto, Japan), where a finger prick was commenced immediately before (baseline value) and three minutes after each lap (Tanner, Fuller, & Ross, 2010). The blood lactate response (BLr) was defined as the difference between pre-lap and post-lap lactate measures.

Statistical analyses

Before analysis, data were tested for normality using a Kolmogorov–Smirnov test and all data were normally distributed. The Statistical Package for the Social Science (SPSS 25) was used to accomplish statistical procedures (SPSS, An IBM Company, Amarouk, NY) and the results are expressed as mean ± SD. Pearson Product-Moment correlations were used to assess the relationships between $\dot{V}O_{2max}$ from the incremental test and BMX race dependent variables including lap time, peak power, blood lactate, and $\dot{V}O_{2peak}$. While dependant variables were compared between successive laps (independent variable) using a repeated-measures ANOVA. Significant main effects were further analysed by Bonferroni adjusted post-hoc test. The level of significance was set at $p \leq 0.05$ except in the instance of a Bonferroni correction in which, 0.05 was divided by the number of comparisons.

Results

The lap time was increased throughout the simulated race, showing a significant effect of lap number, where L1 was faster than L2, L3, L4, L5, L6 and L2 faster than L4, L5, L6 $F(5, 55) = 29.39$, $p = 0.004$. $\dot{V}O_{2peak}$ reached more than 80% of $\dot{V}O_{2max}$ in each lap (mean 87 ± 4% $\dot{V}O_{2max}$), but there were no significant effect of lap number on $\dot{V}O_{2peak}$ $F(5, 55) = 3.41$, $p = 0.421$. As shown in Figure 2, there was a significant effect of lap number $F(5, 55) = 22.94$, $p = 0.012$ on post-lap blood lactate values (mean = 16.4 ± 2.5 $mmol \cdot L^{-1}$).

The correlation between blood lactate and subjects' performance are presented on a scatter plot (Figure 3A). Overall, we found a significant association between mean blood lactate response (BLr) with mean lap time ($r = 0.61$; $p = 0.004$), mean PWR ($r = -0.68$; $p = 0.002$) and mean $\dot{V}O_{2peak}$ post laps ($r = -0.70$; $p = 0.001$). In addition, as presented in Figure 3B, lap time was inversely correlated with subjects' mean PWR ($r = -0.81$, $p = 0.003$) as well as mean $\dot{V}O_{2peak}$ post laps ($r = -0.72$, $p = 0.001$).

The correlations between each lap time and physiological parameters are shown in Table I. LT_{best} was significantly associated with PWR ($r = -0.70$, $p < 0.003$), $\dot{V}O_{2peak}$ ($r = -0.67$, $p < 0.005$), BLr ($r = -0.67$, $p < 0.002$) and $\dot{V}O_{2max}$ ($r = -0.76$, $p < 0.004$). LT1 and LT2 showed a similar pattern and a significant correlation with PWR, $\dot{V}O_{2peak}$, and BLr. LT3 revealed no correlation with PWR, but a significant correlation with $\dot{V}O_{2peak}$ and BLr. LT4 and LT5 were significantly correlated with PWR, $\dot{V}O_{2peak}$, BLr and $\dot{V}O_{2max}$. Going through the final stage of the race, LT6 had poor correlation with PWR, but showed significant association with $\dot{V}O_{2peak}$, BLr and $\dot{V}O_{2max}$. There was no significant correlation for RPE and HR_{max} values with race time performance.

Discussion

This study found that: (a) BMX lap time was significantly correlated with mean PWR but the strength of this association decreased as successive laps were performed; (b) Subjects demonstrated a high contribution of aerobic metabolism during laps and showed a significant correlation with mean lap times. This association indicated an incremental trend; (c) Mean BLr was significantly correlated with mean lap time, and the correlation between BLr and time in each lap was stronger in the latter laps. According to our results, despite the short (~35 s) cycling time in each BMX lap, both aerobic and anaerobic energy systems were associated with performance.

