KINEMATICS OF THE BMX SX GATE START ACTION

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The purpose of this study was to identify the sagittal range of motion across five joints and two body segments during the first three cranks of the BMX SX gate start, and to identify difference between females and males across these seven variables. This was achieved with markerless motion capture of 10 athletes, analysing three maximum effort gate starts using a motion capture and data analysis method previously validated in literature. It was found that the average range of motion for the trunk segment was 39 ± 6°, head segment was 38 ± 35°, shoulder joint was 87 ± 7°, elbow joint was 47 ± 15°, hip joint was 62 ± 11°, knee joint was 93 ± 12° and ankle joint was 58 ± 14°. Further analysis showed a statistically significant difference between females and males. This information can be further used to advise strength and conditioning prescription and to assess movement maturation.

KEYWORDS: cycling, performance analysis, motion capture, gender difference.

INTRODUCTION: In collaboration with coaches and athletes, this study aimed to determine sagittal range of motion during the BMX supercross (SX) gate start action in high performance athletes. The kink time, defined as the time split where the start ramp gradient alters from ~ 18 to ~ 28° (~ 3m from the start gate) is a key performance outcome of this action. The kink time is considered significant by coaches and athletes as a mere handlebar depth advantage at the kink enables an athlete to choose their preferred line into the first jump. Research has shown that the rider able to land the first jump first is most likely to win the entire race (Rylands & Roberts, 2014). Kinematic analysis of movement was chosen as it has been used to characterise movement performance across many different sports. It has proven useful for determining optimal movement patterns, attractor states, movement maturation, and likelihood of movement related injury (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2014). Such analysis is relatively recent in the sport of BMX SX racing (Grigg, Haakonssen, Orr, & Keogh, 2017). Recent work by Gross, Schellenberg, Lüthi, Baker, and Lorenzetti (2017) used 3D motion capture to measure lower body kinematics of the gate start action. Their novel undertaking laid significant ground work for research in this area.
The study presented here used markerless motion capture, an inexpensive, valid and reliable method of measuring sagittal kinematics of the hip, knee, ankle, shoulder and elbow joints, and the trunk and head segments (Grigg, Haakonssen, Rathbone, Orr, & Keogh, 2017). The purpose of this analysis was to begin to understand the relationship between this complex movement performance and the kink time. The second purpose of this analysis was to determine if there was a significant difference between male and female athletes' kinematics during the gate start action. Typically, females and males train for the gate start together, receiving the same technical training. It has been assumed by athletes and coaches that the technique for both genders is essentially the same, with any difference in kink time being attributed to power differences between the genders (Grigg et al., 2017). Demonstration of a clear difference in movement pattern during the gate start action between the genders may help BMX coaches to direct technique training and inform exercise prescription.

METHODS: 10 participants (4 female, 6 male) were recruited, all of whom had competed internationally for at least 5 years, held a current Union Cycliste Internationale (UCI) ranking and there was an average age of 22.3 ± 2.9 years. All participants had achieved a podium finish at a national level within months of testing, with five (2 female, 3 male) representing their country at the 2016 Olympic Games, Rio de Janeiro. Participants wore normal competition clothing and protective gear. Each participant performed at least five maximum effort starts with self-selected recovery periods as per Stergiou, Harbourne, and Cavanaugh (2006), with the fastest three trials being selected for analysis. Informed written consent was obtained from each participant in accordance with the Bond University Human Research Ethics Committee. All video was recorded during a normal training session on a standard SX ramp as per the protocol validated in Grigg et al. (2017). A GoPro Hero4 (GoPro, Inc., US) camera was used with a capture rate of 120fps, normal lens setting and Class10 (or higher) micro SD card. The camera was fixed to the ramp structure with a GoPro bracket and placed such that the rider would be in the centre third of the image for the majority of the gate start action.

A Mylaps AMB ChipX (Mylaps Sports Timing, Netherlands) timing system was used to collect the time split at the kink. Analysis of the first 1.2s after the first start signal was performed in Kinovea (version 0.8.25 Kinovea.org, France). This involved the tracking of 12 points through 1.2s (150 frames). The excursion of these points was then exported and manipulated in Matlab (R2018a, The Mathworks Inc. USA) where the joint and segments angles were calculated. Two body segments, head and trunk, and five joint angles, shoulder, elbow, hip, knee and ankle, were defined from the 12 points as per Figure 1.

Statistical analysis of the results was performed in Matlab. The average and standard deviation for each angle was calculated for each athlete, combined and calculated for females and males, and then overall. A non-paired t-test and Cohen's d effect size calculation was performed to determine significant difference between the genders in ROM across each angle. Alpha ≤ 10% was used to allow for the systematic error (Grigg et al., 2017).

