PEDAL FORCES DURING THE BMX AND TRACK SPRINT CYCLING START

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During the start of a BMX and sprint track cycling race, a high amount of pedal force is required to accelerate the bike. The purpose of this study was to quantify the effective force (Fe), resultant force (Fr) generated in the lead and trail leg in BMX and sprint track cyclists when performing a standing start. Instrumented force pedals quantified the generated forces from each leg separately. Significantly greater Fe was generated with the lead leg than the trail leg ($p=0.011$) and a higher Fe and Fr resulted in a faster time of the first pedal stroke. There was no significant difference found in any of the pedal force variables between the BMX and track cyclists ($p=0.750$). Additionally, cyclists with greater Fe and Fr in the trail leg produced greater maximum power output on the Wattbike test. These data provide further insight into how cyclists propel the bike from a still position.

KEY WORDS: effective force, index of effectiveness, Wattbike

INTRODUCTION: In BMX and track sprint cycling, the execution of the start is strongly related to overall race performance identifying the importance of acceleration in the start phase (Rylands & Roberts, 2014). From a standing start position, the cyclist needs to attain race speed as quickly as possible in order to be faster than their opponents and place themselves in a favorable position. Despite the aim of the start being similar, there are clear differences between the two cycling disciplines. Most notably, in BMX the start is on an inclined ramp of up to 27%. Race analysis has revealed that BMX cyclists can attain velocities at the bottom of the start ramp of on average 56.89 km/h attained within 2.62 sec for male and 52.90 km/h within 2.74 sec for female cyclists (Cowell, McGuigan, & Cronin, 2012). Similarly, in a track sprint cycling event such as the team sprint, a good start in which the cyclist is able to reach a high velocity as quick as possible is a critical component of overall race performance. For both of these disciplines, the ability to propel the bike forward is an essential performance indicator.

The success of the start can be quantified by the pedal forces that result in bike propulsion during the acceleration start phase (Stapelfeldt, Mornieux, Oberheim, Belli, & Gollhofer, 2007). Specifically, the effective force (Fe) is the force generated tangentially to the crank and, when it is aligned forward, is responsible for bike propulsion. The unused force (Fu) is the force generated radially to the crank and does not generate any propulsion. Both of these component contribute to the total force (Fr) that the cyclist applies to the pedal. Ideally, all of the force applied to the pedal should be converted to Fe to favor crank motion. The index of effectiveness (IE) can determine how effective the cyclist is applying force to the pedals to propel them (Bini, Hume, Croft, & Kilding, 2013).

The availability of wireless force pedals allows further analysis into the components that contribute to a successful start. For example, during the first pedal stroke some coaches suggest that the trail leg should generate more force than the lead leg as the lead leg position starts partly into the pedal stroke. Additionally, as male BMX cyclists attain higher velocities in a shorter time at the bottom of the ramp compared to their female counterparts, investigating the between-gender differences in pedal forces may provide insight into how the first pedal stroke is executed. For this reason, the purpose of the current study was to compare the pedal forces of the first and second pedal stroke in the lead and trail leg from a standing start in BMX and track sprint cyclists, and identify whether they were related to time of the pedal stroke or Wattbike power output. It was hypothesized that there would be a significant correlation between pedal forces and time of the stroke and power output. A secondary purpose was to assess whether there were between-discipline or between-gender differences in pedal forces, and was hypothesized that track cyclists and male riders would generate more power than the BMX riders or female riders.

METHODS: A total of 5 BMX (male N=3; age 17.5±0.4yrs, body mass 76.33±5.5kg; female N=2; age 17.9±0.4yrs, body mass 72.45±9.12kg) and 12 track sprint (male N=7; age 18.0±3.2yrs, body mass 80.29±12.57kg; female N=5; age 17.0±0.6yrs; body mass 66.10±3.47kg) cyclists from the Dutch National Talent team participated in this study. As part of their regular performance monitoring, from a standing start the cyclists performed a 5 sec maximal sprint test on a Wattbike cycle ergometer set at Level 1 air resistance (Wattbike Ltd, Nottingham, UK). 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 chains.

In order to collect the Fe and Fu from the starting/lead leg and trail leg, both cranks of the Wattbike were instrumented with validated two-dimensional force pedals (500Hz; Powerforce System; Radlabor, Freiburg, Germany; Stapelfeldt et al., 2007). These wireless force pedals were mounted between the crank and the pedal creating a 12° degree forward rotation between the real and 'virtual' crank arm and recorded the forces on the pedal axis separately for each leg. Pedal force data from the first two full pedal strokes for the starting leg was extracted. Using the crank angle as a reference, the time to produce the first pedal stroke was measured which also included the push phase of the trail leg. At each recorded sample, Fe and Fu was collected whilst Fr was calculated as the vector sum of Fe and Fu. Due to technical difficulties, Fu was only collected for the trials with the BMX cyclists. As time to perform the first and second pedal stroke are important performance factors, a correlation between the pedal stroke time and the maximum Fe for the lead and trail leg were conducted. IE was computed as the ratio of Fe to Fr for the complete pedal stroke (Bini et al., 2013).

