LITERATURE REVIEW **Open Access**

Literature Review: Kinematics of the BMX Supercross Gate Start

Grigg, J.[1] ✉, Haakonsen, E.[2,3], Orr, R.[1] Keogh, JW.[1, 4, 5]

Abstract

The aim of this literature review was to identify the depth and scope of peer reviewed literature on rider kinematics of the Bicycle Motocross Supercross (BMX SX) gate start action, in particular literature that describes the optimal BMX SX gate start technique or relates to the prescription of training methods to improve performance. A pilot search was conducted to identify the optimal databases to use. Key search terms and inclusion and exclusion criteria were applied to select the articles of relevance which were then critically analysed using the Quality Assessment Tool for Observational and Cross-Sectional Studies. Two studies were retained for review. Both the studies were limited by number of participants and methodological rigour and scored poorly on the Quality Assessment Tool for Observational and Cross-Sectional Studies. No studies were found that correlated kinematic measures from the gate start action to gate start performance outcome. A secondary aim was to investigate the tactical importance of the gate start, power generation at the start of a BMX race and skill acquisition. Literature reported discrepancies between field and laboratory results which demonstrates the importance of ecologically valid research methodology. Despite evidence that the gate start is a critical component of the race with direct implications for race outcome, this review of the literature identified very limited research in the area of BMX rider kinematics of the BMX SX gate.

Keywords: cycling, kinematics, bicycle motocross, bicross

✉ jgrigg@bond.edu.au

[1]Faculty of Health Sciences and Medicine. Bond University, Gold Coast, Australia.
[2]Australian Institute of Sport, Canberra, Australia.
[3]Cycling Australia, High Performance Unit, Adelaide, Australia.
[4]Sports Performance Research Institute, New Zealand, AUT University, Auckland, New Zealand.
[5]Cluster for Health Improvement, Faculty of Science, Health, 6 Education and Engineering, University of the Sunshine Coast.

Received:18 April 2017. Accepted.18 May 2017.

Introduction

Bicycle motocross (BMX) was developed in the USA in the late 1960s as an alternative to motocross (Nash 1986). The first BMX racing tracks were inspired by motocross tracks and the bicycles were adapted into a new shape to suit the terrain. Throughout the next decade a new subculture formed around this novel form of cycling. BMX racing and BMX freestyle grew in popularity as competitive sports throughout the 1980s and gained a greater following via the medium of the newly created X Games (Nash 1986). In the 1990s, BMX was one of the fastest growing sports amongst youths aged 12-24 years (Honea 2013; Nelson 2010). While BMX racing has traditionally existed outside of the mainstream sporting world, in recent years this 'lifestyle sport' has entered the domain of mainstream sport (Nash 1986).

Academic BMX research began in the 1980s with a focus on injury mechanism and prevention (Brøgger-Jensen et al. 1990; Illingworth 1985; Stathakis 1997). Further areas of interest to researchers included the sociological context of the BMX subculture (Edwards and Corte 2010; Honea 2013; Rinehart and Grenfell 2002; Scott and Shafer 2001), and the bike itself (Manolova et al. 2010; Mateo-March et al. 2014; Mateo-March et al. 2012b).

With the inclusion of BMX in the 2008 Beijing Olympics, the profile of BMX Supercross (SX) racing rose and performance related research increased with studies into performance measurement tools such as power meters (Bertucci et al. 2013; Chiementin et al. 2013; Costa 2013), key components of the BMX race such as pumping and pedalling (Cowell 2011; Rylands et al. 2016a), physiological and psychological demands (Herman et al. 2009; Louis et al. 2013; Marquet et al. 2015; Mateo-March et al. 2012a; Mateo et al. 2012; Zabala et al. 2011; Zabala et al. 2008), skill acquisition (Zabala et al. 2009) and biomechanics including power generation, the difference between laboratory and field results, and rider kinematics (Bertucci and Hourde 2011; Bertucci et al. 2007; Chiementin et al. 2012; Gianikellis et al. 2011; Mateo-March et al. 2012b; Rylands et al. 2013; Rylands et al. 2016b; Rylands et al. 2016c; Zabala et al. 2009).

The start of the BMX SX race is critically important and has been shown to relate directly to race placings (Rylands and Roberts 2014). It is performed using a specific start protocol and start ramp design as directed by Cycling's governing body, the Union Cycliste Internationale (UCI) (Union Cycliste Internationale 2014b). The Olympic standard SX tracks have an 8 m high ramp with initial gradient of ~18° which changes to ~28° at ~3 m. The location on the ramp where this angle change occurs is often referred to as the 'kink' and is shown in Figure 1.