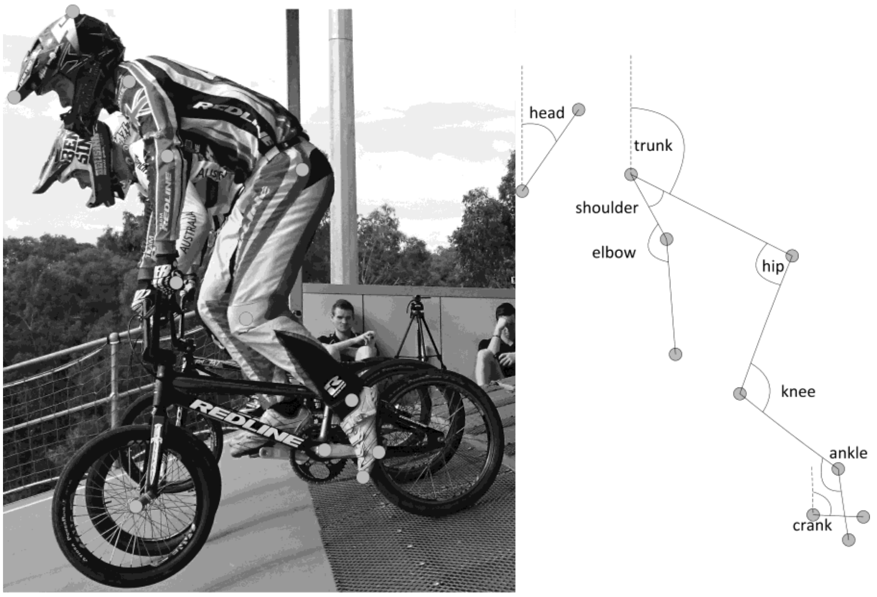

Figure 1. 12 virtual markers on the athlete and bike define 2 segments and 5 joint angles.

RESULTS: Table 1 shows a summary of the kink time, minimum, maximum and range of the joint angles (Ave ± SD°) and the kink time split for females, males and overall. A significant difference was found between the females and males in kink time, with the males on average being faster ($p < 0.00$, $d = 1.69$). Females had a larger max trunk angle, i.e. a more vertical trunk, ($p = 0.02$, $d = 1.2$) while males had a larger max elbow angle, i.e. greater elbow extension ($p = 0.08$, $d = 1.26$). Figure 2 shows that there was a clear difference between the athletes, particularly with regard to the shoulder/elbow and hip/knee/ankle movement.

DISCUSSION: The results in the study presented here demonstrate the inter-athlete difference in gross movement pattern during the BMX SX gate start action. This is

represented in Figure 2 by the difference in sagittal ROM across the two segments and five joints for each athlete. This highlights how unique to the individual this action can be, and must be considered by coaches and in exercise prescription. It also contributes to the standard deviation of the overall results. There is however, good comparison to results in literature, particularly those by Gross et al. (2017) which used 3D motion capture, the 'gold standard' method. Gross et al. (2017) reported hip ROM = 60° and knee ROM = 88° which agrees with the results presented
here; hip ROM = 62 ± 11°, knee ROM = 93 ± 12°.

Table 1 Summary of results, showing average kink time, segment and joint range of movement for females, males and across all, and the t-test comparing males and females, with statistically significant results shaded.

		Female (n=4) Ave	Male (n=6) Ave	p (Alpha ≤ 0.1)	Effect Size	Total (n=10) Ave
Kink time (s)		1.350 ± 0.030	1.258 ± 0.071	0.00	1.69	1.295 ± 0.073
Trunk Segment (°)	Max	147 ± 3	142 ± 5	0.02	1.2	144 ± 6
	Min	105 ± 5	104 ± 4	0.91	0.22	104 ± 7
	Range	41 ± 4	38 ± 5	0.15	0.66	39 ± 6
Head Segment (°)	Max	168 ± 4	171 ± 10	0.64	0.39	170 ± 9
	Min	139 ± 2	147 ± 13	0.96	0.86	143 ± 11
	Range	29 ± 4	45 ± 45	0.50	0.50	38 ± 35
Shoulder Joint (°)	Max	90 ± 3	93 ± 5	0.15	0.73	92 ± 5
	Min	6 ± 4	5 ± 6	0.75	0.20	5 ± 6
	Range	85 ± 3	88 ± 7	0.14	0.56	87 ± 7
Elbow Joint (°)	Max	175 ± 4	179 ± 2	0.08	1.26	177 ± 5
	Min	130 ± 10	128 ± 12	0.68	0.18	129 ± 15
	Range	45 ± 7	49 ± 15	0.47	0.34	47 ± 15
Hip Joint (°)	Max	134 ± 5	133 ± 9	0.65	0.14	133 ± 9
	Min	74 ± 3	72 ± 7	0.96	0.37	73 ± 7
	Range	63 ± 6	60 ± 10	0.50	0.36	62 ± 11
Knee Joint (°)	Max	152 ± 8	158 ± 12	0.25	0.59	156 ± 14
	Min	64 ± 3	63 ± 5	0.45	0.24	64 ± 5
	Range	89 ± 7	95 ± 10	0.17	0.69	93 ± 12
Ankle Joint (°)	Max	140 ± 8	137 ± 22	0.93	0.18	138 ± 19
	Min	96 ± 23	79 ± 18	0.17	0.82	86 ± 32
	Range	53 ± 4	62 ± 16	0.14	0.77	58 ± 14

