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Performance analysis and mechanical determinants of the opening lap of the team sprint in elite-level track cycling

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Abstract

The team sprint (TS) is a three-lap pursuit and the most revered event in track sprint cycling. The opening lap of the TS is an important determinant to the overall performance. But despite it being the most controlled and repeatable task in track sprint cycling, very little data are available to better understand the performance of the opening lap. The aim of this study was split into three-parts: part one, to better understand the profile and the indices thought to be determinants of the opening lap of the TS in elite sprint track cyclists. Part two of the study examined all available timing splits (15, 65, 125 and 250 m) from 36 standing-start laps. Part three of the study examined the peak torque outputs and peak power outputs of different various starts performed over a 3-month period. The results showed time to 125 m exhibited a near perfect relationship with starter lap performance. Very strong relationships were seen with 15 and 65 m split times and final lap performance. Peak torque of the lead starting leg and peak power output were shown to be highly predictive 15 m, 65 and 125 m performance in training. These data suggested the first 15 m is highly important and predicts a disproportionately high level of final opening lap time performance. Therefore, it is likely that peak power output normalised to system mass and peak torque of lead leg is a strong determinant of overall performance in the TS.

KEYWORDS
maximum power, maximum torque, pedalling

Highlights

- Peak speed of the opening lap is achieved in the final quarter of the lap.
- The timing split of the second half of the opening lap can be used as a proxy of peak speed achieved in the opening lap.
- The first 15 m (6%) and 65 m (26%) of the opening lap in the track cycling team sprint shows a disproportionately high level of predictability of the final time achieved in the opening lap.
- Peak power output normalised to system mass is a significant predictor in performance for the first 15 and 65 m.
- Peak power output is underpinned by maximal torque output of the lead leg normalised to body mass which also is a significant predictor of 15 and 65 m performance.

1 | INTRODUCTION

The team sprint (TS) is considered the 'blue ribbon' event in track sprint cycling. In recent years, the event has generated high interest in Olympic track cycling for two main reasons. Firstly, if a national team qualified a TS team for the Olympics, they are automatically awarded two individual places for the individual events: match sprint and Keirin and hence increase the chances for medal success across numerous events. Secondly, it is the only sprint cycling event in the Olympics that the success is solely determined by time meaning that is more "predictable" and "measurable" for coaches and riders. The TS event is a three-rider pursuit over three laps of a 250 m velodrome (totalling 750 m). All three riders start from a stationary start with Rider 1 (also known as 'the Starter') commencing the pursuit from a start gate at the 'pursuit line', which is positioned in the middle of the straight of the track. At the end of the first lap, the leading rider exits the race by riding up the banking leaving the remaining riders to continue lap 2. When lap 2 is complete the second rider departs in the same manner as the Starter leaving Rider 3 to complete the last lap. The timing stops once Rider 3 crosses the pursuit line. At every World Championships between 2010 and 2022, only once has a team that recorded the fastest opening lap in the (three rider) TS and qualified for the subsequent round not gone on to win a medal. Furthermore, a basic regression analysis of 157 international level men's TS performances (as women only switched to the 3-rider TS in 2020 and in comparison data is limited), using publicly available data via www.tissottiming.com between 2018 and 2022, suggested that when only accounting for <18.3 s opening laps and <45.0 s final time, the opening lap alone accounts for 54% of the variation of the final time (r = 0.73; Figure 1A). When the opening half (Figure 1B) and second half (Figure 1C) of the lap times are analysed (also freely available in the public domain) they exhibit similar, positive and large relationships ($r = 0.67/R^2 = 45\%$ and $r = 0.66/R^2 = 44\%$, respectively) to final performance time suggesting that there is a disproportionately high degree of predictability of the final TS time from opening lap (and two half lap times that make up the opening lap). Thereby suggesting the opening lap is a strong predictor of overall TS performance.

The opening lap simply requires the rider to complete one lap of the velodrome in a maximal 'all-out' effort. By having to accelerate from a stationary start, the main resistive force is system mass (total of rider and bicycle) rather than aerodynamic forces meaning the atmospheric conditions are less influential than in other cycling events, such as the individual and team pursuit (Martin et al., 2006, 2007). It is also the most repeatable part of the race because it can be considered a closed task that does not inherently change. Despite this, to the authors' knowledge, there are no data available in the scientific domain that have described the opening lap in more detail and/or determinants of Starter performance in the TS event.