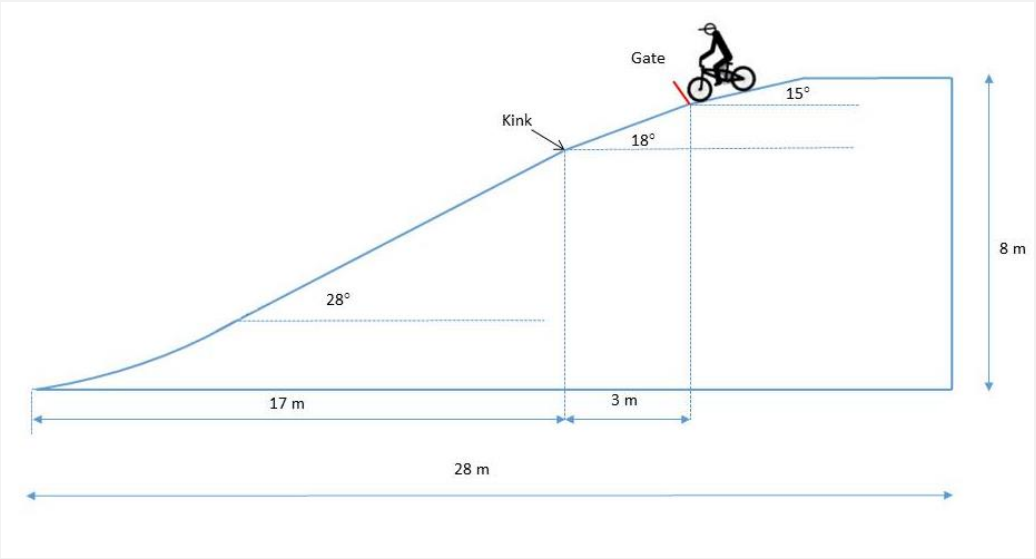

Figure 1. Supercross ramp design as specified by the UCI BMX Track Guidelines (Union Cycliste Internationale

Leading the race early enables a rider to pick the most advantageous line into the first jump (Mateo-March et al. 2014; Mateo et al. 2011; Zabala et al. 2009). Coaches and riders focus a large proportion of training time on improving the gate start action. This occurs not only at the track, but also by supplementing with gym based strength and power training movements that are believed to be functionally similar to the gate start action (Cowell et al. 2012a). Given the tactical importance of the race start, there is value in examining the rider kinematics of the gate start action and their relationship to performance in this key phase of the event. Enhancing knowledge of the optimal gate start action will guide coaches to provide valid technical feedback and may aid in the prescription of more functionally appropriate gym based training methods.

The aim of this literature review was to identify the depth and scope of peer reviewed published literature on rider kinematics of the BMX SX gate start action. Literature on the tactical importance of the gate start, power generation and skill acquisition were reviewed as a secondary aim because of their importance to coaching and training.

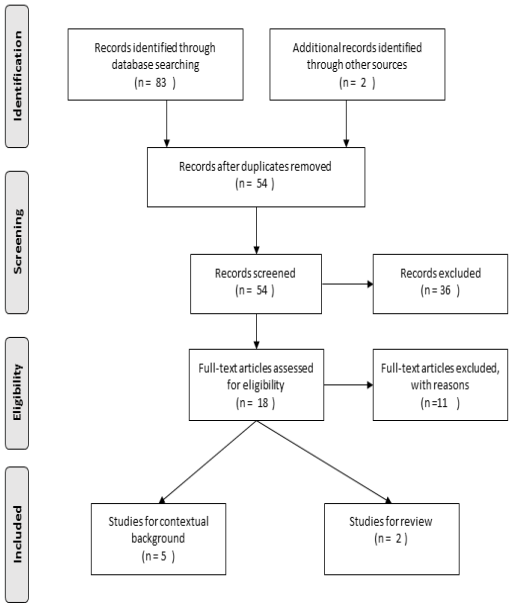

Figure 2. Search process flow chart

Search Method

A pilot search was conducted in AUSport, SPORTDiscus, ProQuest, GoogleScholar, Google, PubMed and Scopus to identify where suitable literature was most likely to be listed. Search terms were 'bmx' OR 'bicycle motorcross' OR 'bicycle motocross' AND 'cycling'. Adding the search term 'biomechanics' proved too restrictive in the pilot search as many studies in this area did not use this term as a key word or include it in the text. The term 'bicross' used in some European countries to refer to BMX racing did not yield any further results. Based on the number of returns from the pilot search, it was decided that SPORTDiscus, ProQuest and Scopus were the most suitable databases to search. Figure 2 outlines the review process. Further to the database searches, a search in Google Scholar was performed. Reference lists of retained articles were also reviewed for further relevant literature and a forward search was performed to identify any articles that cited the studies included in the review. All identified records were imported into Endnote and the duplicates were removed. The inclusion and exclusion criteria as outlined in Table 1 were applied. The quality of studies relating to rider kinematics were assessed by two assessors using the NIH National Heart, Lung, and Blood Institute: Quality Assessment Tool for Observational and Cross-Sectional Studies (National Institute of Health USA 2014). Studies that provided valuable information for contextual background were retained and discussed.