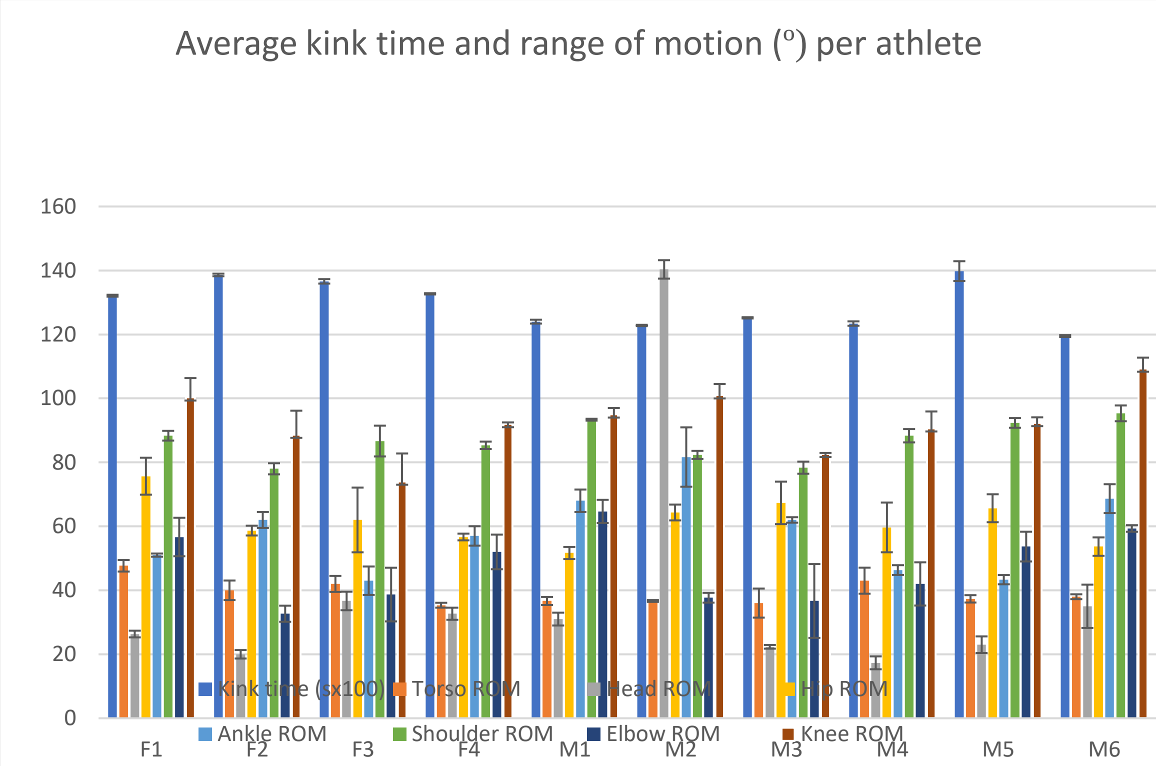

Figure 2 Comparative graph showing the kink time (s x 100 for ease of reference) and the average range of motion (º) across 2 segments and 5 joints for 10 athletes

The Australian coach observed that females tended to bring the body to a more vertical position in order to lift the front wheel over the falling gate, while males bend the elbow to pull the handlebars to the body and keep the body more horizontal. This could be due to greater upper body strength in the males. Keeping the body more horizontal reduces the vertical trajectory of the athlete's centre of mass and as such is a more energy efficient action. It also aids in propelling the body forward, rather than up, which is the overall aim of the action. The demonstration of a clear difference in movement pattern between the genders may help coaches adapt their training to the specific technique needs of each gender, rather than just focusing on power development in order to decrease kink time.

As shown in Grigg et al. (2017) kinematic analysis using markerless motion capture is not accurate to the degree. The validity is within 2°, and intra-tester reliability is up to 6°, hence the large confidence interval used for the t-test. The methodology only measures sagittal movement, which has been shown to be asymmetrical, even for Olympic level athletes (Grigg, Haakonssen, Rathbone, Orr & Keogh, 2017a). While the number of athletes in this study is small, it does include all the athletes that participated in the Cycling Australia BMX High Performance Program in 2015-2018, as well as two further athletes both of whom have won national championships. Future research will analyse data for a further six athletes and increase the number of trials to five per athlete enabling robust analysis of the action and its relationship to kink time. This will inform preparation of athletes for the Tokyo 2020 Olympic games. Kinematic data will also be statistically analysed with kink time and anthropometry to further understand how to maximise any kinematic advantage for a developing athlete.

CONCLUSION: This study provides a summary of the range of motion of two segments and five joint centres during the BMX SX gate start action by ten high performance athletes and demonstrates a significant difference between the kink times and upper body action between females and males. The difference in ROM between the genders may explain some of the difference in performance outcome, but not all. It does suggest that males more effectively engage the upper body, and that focussed training in this area could be of benefit to female athletes. Because athletes of the highest calibre were used for this study, and the methodology is simple and replicable by coaches, this data can be used by coaches to help measure performance and prepare athletes as they enter competition at the highest level.

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