For over the last 2 decades, instrumented cranks have been commercially available that can be mounted on bicycles to measure mechanical output of cyclists (Balmer et al., 2000). These instrumented cranks have evolved to measure power (i.e., the product of average torque and average cadence [measured as angular velocity] over a crank revolution), and more recently, torque in each crank arm in high resolution of up to 256 Hz (Bouillod et al., 2022; Gardner et al., 2004; Kordi et al., 2021) that allow a more detailed understanding of mechanical determinants of Stater lap performance. Despite the TS being an important event in sprint cycling and the opening lap being an apparent important determinant of overall performance, there are no data that attempt to explain what might help predict the performance of a Starter. Laboratory based studies suggest that peak power output (PPO), the maximal power produced over a pedal revolution in a short period of time (<7 s), is an important determinant of sprint cycling ability (Bundle et al., 2012; Weyand et al., 2006). The only literature that sought to examine sprint cycling performance suggested PPO normalised to frontal area is a significant determinant of performance in the 'flying' (i.e. three laps to wind up to perform a) 200 m time-trial (TT) (Dorel et al., 2005). Better understanding of the determinants of the Starter lap (from a standing start) in the TS would help coaches, practitioners and riders better understand the event and be able to better monitor and optimise training and subsequently, performance.

Accordingly, aim of this study was three-fold: firstly, establish the performance profile of a standing lap. Secondly, then take a more detailed performance analysis within the lap. Lastly, using individually instrumented cranks that record torque and power, we sought to identify what mechanical measures might be used to determine the different split times to better understand components of standing start performance.

2 | METHODOLOGY

2.1 | Participants

Seven elite sprint riders (age: 28 ± 4 yr; body mass: 84 ± 11 kg; stature: 1.79 ± 0.08 m) participated in this study and were six men and one woman and gave informed consent to have their data used for this study. At the time of writing, all the riders who participated had at least won either a European or World Championship medal in the TS discipline. This data collection was approved by The Hague University of Applied Sciences Ethics Committee.

2.2 | Study overview

For part one, to get a better overview of the performance profile of starter lap, 3 different male starters performed a total of 7 opening laps in official competition or internal test events over a period of 3 years where their speed profiles and timing splits were compared. For part two, 36 opening laps were performed as solo standing laps over a course of a week (using all the participants mentioned in this manuscript) where times at 15, 65, 125 and 250 m were assessed.

Part three analysed the physiological determinants of performance within an opening lap by examining the mechanical data in the

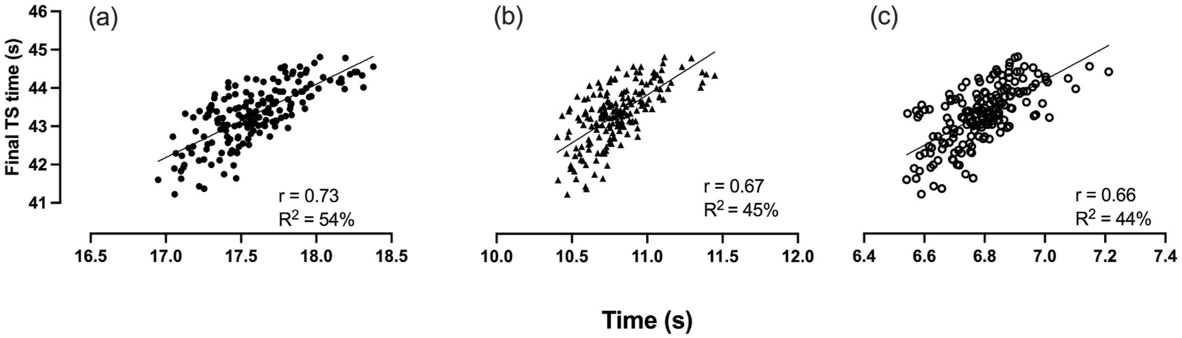

FIGURE 1 Relationship (r) and coefficient of variation of the (A) opening lap (B) first half of the opening lap and (C) second half of the opening lap with final team sprint (TS) performance of 157 elite level 3-rider men's TS. Data taken from tissottiming.com.

most important areas of the opening lap as identified by the previous steps.

2.3 | Procedure and instruments

All data were collected and/or analysed on the same indoor 250 m velodrome (Omnisport, Apeldoorn, The Netherlands). For part one, all performances were commenced from start gates that were used for international competition (Swiss Timing Start Gate, Swiss Timing Switzerland or ST-BSM1, Alge Timing GmbH, Austria) and electronic timing (Tissot Timing, Switzerland or Time Tronics, The Netherlands) accurate to 0.001 s was used to give half and full lap timing splits. Post-race video analysis accurate to 0.01 s would ascertain the 187.5 m times as well as the time in gate which was subtracted from the final time. All video analysis was done by two separate investigators to ensure accuracy. Furthermore, the Starters track bikes were instrumented with speedometers and odometers (SRM Speedpod, Schoberer, Rad Messtechnik, Germany) that would record to a cycling computer (Garmin 530, Garmin, United States) at a frequency of 1 Hz.