Table 1. Areas of research to be included in the literature for inclusion.

Inclusion criteria	Exclusion criteria
BMX cycling power generation	Not related to BMX racing, e.g. BMX freestyle
Gate start technique	Duplicates
BMX race start tactics	Not published in an academic journal
BMX race coaching methodology	No English translation available
BMX cycling biomechanics	

Results

As shown in Figure 2, 83 records were returned in September 2016. Kalichová et al. (2013) and Gianikellis et al. (2011) (see Table 2) were reviewed according to NIH National Heart, Lung, and Blood Institute: Quality Assessment Tool for Observational and Cross-Sectional Studies (National Institute of Health USA 2014) and were both found to be of 'poor' quality by both reviewers. While Zabala et al. (2009) demonstrated the usefulness of kinematic parameters in the administration of feedback to riders, this study was not included in the primary review as rider kinematics were not reported. Five publications were reviewed as part of the secondary aim relating to tactical importance of the gate start, power generation and skill acquisition (Bertucci and Hourde 2011; Cowell et al. 2012a; Mateo et al. 2011; Rylands et al. 2013; Zabala et al. 2009). These additional five studies are summarised in Table 3.

Discussion

The ultimate aim for a BMX rider is to win a race, with the results of Rylands and Roberts (2014) demonstrating a clear correlation between gate start performance and race outcome. While correlations do not necessarily identify causation, the demonstrated relationship between gate start performance and race outcome observe by Rylands and Roberts (2014) justifies further specific examination of the BMX gate start. Research on the gate start identified in this review can be grouped as relating to the kinematics of the gate start action, power generation and skill acquisition. A consensus around the optimal gate start action has not been demonstrated. A study investigating rider kinematics and their relationship to performance outcomes would assess the validity of theories proposed by experienced coaches and riders and may contribute greatly to coaching pedagogy and strength and conditioning programming methods for the sport of BMX.

Kinematics of the BMX Gate Start Action

The review process conducted for this study only identified two studies of BMX gate start biomechanics. These two studies described the forward movement of the bike (Gianikellis et al. 2011) and body segment movement (Kalichová et al. 2013) but did not relate findings to coachable quantitative performance factors such as timing splits. While the number of trials performed per rider was more than one, in each study only one trial per rider was reported. No validity or reliability data were referenced for the methodology used in either of these two studies. The first of these studies used an outdoor ramp with a 20° slope and rather than a UCI standard SX ramp as per Figure 1 (Gianikellis et al. 2011). This article gives an example of motion capture during the BMX gate start action and a preliminary analysis of kinematics during this action which could be used for further examination of this action. This study was limited by the small number of riders (n = 3), number of trials analysed (1 per rider), low frame rate (50 FPS) and the use of only two video cameras to construct the 3-D coordinates for the bike and rider. The digitisation process used 28 markers (21 on the body and 7 on the bike) to rectify a simple free body diagram in 3D.

A key parameter used by Giankellis et al. (2011) to describe the efficiency of the start was the position of the front hub relative to the front edge of the gate at two points in time: the start and when the gate landed flat to the ground. The action was divided into two phases: the start of the rider movement to when the gate starts to move; and the point at which the gate starts to move to when it lands flat to the surface of the ramp. Position, speed and acceleration at the gate landing were reported. The highest bike velocity in the anterior-posterior (horizontal) direction was 12.12 m/s. It was reported that when the gate began to fall, two of the riders were still moving in a backwards direction (-0.17 m/s and -0.55 m/s). In contrast, the rider that was moving forward when the gate started to fall had already reached their highest velocity in the backward direction (-1.95 m/s). This suggests that the aspect of the start action relating to navigating the bike over the falling gate was performed more efficiently by this rider, however the association between the rider action and total ramp time was not quantified. The range of knee flexion for two participants was reported (17° and 18°). It is reasonable to assume that the front leg was the reference leg, although this was not specified. Trunk flexion was reported for one rider as 15.18°, however it was not clear whether this was spinal flexion which is common during the gate start action, or change in angle of trunk segment. The rider with the least amount of knee flexion (value not reported) and most trunk flexion produced the highest vertical bike velocity. No statistical comparisons were performed between the riders and the smallest worthwhile difference in the kinematics is unclear. As data from only one trial per rider is reported, the magnitude of between-trial variability is also unknown. Angular results in this study were reported to two decimal places, however validity studies of 2D marker systems suggest that this methodology may not be sensitive to this level (Maykut et al. 2015). This study

provides some preliminary evidence that a larger range of movement in the trunk and smaller range of movement at the knee may produce result in a faster gate start. While this study provides some very general parameters around gate start kinematics, in the absence of a more robust comparison to performance and no validity or reliability data, it is difficult to take meaningful outcomes from this work to apply in practice.