Several reports have shown that peak power is one of the most important factors related with success in BMX (Daneshfar, Petersen, Koozehchian, et al., 2020; Grigg, Haakonssen, Orr, & Keogh, 2017; Rylands, Roberts, & Hurst, 2017). In line with our results, Bertucci and Hourde (2011) reported an

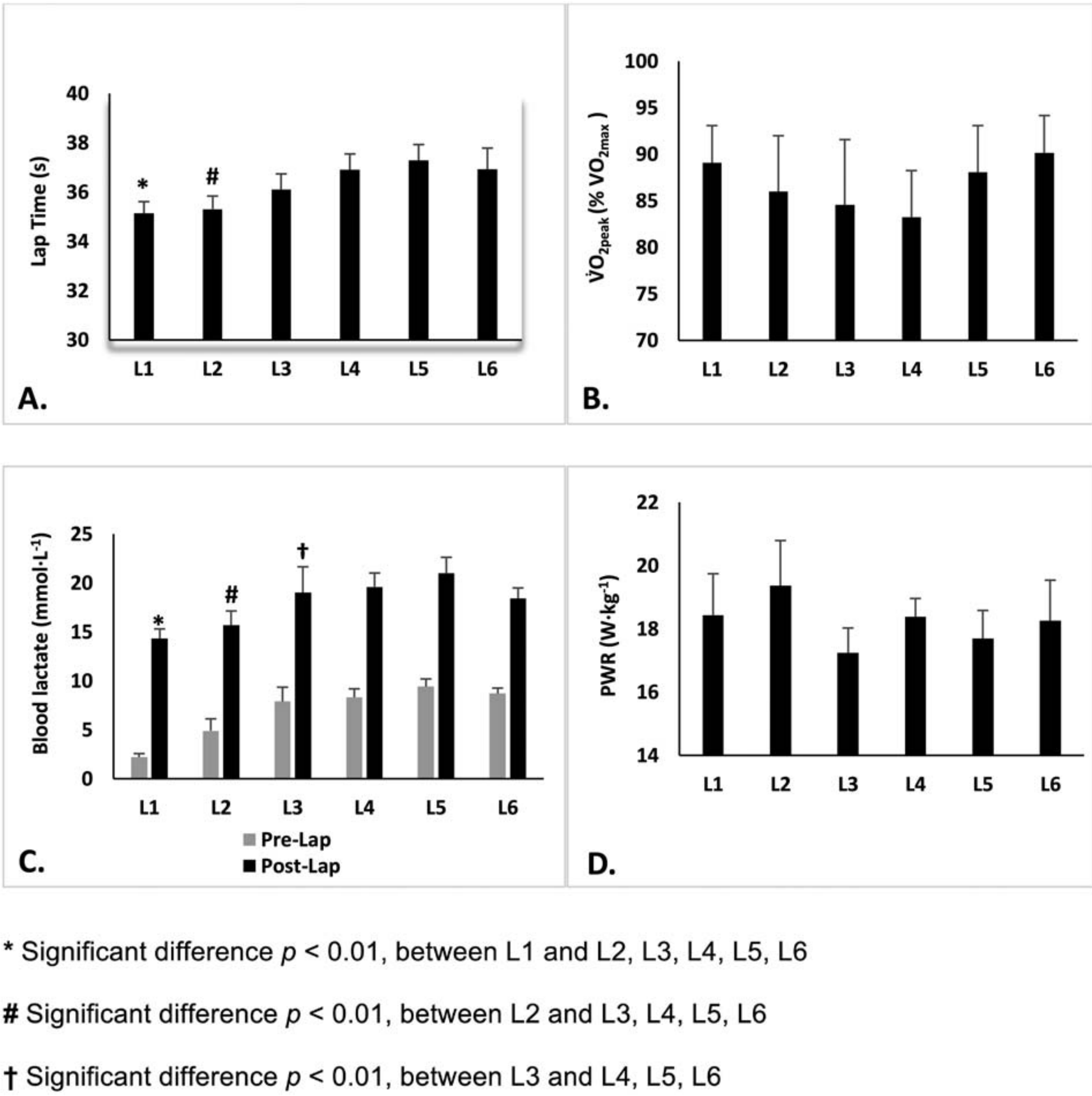

Figure 2. Simulated BMX race (Lap1–6) selected physiological components.

inverse correlation ($r = -0.67$) between PWR and sprint time in national level BMX riders over 75 m of the track (Initial Straightway).