A paired samples *t*-test was conducted to compare the Fe generated in the lead and trail legs for all cyclists. The Pearson's product-moment correlation was used to investigate the relationship between pedal forces and time of the pedal stroke and maximum power attained during the Wattbike test. In order to investigate whether there were between-discipline or between-gender differences in Fe and Fr, independent sample *t*-tests were conducted (IBM SPSS Statistics 21.0.0; Somers, NY). Statistical significant was set at $P<0.05$.

RESULTS AND DISCUSSION: The start of a BMX and track sprint cycling race have been shown to be predictive of performance (Rylands & Roberts, 2014). When comparing the data from all cyclists, there was significantly greater Fe generated with the lead leg (1225 ± 245 N) than the trail leg (1089 ± 237 N; $t(16)=2.804$, $p=0.004$). This indicates that cyclists generated greater Fe in the first push phase (lead leg) compared to the second push phase (trail leg). Previous research revealed that most Fe occurs in the propulsive phase of the pedals stroke and not during the recovery phase (Bini et al., 2013). Unfortunately, due to technical difficulties we were unable to collected Fu for one of the pedals in some of the cyclists, and thus to calculate Fr, in order to assess how these differences in Fe resulted in differences in Fr. As the lead leg varied, this translated into missing data for either the lead or the trail leg. Some coaches advocate that the stronger leg should be in the trail position, thus allowing a greater range of motion for the second push phase. This was not found in the current study, assuming that the stronger leg would generate greater Fe and this would result in greater Fr. It must be noted, however, that leg dominance and strength was not collected. Additionally, maximum strength in the gym setting may not directly translate to high force production on the bike if the athlete is unable to transfer this force effectively. In order to further understand the relationship between maximum strength and transfer of force onto the pedals, we aim to include this analysis in the future.

At the start of a race, cyclists place their foot and pedals at an angle such that they are able to generate maximum power once pedaling commences. The time of the first pedal stroke was negatively correlated with lead leg Fe ($r=-0.64$, $p=0.006$) and Fr ($r=-0.78$, $p=0.003$) as well as trail leg Fe (r=-0.66, p=0.004) and Fr (-0.73, p=0.017). This indicates that a greater Fe and Fr resulted in a faster time of the first pedal stroke. On average, this first pedal stroke took 0.83 sec and the accumulative time for the second pedal stroke was 1.24 sec. Previous research revealed that BMX cyclists attain their peak power 1.60 sec into a simulated race (Herman, McGregor, Allen, & Bollt, 2009). For this reason, perhaps solely quantifying the first two pedal strokes may not be sufficient in understanding how the start is executed. When considering the second pedal stroke, a significant negative correlation was found between time of the second pedal stroke and lead leg Fe (-0.635, p=0.006) and Fr (-0.707, p=0.010), but not trail leg Fe (-0.313, p=0.221) or Fr (-0.227, p=0.529). These data suggest that the force generated by the lead leg during the first and second pedal stroke strongly influence the pedal stroke time, while for the trail leg this is only true for the first pedal stroke. Therefore, the lead leg seems more important to finish the first two pedal strokes.

Table 1
Pedal force data for the first and second pedal stroke (mean ± SD) for male and female BMX and track sprint cyclists. Significant between-discipline (*) and between-gender (‡) differences were observed.

Variable	BMX Cyclists (n=5)	Track Sprint Cyclists (n=12)	Male Cyclists (n=10)	Female Cyclists (n=7)
Max Fe lead 1 (N)	1208 ± 172	1232 ± 276	**1340 ± 217‡**	**1060 ± 188‡**
Max Fr lead 1 (N)	1268 ± 195	1345 ± 266 (n=7)	1383 ± 237 (n=8)	1172 ± 165 (n=4)
Max Fe trail 1 (N)	1083 ± 197	1091 ± 260	**1197 ± 244‡**	**934 ± 116‡**
Max Fr trail 1 (N)	1337 ± 176	1248 ± 216 (n=5)	**1458 ± 75 (n=5)‡**	**1127 ± 91 (n=5)‡**
IE lead 1	0.76 ± 0.08	0.82 ± 0.04 (n=7)	0.79 ± 0.08 (n=8)	0.80 ± 0.03 (n=4)
IE trail 1	0.77 ± 0.04	0.77 ± 0.05	0.77 ± 0.06 (=5)	0.77 ± 0.03 (n=5)
Max Fe lead 2 (N)	925 ± 152	922 ± 191	1017 ± 119	787 ± 159
Max Fr lead 2 (N)	1045 ± 101	1098 ± 100 (n=7)	1067 ± 111 (n=8)	1094 ± 81 (n=4)
Max Fe trail 2 (N)	838 ± 102	805 ± 248	875 ± 253	727 ± 97
Max Fr trail 2 (N)	1089 ± 226	1082 ±166	1181 ± 174 (n=5)	990 ± 161 (n=5)
IE lead 2	**0.55 ± 0.09***	**0.70 ± 0.06 (n=7)***	0.64 ± 0.10 (n=8)	0.64 ± 12 (n=4)
IE trail 2	**0.55 ± 0.16***	**0.75 ± 0.06***	0.60 ± 0.19 (n=5)	0.70 ± 0.12 (n=5)
Time 1st rev (sec)	0.82 ± 0.90	0.84 ± 0.13	0.79 ± 0.11	0.89 ± 0.11
Time 2nd rev (sec)	0.48 ± 0.06	0.43 ± 0.05	0.43 ± 0.06	0.47 ± 0.03
Max power (Watt)	1329 ± 163	1335 ± 335 (n=6)	**1512 ± 282‡**	**1182 ± 102‡**