Kalichová et al. (2013) studied BMX gate start kinematics of two riders. Five trials were completed by one elite male and one elite female on a gate with a ramp of unreported gradient. Only the fastest trial for each rider was analysed. Two 100 FPS cameras were used to record the motion and a 3D model was constructed based on markers at the wrist, shoulder, hips, knees, ankle and elbows on each side of the body (12 markers in total).

The gate start action was divided into five phases for biomechanical analysis as shown in Table 4. Movement descriptors including instantaneous velocities and joint angles were reported at the beginning and end of each phase for the shoulder, hip and knee. From the angles reported, the range of motion of the shoulders varied from 37° to 65°; hips: 30° to 66°; and knees: 63° to 78°. The study results shows a clear asymmetry in the shoulders and elbow, however as only one trial was reported the generalisability of these results is not clear. urther research in the area of upper body symmetry may be warranted. The reported knee range of motion is significantly different to the 17° and 18° degrees reported for the two riders by Giankellis et al. (2011), which may be due to different analysis protocols.

Kalichová et al. (2013) refers to the 'ideal technique' and the potential to use kinematic analysis in a coaching environment to provide quantitative feedback with the aim of improving performance. Kinematic parameters that constitute an 'ideal technique' are not quantified and objective information for the optimal gate start technique is not given in Kalichová et al. (2013) or any other known studies.

It was acknowledged by both assessors using the Quality Assessment Tool for Observational and Cross-Sectional Studies that Giankellis et al. (2011) and Kalichová et al. (2013) are better described as case studies rather than true observational studies because of the limited number of participants. There was limited detail in terms of the participants and data analysis procedures. These studies represent valuable preliminary investigations but were insufficiently powered in terms of participant and trial number to be able to provide a detailed kinematic description of the BMX gate start or its relation to performance. If more than one trial per rider had been analysed, then consistency of movement and associations between movement characteristics and performance could have been investigated. The limitations of Giankellis et al. (2011) and Kalichová et al. (2013) in regards to the number of participant and trials analysed make it difficult to draw specific outcomes that can be applied to enhance the training of BMX riders. A consistent finding from both studies was that the rider able to generate the greatest peak velocity reached the target destination first.

There are many factors that may possibly influence BMX gate start kinematics. Parameters such as rider anthropometry may be important in this context as the BMX bike dimensions do not vary greatly between bikes (top tube lengths vary by ~5cm), so riders of varying sizes need to self-organise around the bike. The influence of gender, age, strength or experience on BMX rider kinematics also remains unknown in the scientific literature. Similar investigations in other human movements such as walking gait have used statistical tools such as regression, principle component analysis and hierarchical modelling to identify kinematic parameters that effect performance (Chow and Knudson 2011; Knudson 2009). These processes may be used in BMX studies to help to identify critical kinematics parameters worthy of further investigation. An improved understanding of these parameters would be useful in BMX coaching as it would aid in providing a more targeted focus in training and may improve the validity of performance feedback. More rigorous study into the kinematics of the BMX gate start action may provide insight into movement characteristics that optimise performance.

Importance of the Gate Start in BMX SX Racing

Riders and coaches alike agree that the start of the BMX race is critical to overall race performance. Trailing riders are more likely to make contact with other riders which can result in race-ending collisions (Mateo-March et al. 2014; Mateo et al. 2011; Zabala et al. 2009). Rylands and Roberts (2014) investigated placings at four time splits within four different 2012 World Cup events (Canada, Holland, Norway and USA). The first time split was typically at a point on the ramp and the last was at the finish line. Riders who placed 1st, 2nd and 3rd at the first split were more likely to achieve a top 3 ranking at the end of the race (Kendall's tau-b bivariate correlation (τ=0.586, P<0.01). Race finish placing is important even in the preliminary qualifying heats (Motos) of competitions. Whilst the top four qualifiers progress to the next round (depending on the number of starters), the order in which they finish and lap time can impact lane selection privileges. Thus, much of the track based training as well as strength and conditioning training is focussed on improving the gate start action (Cowell 2011; Cowell et al. 2012a; Cowell et al. 2012b).

Power studies in BMX

The gate start action is a fast, forceful movement. Therefore, studies examining the relationship between muscular power development and gate start performance may provide insight into critical factors that influence gate start performance. Bertucci and Hourde (2011) have shown a strong correlation ($r > 0.70$) between performance in the first straight and other measures of performance such as peak power output generated during stationary cycling on an ergometer, squat jump and counter movement jump performance. Strength and conditioning coaches may benefit from greater quantitative data on the muscle activation and/or