More recently, Daneshfar, Petersen, Gahreman, and Knechtle (2020) reported that PWR of sub-elite riders $18.3 \pm 2.3\ \mathrm{W \cdot kg^{-1}}$ was significantly correlated with race time ($r = -0.68$). In the current study, PWR presented a strong correlation with the lap time ($r = -0.81$; $p = 0.003$). As the peak power occurred during the first 30 m of the track, our results were in agreement with Rylands and Roberts (2014) who concluded that riders' start performance were significantly correlated with the lap final placement. We measured riders' performance under simulated race condition, which increases the content validity and transferability of our results.

The results of the present study suggest that lap time has a significant correlation with post laps $\dot{V}O_{2peak}$ ($r = -0.72$; $p = .001$). Our results reflect those of Louis et al. (2013) who also used backward extrapolation to predict race $\dot{V}O_{2peak}$ amongst BMX riders. The authors concluded that elite BMX riders reach a very high relative $\dot{V}O_2$ during every lap (Mean $\dot{V}O_{2peak}$ $94 \pm 1\%$ of $\dot{V}O_{2max}$). A slightly lower value for mean $\dot{V}O_{2peak}$ in our study ($87 \pm 1\%$ $\dot{V}O_{2max}$), might be due to the differences in riders' aerobic capacity or their competitive level, which enabled them to perform at a greater