Effective force (Fe), Total force (Fr), lead = lead leg, trail = trail leg, IE = index of effectiveness, 1 or 2 refers to the revolution, rev = revolution, N = newton

In order to determine how effective the cyclists were at transferring Fe to the pedal in a propulsive manner, the average IE of the pedal stroke was calculated. When IE is close to 1, a greater proportion of Fr is transferred to Fe and there is little loss of force and energy. Conversely, an IE of close to -1 the cyclists is generating Fe in the opposite direction resulting in unfavorable resistive force for the contralateral leg. It has been demonstrated that higher skilled cyclists have a higher IE than lesser skilled cyclists (Bohm, Siebert, & Walsh, 2008). In the current study, IE ranged from the most effective (0.87) to the least effective (0.61) first pedal stroke.

When comparing the BMX and track sprint cyclists, no significant difference was found in any of the pedal force variables or time for the first or second pedal stroke. However, track sprint cyclists were more effective (had greater IE) than the BMX cyclists in both the lead ($t(10)$=3.835, p=0.003) and trail legs ($t(8)$=2.594,p=0.032) of the second pedal stroke, although no differences were found in the first pedal stroke (lead $t(10)$=1.980, p=0.076, trail $t(8)$=-0.138, p=0.893) (Table 1).

Both BMX and track sprint cycling require substantial ability to generate high force during the start acceleration phase, although require different technical aspects. In fact, it is not uncommon for a BMX athlete to transfer to track sprint cycling if they possess the ability to generate a high amount of power for the start but lack the technical skills for the acrobatic aspects of BMX. Potentially, the between-discipline differences found in the present study may be due to the sport-specific requirements, where the sprint track cyclists still needs to accelerate further to reach peak velocities, whereas BMX cyclists may already be close to peak velocities at the bottom of the start ramp when they finish their second pedal stroke. Nevertheless, collecting these data on the track in the future will provide further insights into these results and may possibly identify more differences between BMX and track cyclists.

Between-gender differences in pedal forces were observed. Specifically, male cyclists generated greater Fe in the lead leg ($t(15)=-2.763$, $p=0.014$) and Fe and Fr in the trail leg ($t(15)=-2.635$, $p=0.010$) compared to the female cyclists in the first pedal stroke. However, no between-gender differences in IE were observed (lead leg $t(10)=0.236$, $p=0.818$, trail leg $t(8)=-0.138$, $p=0.893$), potentially suggesting that female cyclists were able to direct their force production in a more favorable manner than the male cyclists. The men, however, did attain a higher maximum power on the Wattbike results ($t(9)=-2.692$, $p=0.025$) (Table 1).

As the Wattbike performance tests are commonly used to assess performance and progress, being able to relate these results to the pedal force data is desired. Significant positive correlations were found between the maximum Wattbike power output and first pedal stroke trail Fe ($r=0.82$, $p=0.002$) and Fr ($r=0.79$, $p=0.012$) and second pedal stroke Fe in the lead $r=0.78$, $p=0.004$ and trail legs $r=0.71$, $p=0.014$. This indicates that cyclists that produced greater maximum power output on the Wattbike test likely did so as a result of generating greater Fe and Fr with the trail leg. Interestingly, no relationship was found between maximum power output and lead leg Fe or Fr. Perhaps it is the contribution of the trail leg which provides a more accurate representation of how pedal forces influence performance on a Wattbike. Rylands et al (2013) previously found that track cyclists were able to generate greater power than BMX cyclists, contrary to the current findings, when measured with a SRM power meter system. The discrepancy in findings may be due to the differences in methodology or instrumentation. It must be noted, however, that these tests were conducted on a stationary Wattbike in a laboratory setting requiring very different body movements than on a BMX start ramp or on a velodrome. Although these results provide an indication of performance, it is recommended that similar data be collected and compared on the discipline-specific bike and location.

CONCLUSION: In BMX and sprint track cycling, a high amount of effective pedal force is required for an advantageous acceleration phase in the start. The results of this study provide insight into how cyclists apply force to the pedals. Quantifying pedal forces provides further insights for sports scientists and coaches into how each cyclist is generating pedal forces and identifies which aspect of the pedal stroke is not optimized and where improvements for performance are possible.

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