Table 2. Literature on the kinematics of the BMX gate start

Author Date	Main Aim	n	Setting	Kinematic parameters	Trials	Equipment	Validity and reliability of methodology	Statistics	Finding Summary
Gianikellis, Skiadopolous & Bote (2011)	Evaluate gate start technique of three riders and examine influence of individual characteristics	3 int Gender – NR Age – NR Training – NR Mass – NR	Training track 20º slope	Displacement (m) Velocity (m/s) Joint Angle (°) Segment Angle (°)	Number performed - 5 Fasted 1 reported	2 S-VHS video cameras (Panasonic AG-DP800H, AG-DP200E) Frame rate – 50 fps Kinescan/IBV 3D video photogrammetry system (version NR) Markerless 28 digitised points (bike and rider)	NR	All information reported per participant. No summary information	Preliminary study only. Each rider had their own individual technique and should be coached accordingly
Kalichová et al. (2013)	Describe dominant movements throughout defined phases of the gate start in a small sample – pilot study	2 int 1 male 1 female Age – 21,22 Training – 14, 14 years Mass – 88, 65 kg	NR	Temporal (s) Joint Angle (°) Joint velocities (m/s)	Number performed -NR Fastest 1 reported	2 Camera (not specified) Camera placement NR Frame rate – 100fps SIMI Motion software (version NR) Reflex marks (sic) 7 markers (rider)	NR	All information reported per participant. No summary information	Preliminary study only. Gate start action defined in 5 distinct phases each with distinctive kinematics

NR = not reported

Table 3. Significant literature on the BMX Gate Start

Author Date	n	Discipline	Outcome Measures	Design	Finding
Bertucci (2011)	9 int 17 nat	Physiology	Vertical jump (cm) Sprint cycling test (W; W/kg) Wingate test (W; W/kg)	Cohort - descriptive	Correlation existed between squat jump, countermovement jump, seated sprint test, standing sprint test, seated Wingate test, and standing Wingate test.
Cowell, McGuigan & Cronin (2012a)		Strength and conditioning		Educated opinion	Recommended strength training exercises for BMX riders with a focus on appropriate rate of force development.
Mateo, Blasco-Lafarga & Zabala (2011)	9 int	Biomechanics Physiology	Cycling power at the pedal (W) Bike speed (m/s) 3 different types of race tracks	Cohort - descriptive	Peak pedalling power as measured on an ergometer was not matched during gate start, suggesting that application of technique was critical during the start phase.
Rylands et al. (2013)	7 int	Biomechanics Physiology	Peak power (W; W/kg) Velocity at peak power (m/s) Cadence at peak power (rpm) Mean fatigue index where Fi (W/s) = (peak power – minimal power)/time (s)	Cohort - descriptive	In a 50m sprint test, the BMX riders' absolute (W) and relative (W/kg) peak pedalling power (21.29 ± 0.84 W/kg) were similar to those reported in other sprint cycling disciplines such as track sprint (21.83 ± 0.76 W/kg; (Gardner et al. 2005). BMX riders fatigued earlier. Once peak power was reached, velocity was controlled by cadence.
Zabala, Sánchez-Muñoz & Mateo (2009)	6 int	Motor learning	Time to 4.5 m from gate start (s)	Cohort – intervention (no control)	Audio-visual and coaching feedback during a gate training session improved gate - 4.5 m time (pre-treatment: 1.264 ± 0.045 s; post-treatment: 1.047 ± 0.019 s). Improvements remained 2 weeks after treatment (1.041 ± 0.021 s). Initial times were 1.264 ± 0.045 s, which reduced to 1.047 ± 0.019 s after treatment and was 1.041 ± 0.021 s in the retention test.

Int = international competitor, Nat = national competitor, rpm = revolutions per minute.

Table 4. Kalichová et al. (2013) divided the gate start into these five phases.

Phase	Characteristic
1. Reaction time	Assume set position
2. Preparation movement	All movement before initiation of first pedal stroke
3. First pedal stroke	Starts at initiation of first pedal stroke and finishes when the cranks are parallel to the direction of gravity i.e. vertical
4. Dead point pedal passage	Time between first and second pedal stroke
5. Second pedal stroke	From point where pedal begins to move forward to end of second pedal (i.e. where crank is vertical again)

pedal forces produced during the BMX gate start to better match specific strength and conditioning exercises to this activity.

Recognising that the SX race start is an explosive action, Debraux and Bertucci (2011) aimed to define factors determining sprint performance. This showed the importance of understanding the relationship between power, cadence and gearing; however, studies to date have been limited by the availability of suitable valid and reliable power meters. Power has been measured using different power meters on a BMX, but the results may be limited by low sample rates. The SRM Powermeter (Schoberer Rad Messtechnik, Germany) and PowerTap (PowerTap, USA) were developed for road racing conditions were a low sample rate is used over extended periods (hours). The G-Cog (Rennen Design Group, USA) was the first power meter marketed specifically for use on a BMX and provides data sampling at 250 Hz. Bertucci and colleagues tested the validity and reliability of the G-Cog power meter and found that the results did not correlate with those obtained from the SRM (Bertucci et al. 2013). A response to this research was written by the manufacturers of the G-Cog suggesting that the use of a 2Hz signal (as per the SRM) to validate the 250 Hz signal (as per the G-Cog) is not reasonable (Costa 2013).