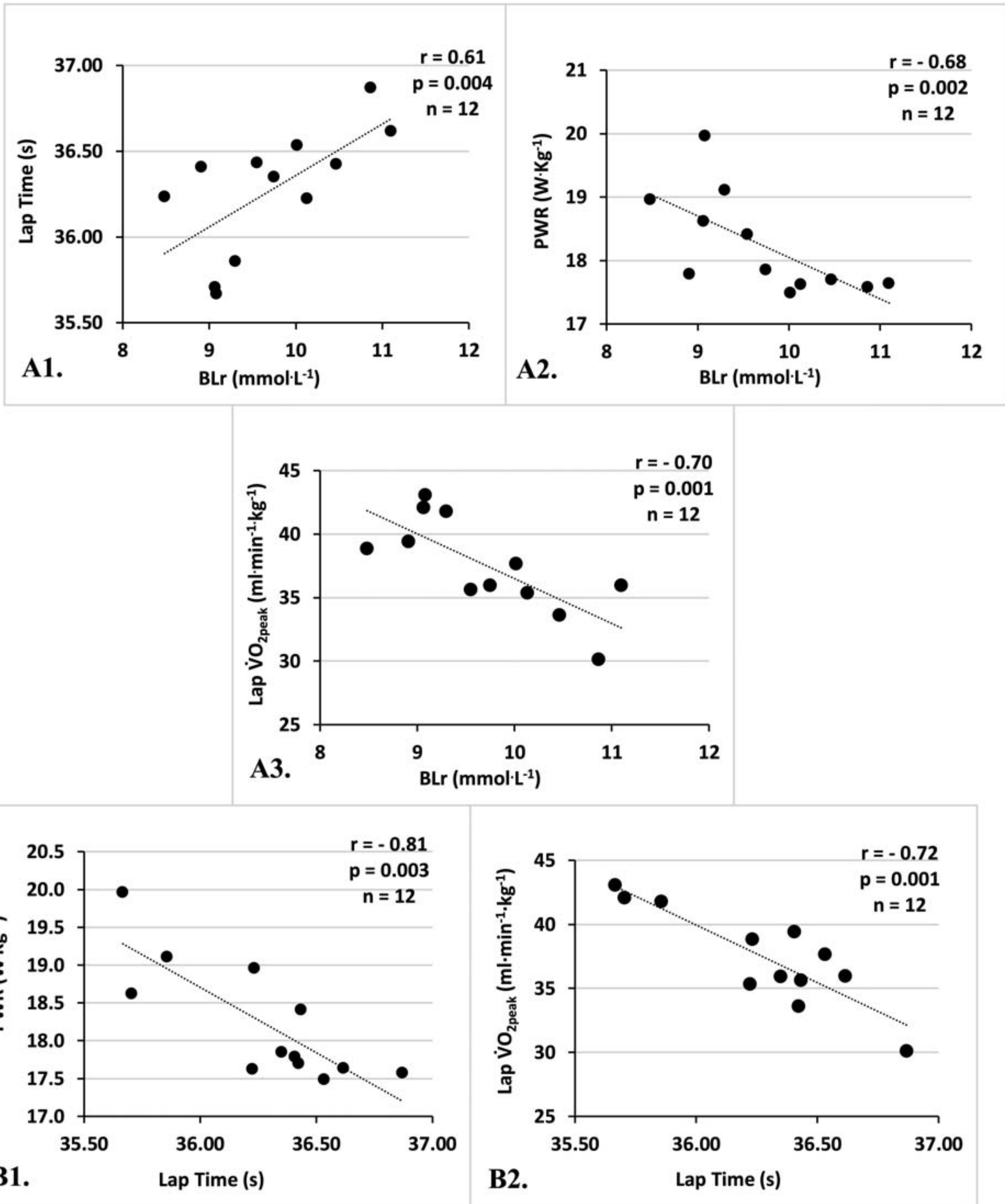

Figure 3. Scatter plot between mean BLr and (A1) mean lap time, (A2) mean PWR, and (A3) mean lap $\dot{V}O_{2peak}$. Mean lap time and (B1) mean PWR, (B2) mean lap $\dot{V}O_{2peak}$. BLr: difference blood lactate of pre and post laps, PWR: peak power to weight ratio of Lap1–6, Lap Time: finish time of Lap1–6, Lap $\dot{V}O_{2peak}$: $\dot{V}O_{2peak}$ measured post Lap1–6.

percentage of their maximum aerobic capacity. In addition, using a different tool (K4B2) and application of this equipment to measure $\dot{V}O_{2peak}$ in their study might potentially be another reason for different results. In the present study, we set out with the aim of determining the importance of metabolic pathways in BMX race performance. An incremental relationship was found between post laps $\dot{V}O_{2peak}$ with each individual lap time (R1–R6). In the earlier laps, riders' performance was more strongly associated with their anaerobic metabolism and sprint capacity; in contrast, during later

Table I. Relationship between BMX lap times with physiological variables.

	PWR	$\dot{V}O_{2peak}$	BLr	$\%HR_{max}$	RPE	$\dot{V}O_{2max}$
LT_{best}	−0.70*	−0.67*	0.67*	−0.25	0.35	−0.76**
%Dec	0.16	0.15	−0.37	0.20	−0.12	0.16
LT1	−0.70*	−0.54*	0.53*	−0.27	0.32	−0.35
LT2	−0.70*	−0.55*	0.55*	−0.02	0.45	−0.48
LT3	−0.38	−0.64*	0.56*	−0.35	0.14	−0.31
LT4	−0.60*	−0.66*	0.63*	−0.30	0.11	−0.55*
LT5	−0.53*	−0.69*	0.65*	−0.15	0.43	−0.68*
LT6	−0.38	−0.70*	0.68*	−0.09	−0.01	−0.79**

LT_{Best}: fastest time over 6 laps; %Dec: the percentage in a sprint decrement for the 6 laps; LT1–6: mean time to finish Lap1 to Lap6; PWR: mean peak power to weight ratio of 6 laps; $\dot{V}O_{2peak}$: mean $\dot{V}O_{2peak}$ of 6 laps; BLr: mean difference blood lactate of pre and post laps; $\%HR_{max}$: mean percentage of maximum heart rate; RPE: mean rating of perceived exertion of 6 laps; $\dot{V}O_{2max}$: mean maximum aerobic capacity measured in the lab; **: correlation is significant at the 0.01 level; *: correlation is significant at the 0.05 level

laps, their performance relied on aerobic metabolism. These results are in line with other researchers who have reported significant correlations between $\dot{V}O_{2max}$ and repeated-sprint ability (RSA) performance (Bishop & Edge, 2006; Pareja-Blanco et al., 2016). In general, a more developed aerobic capacity enabled the riders to recover faster and as a result, the riders' performance declined to a lesser degree. It is worth noting that to measure post-laps VO_2, there was some delay (>5 s) from crossing the finish line to wearing the mask, therefore, the first few seconds of oxygen recovery curve might be missing and potentially influenced the VO_{2peak} values.