A power – cadence profile highlighted the importance of a smooth pedalling technique in order to optimise power (Chiementin et al. 2012). A power:cadence profile for 7 elite BMX riders sprinting on a flat 80 m track was created using a PowerTap powermeter (CycleOps, Madisson, WI, USA) with an undisclosed sample rate (Debraux and Bertucci 2011). This study suggested that the optimal cadence for peak power was ~ 120 rpm. This is consistent in other studies that measured optimal cadence for peak power with sprint cyclists using 6 s cycle ergometer trials (128 ± 7 rpm) and 65 m track trials (129 ± 9 rpm) for sprint cyclists (Gardner et al. 2007). Likewise, Martin et al. (2000) reported average values of 124 ± 8 rpm in a large sample of subjects (n = 86; 12-40y). Rylands et al. (2013) discussed the impact of gearing as it relates to velocity generation and power generation in sprint events. During a 50 m maximal sprint test, BMX riders produced average (±SD) peak powers of 1030 W for 1 female and 1539 ± 148 W for 5 males. BMX riders typically generated more power in the sprint test than on the BMX track (the same bike setups were used for both tests). An important observation was that once BMX riders reached top speed they relied upon cadence to maintain bike velocity, highlighting the impact of gearing selection. Gearing choice is often optimised for gate start performance and the cadence quickly exceeds that which is optimal for power production (Rylands and Roberts 2014; Rylands et al. 2013). The impact of gearing, the fact that its selection is aimed at optimising start performance and that it remains unchanged throughout the race (generally single speed), suggests that factors that affect the gain ratio (gearing, crank length, exact tire circumference) should be reported in rider kinematic studies as they will certainly impact on the power cadence relationship.

Mateo, Blasco-Lafarga and Zabala (2011) showed that peak power did not occur during the first movements of the gate start action, but within the first 2 s of the start. In this study, riders performed a peak power output test on a stationary ergometer first which was compared to peak power output measure during the gate start. Riders then completed full-laps under three different conditions (no pedalling, gate start only pedalling, free pedalling) all on three tracks of varying technical difficulty. Power and average velocity were both measured using a PowerTap SL 2.4 powermeter (CycleOps, Madisson, WI, USA). The initial part of the race was described as strongly influenced by determinants of acceleration including slope of the ramp, and power generation. Peak power occurred in this phase, but not necessarily on the ramp, for all three tracks, with the average time to peak power being 1.42 ± 0.02 s, a point typically on the upward incline of the first jump, with a coefficient of variation of 2.5% across all results. This emphasises the importance of using a SX ramp that complies with UCI standards to specifically inform SX coaching, training and testing methodology. Limitations in power measuring technology must be considered when measuring time to peak power and other metrics such as peak torque. These are likely to be heavily influenced by the time it takes for the power meter to begin recording from a standing start as well as the sampling frequency and placement of the read switches on the power meter.

Cowell et al. (2012a) used the results of such studies to advocate power training for BMX riders. The importance of matching the component movements of the gate start action to gym based activities such as a dead lift is highlighted. Further analysis of the kinematics of the gate start action would benefit such an analysis as aspects such as range of motion could be used to design gym based power development with greater specificity.

Skill Acquisition

Zabala, Sanchez-Munoz and Mateo (2009) looked at the importance of providing augmented feedback during a gate start training session for 6 elite riders. Augmented feedback was divided into knowledge of performance and knowledge of results. Knowledge of results is feedback relating to the outcome of the task, rather than technical aspects that may have contributed to task outcome. In this instance knowledge of results was the start - 4.5 m timing split. Knowledge of performance was given in the form of information about how the task was performed, such as the angle of the head, speed of the second crank and maximum angle of the torso. Video feedback was also used to relay information about performance to the rider. The impact of the intervention was measured immediately, 2 days and then 2 weeks post intervention. All participants received the intervention. The results clearly showed a significant reduction in time to 4.5 m after two feedback sessions for each of the individuals as well as the group mean results (average time 1.27 ± 0.05 s reduced to 1.04 ± 0.04 s). This learning effect was maintained when retested two weeks later. A limitation of this study was that it did not include a control condition involving only task-intrinsic feedback or compare different forms of augmented feedback. It is therefore unclear whether the augmented feedback was more effective than task intrinsic feedback, and if so, what form of augmented feedback would provide the greatest benefit. This study suggests that quantitative knowledge of performance including the use of kinematic parameters, may improve gate start performance outcome i.e. reduction in time split.

Conclusions

In conclusion, there is little published research in the area of BMX rider kinematics. Existing research in this area is exploratory only and uses small sample sizes and non-SX regulation gates. As yet there are no well controlled studies that describe the kinematic movement characteristics that optimise gate start performance. Research has demonstrated the importance of ecologically valid and reliable quantitative kinematics data that can be used to augment feedback for performance improvement (Zabala et al. 2009). Future research into valid methods of measuring rider kinematics and kinetics during the SX gate start would open pathways into investigation in these areas. Clear association between kinematic characteristics and gate start performance would be useful for coaches. It is expected that the strength of these relationships may depend upon a range of factors such as rider anthropometry and gearing, particularly in BMX because of the bike dimensions. In order to create ecologically valid information, it is important to collect data in the environment in which the results are to be applied. The BMX gate start is a more dynamic movement than those observed in other cycling disciplines and is unlikely to be effectively replicated on a stationary ergometer. If field based testing is used as an alternative, and aim is to collect date that is meaningful to the SX gate start, the research data should to be collected on a UCI regulation 8 m gate. The literature in this area is expected to increase with the continued growth of BMX SX as a participation and spectator sport, with an increasing presence in the mainstream sporting world.

Acknowledgement

The authors wish to acknowledge BMX Australia High Performance Unit Coach Wade Bootes and the BMX Australia High Performance Program and Development Academy riders for their input and participation.

Conflict of interest

None of the authors have any financial interest or benefit arising from the direct applications of their research.

References

1. Bertucci W, Crequy S, Chiementin X (2013) Validity and reliability of the G-Cog BMX powermeter. International Journal of Sports Medicine 34: 538-543
2. Bertucci W, Hourde C (2011) Laboratory testing and field performance in BMX riders. Journal of Sports Science and Medicine 10: 417-419
3. Bertucci W, Hourde C, Manolova A, Vettoretti F (2007) Mechanical performance factors of the bmx acceleration phase in trained riders. Science and Sports 22: 179-181
4. Brøgger-Jensen T, Hvass I, Bugge S (1990) Injuries at the BMX Cycling European Championship, 1989. British Journal of Sports Medicine 24: 269-270
5. Chiementin X, Crequy S, Bertucci W (2013) Validity and Reliability of the G-Cog Device for Kinematic Measurements. International Journal of Sports Medicine 34: 945-949
6. Chiementin X, Crequy S, Rasolofondraibe L, Bertucci W (2012) New performance indicators for BMX riders. Computer Methods in Biomechanics and Biomedical Engineering 15 Suppl 1: 218-219
7. Chow JW, Knudson DV (2011) Use of deterministic models in sports and exercise biomechanics research. Sports biomechanics 10: 219-233
8. Costa G (2013) G Cog Research. RennenDesignGroup, USA
9. Cowell JF (2011) Time motion analysis of Supercross BMX Racing. Journal of Sports Science & Medicine 10: 420-421
10. Cowell JF, McGuigan M, Cronin J (2012a) Strength Training Considerations for the Bicycle Motocross Athlete. Strength & Conditioning Journal 34: 1-7
11. Cowell JF, McGuigan MR, Cronin JB (2012b) Movement and skill analysis of supercross bicycle motocross. Journal of Strength and Conditioning Research 26: 1688-1694
12. Debraux P, Bertucci W (2011) Determining factors of the sprint performance in highlevel BMX riders. Computer Methods in Biomechanics and Biomedical Engineering 14: 53-55
13. Edwards B, Corte U (2010) Commercialization and lifestyle sport: lessons from 20 years of freestyle BMX in 'Pro-Town, USA'. Sport in Society 13: 1135-1151
14. Gardner AS, Martin DT, Barras M, Jenkins DG, Hahn AG (2005) Power output demands of elite track sprint cycling. International Journal of Performance Analysis in Sport 5: 149-154
15. Gardner AS, Martin JC, Martin DT, Barras M, Jenkins DG (2007) Maximal torque- and power-pedaling rate relationships for elite sprint cyclists in laboratory and field tests. Eur J Appl Physiol 101: 287-292
16. Gianikellis K, Skiadopoulos A, Bote A (2011) 3D Kinematics applied to the study of individual BMX Gate Start Technique. Portuguese Journal of Sport Sciences 11: 251-254
17. Herman CW, McGregor SJ, Allen H, Bollt EM (2009) Power Capabilities Of Elite Bicycle Motocross (BMX) Racers During Field Testing In Preparation For 2008 Olympics. Medicine & Science in Sports & Exercise 41: 306-307