Our results found a high metabolic demand in a BMX race, especially in the first 10–15 s of the race, where riders generated a great power output resulting in a large rate of force development. The high metabolic demands are extended due to the continued technical work and isometric efforts of the upper body, throughout the entire lap (Rylands, Hurst, Roberts, & Graydon, 2017). In line with previous studies that have investigated the impact of aerobic metabolism on RSA, oxidative metabolism can improve performance by increasing PCr resynthesize between multiple sprints (McGawley & Bishop, 2015). These findings assist BMX coaches and riders to better understand the importance of aerobic capacity in BMX, and consider this factor when developing training programmes. Further studies should aim to re-evaluate the importance of aerobic capacity in BMX race in athletes at various levels.

In the current study, the mean blood lactate values after each lap was 16.44 ± 1 mmol L^{-1} (mean BLr = 10 ± 0.6 mmol L^{-1}). This is in agreement with those obtained by Louis et al. (2013) who reported a high blood lactate concentration (14.5 ± 4.5 mmol L^{-1}) in elite BMX riders after six laps. More recently, Petruolo, Connolly, Bosio, Induni, and Rampinini (2020) also showed that the lactate levels in elite riders reached 12.9 ± 1.6 mmol L^{-1} following four laps of simulated BMX race. The authors concluded that the performance of the subsequent lap could be affected as post-lap blood lactate values did not completely recover over 30-min rest periods. The high lactate concentration reflects high anaerobic glycolysis across the BMX laps and confirms the importance of anaerobic energy system in repeated sprints bouts. Our results also presented a strong correlation between mean BLr with lap time (Figure 3A). This may raise the assumption that subjects who have achieved better performance in their BMX lap, are those who had higher lactate concentrations post laps as a result of the greater work intensity, as well as better lactate clearance capability during the recovery. Lactate removal is an oxygen-dependent process and it is known that endurance-trained individuals have a greater ability to remove lactate following intense exercise (McLester, Green, Wickwire, & Crews, 2008). Therefore, even if aerobic fitness does not directly improve a single lap time in BMX, potentially due to greater anaerobic energy demand, it is plausible that greater oxidative capacity contributes to improved cycling performance in successive laps.

The results of the current study provide further support for the hypothesis that the ability to repeatedly perform anaerobic efforts is an important determinant of maximal anaerobic performance (McGawley & Bishop, 2015). Similar to RSA, one of the most suggested factors that may impair performance is acidosis (increased hydrogen ions H^+). Prior studies applied induced alkalosis using bicarbonate to explore ways of improving performance (Zabala et al., 2008; Zabala, Sanchez-Munoz, & Mateo, 2009), but fail to report any positive effects on riders' sprint performance. More recently Peinado et al. (2019) in a field-simulated BMX did not report any ergogenic benefit of bicarbonate on BMX performance consisting of three laps separated by 15 min of recovery. In the current study, 61% of the lap time variation was explained by BLr. To better understand the role of acidosis during BMX laps, it is essential to consider the impact of aerobic fitness and recovery approaches undertaken after laps, which are known to influence the lactate removal and acidosis level. BMX coaches should also consider sprint interval training programmes inducing high metabolic stress to improve repeated laps via greater improvements in H^+ regulation, natural buffering system, and developing aerobic capacity (Gist, Fedewa, Dishman, & Cureton, 2014; Ramos-Campo et al., 2018).

In summary, according to the results of this study, despite the short cycling time in each BMX lap, both aerobic and anaerobic energy systems showed to be associated with riders' performance. BMX coaches and practitioners may consider the importance of these factors when designing conditioning programmes. While focusing on improving riders' lap time, peak power, and technique, they should also develop riders' aerobic capacity as it plays a critical role in overall BMX performance. Sprint interval training can be a useful method for improving successive BMX laps via greater improvements in H^+ regulation, natural buffering, and developing aerobic capacity. The current approach will prove useful in expanding our understanding of how different physio-metabolic variables play roles in BMX simulated race. Future research should consider using a greater number of subjects to compare the lap demands of female and male BMX riders, as well as comparing elite and national-regional riders' performance. In addition, applying different recovery methods for BMX race and determining their effect on performance is also worthy of investigation.

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No potential conflict of interest was reported by the authors.

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