18. Honea JC (2013) Beyond the Alternative vs. Mainstream Dichotomy: Olympic BMX and the Future of Action Sports. Journal of Popular Culture 46: 1253-1275
19. Illingworth CM (1985) BMX compared with ordinary bicycle accidents. Archives of Disease in Childhood 60: 461-464
20. Kalichová M, Hřebíčková S, Labounková R, Hedbávný P, Bago G (2013) Biomechanics Analysis of Bicross Start. International Journal of Medical, Health, Pharmaceutical and Biomedical Engineering 7: 361-369
21. Knudson D (2009) Significant and meaningful effects in sports biomechanics research. Sports biomechanics 8: 96-104
22. Louis J, Billaut F, Bernad T, Vettoretti F, Hausswirth C, Brisswalter J (2013) Physiological Demands of a Simulated BMX Competition. International Journal of Sports Medicine 34: 491-496
23. Manolova A, Debraux P, Bertucci W (2010) Poster Session I, July 14th 2010 — Abstracts Strain in BMX frame through different tests. Procedia Engineering 2: 3433
24. Marquet L-A, Hausswirth C, Hays A, Vettoretti F, Brisswalter J (2015) Comparison of Between-Training-Sessions Recovery Strategies for World-Class BMX Pilots. International Journal of Sports Physiology & Performance 10: 219-223
25. Mateo-March M, Fernández-Peña E, Blasco-Lafarga C, Morente-Sánchez J, Zabala M (2014) Does a non-circular chainring improve performance in the bicycle motocross cycling start sprint? Journal of Sports Science and Medicine 13: 97-104
26. Mateo-March M, Zabala M, Blasco-Lafarga C, Guzmán JF (2012a) Blood lactate concentration versus design and difficulty of the track in BMX. Revista Internacional de Medicina y Ciencias de la Actividad Fisica y del Deporte 12: 52-66
27. Mateo-March M, Zabala M, González-Badillo JJ (2012b) Effects of the orientation of the maximum torque point with a Q-Ring™ non-circular chainring system on the BMX cycling sprint performance. / Effets de l'orientation du point maximum de couple avec un plateau non-circulaire Q-Ring (OCP) dans la performance d'une course de BMX. Science & Sports 27: e15-e19
28. Mateo M, Blasco-Lafarga C, Martínez-Navarro I, Guzmán J, Zabala M (2012) Heart rate variability and pre-competitive anxiety in BMX discipline. European Journal of Applied Physiology 112: 113-123
29. Mateo M, Blasco-Lafarga C, Zabala M (2011) Pedaling power and speed production vs. technical factors and track difficulty in bicycle motocross cycling. Journal of Strength and Conditioning Research 25: 3248-3256
30. Maykut JN, Taylor-Haas JA, Paterno MV, DiCesare CA, Ford KR (2015) Concurrent validity and reliability of 2D kinematic abalysis of frontal plane motion during running. International Journal of Sports Physical Therapy 10: 136-146
31. Nash JE (1986) Expensive Dirt: Bicycle Motocross and Everyday Life. Journal of Popular Culture 20: 97-122
32. National Institute of Health USA (2014) Health NIo: Quality assessment tool for observational cohort and cross-sectional studies. Systematic Evidence Reviews and Clinical Practice Guidelines. National Heart, Lung and Blood Institute, Maryland, USA
33. Nelson W (2010) The historical mediatization of BMX-freestyle cycling. Sport in Society 13: 1152-1169
34. Rinehart R, Grenfell C (2002) BMX Spaces: Children's Grass Roots' Courses and Corporate-Sponsored Tracks. Sociology of Sport Journal 19: 302-314
35. Rylands L, Roberts SJ (2014) Relationship between starting and finishing position in World Cup BMX racing. International Journal of Performance Analysis in Sport 14: 14-23
36. Rylands L, Roberts SJ, 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: 40-50
37. Rylands LP, Hurst HT, Roberts SJ, Graydon R (2016a) The effect of 'Pumping' and 'Non-pumping' techniques on velocity production and muscle activity during field-based BMX cycling. Journal of Strength and Conditioning Research: 1
38. Rylands LP, Roberts SJ, Hurst HT (2016b) Effect of gear ratio on peak power and time to peak power in BMX cyclists. European Journal of Sport Science: 1-5
39. Rylands LP, Roberts SJ, Hurst HT, Bentley I (2016c) Effect of cadence selection on peak power and time of power production in elite BMX riders: A laboratory based study. Journal of Sports Sciences: 1-5
40. Scott D, Shafer CS (2001) A rejoinder to reviewers' comments. Journal of Leisure Research 33: 357-361
41. Stathakis V (1997) Recreational injury to older children (10-14 year olds): BMX bicyclist injury to older children. Australia, p. 9
42. Union Cycliste Internationale (2014a) BMX Track Guide. BMX Track Guide. Union Cycliste Internationale, Aigle
43. Union Cycliste Internationale (2014b) Part 6 BMX. UCI Cycling Regulations. Union Cycliste Internationale, Aigle
44. Zabala M, Peinado A, Calderón F, Sampedro J, Castillo M, Benito P (2011) Bicarbonate ingestion has no ergogenic effect on consecutive all out sprint tests in BMX elite cyclists. European Journal of Applied Physiology 111: 3127-3134
45. Zabala M, Requena B, Sanchez-Munoz C, GonzáLez-Badillo JJ, García I, Ööpik V, Pääsuke M (2008) Effects of sodium bicarbonate ingestion on performance and perceptual responses in a laboratory-simulated bmx cycling qualification series. Journal of Strength and Conditioning Research 22: 1645-1653
46. Zabala M, Sánchez-Muñoz C, Mateo M (2009) Effects of the administration of feedback on performance of the BMX cycling gate start. Journal of Sports Science and Medicine 8: 393-400