For part two, each effort was performed under race conditions where the rider's individual track bicycle was mounted in a start gate (ST-BSM1, Alge Timing GmbH, Austria). The riders wore their standard race equipment (wheels, tyres and attire). Each effort was initiated with a standard 50 s count down, identical to track competition. As with what happens in competition, once the countdown reaches zero, the brake calliper that holds the rear wheel in the start gate is released allowing the rider to leave the start gate and commence the effort. Electronic timing was accurate to 0.001s (MYLAPS ProChip Timing System, Haarlem, The Netherlands) enabled the investigators to assess the time taken from the start of the effort to 15, 65, 125 and 250 m.

Part three of the experiment involved four (of the seven) elite sprinters (three men and one woman). Data were collected over a 4-month training period where a total of 94 stationary starts were recorded from the start gate which were either 65 m or 125 m in distance. The timing splits of any timing point that was surpassed were also recorded within the predetermined start. For example, in a 65 m start, times from 0 to 15 m and 0–65 m were also noted and included in the data set. In parallel to the starts, each rider had instrumented cranks (InfoCrank Track 144 BCD, Verve Cycling, Australia) that was continually recording their instantaneous torque (256 Hz) and power averaged over a complete revolution of each crank individually as well as cumulatively on to a mobile app (VINC Pro, Verve Cycling, Australia). The riders consistently wore their training equipment and attire (such as wheels, skinsuits and helmets) for all starts. The wheels were inflated to 11 bar and prior to every start that was performed, the gear ratio (the number of teeth on the big chain ring/number of teeth on the rear sprocket) and the system mass (the total mass of the rider and bicycle) were noted. As with the previous part of the experiment, a video camera also recorded all the efforts at a rate of 100 Hz and used to judge when the rider had started to move in comparison to when the start gate opened. The time in gate was subtracted from each timing point.

2.4 | Data analysis

Part one of the study displays and identifies peak speed and distance where peak speed is achieved. Following this, Pearson's correlation coefficient (*r*) as well as the determinants used to ascertain the relationships between peak speed and specific timing splits to assess whether timing (more common and accessible) splits can be used as surrogates of delivery speed.

Part two also used Pearson's correlation coefficient to ascertain the relationship between the time taken to each between each distance check point combination (i.e. time to 15 m, 65 and 125 m; 15–65 m; 65–125 m and 125–250 m) and final lap performance.

Part three of the study, as starts are maximal and all-out in nature, previous studies have shown that the maximum mechanical values (e.g., maximum force/torque and power) are the best predictors of performance (Folland et al., 2007; Kordi et al., 2017; Weyand et al., 2006). System mass (total mass of rider and bicycle) is the largest resistive to overcome when trying to aggressively accelerate from a stationary start, so the mechanical measures were also normalised to system mass. From the mechanical data recorded, cumulative peak torque output: mass (PTO), peak power output:

mass (PPO), peak torque output of lead starting leg: mass (PTL), peak power output of starting leg: mass (PPL) were recorded. The aforementioned measures were used as the independent variables and the segment times were the dependent variables. The strength and predictability of the relationship with the segment times were assessed in the same way as in part one of the experiment (i.e., Pearson's correlation coefficient and R^2).

Correlations of >0.3, >0.5, >0.7, >0.9 were described as small, moderate, large, very large and nearly perfect, respectively (Hopkins et al., 2009). The goodness-of-fit/variance explained between the independent and dependent variables that were assessed by using the coefficient of variance (R^2).

3 | RESULTS

For part one, of the seven team sprints where both average speed and wheel speed were measured. The peak speed achieved in an opening lap is 19.65 ± 0.22 m/s which occurred at 208.5 ± 16.7 m. Consequently, the peak cadences that were reached were 152 ± 2 revolutions per minute. All the maximum speeds were attained within the final quarter (187.5–250 m) of the lap. The peak average speed between the timing markers were 18.83 ± 0.30 m/s which was also achieved in the 187.5–250 m zone. These results are shown in Figure 2.

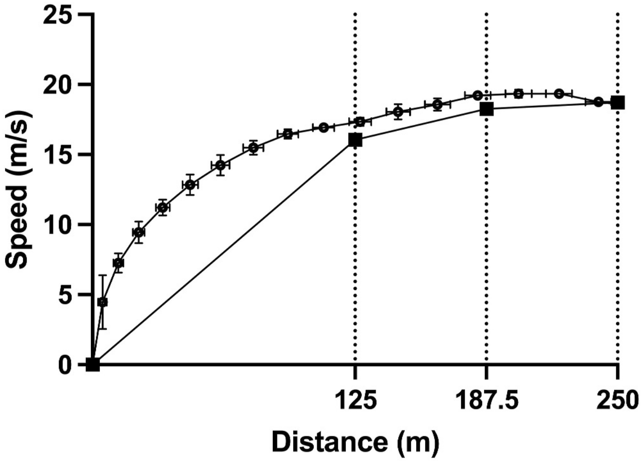

FIGURE 2 Mean ± SD of wheel speed and distance travelled of seven elite male opening laps of the Team Sprint at a frequency of 1 Hz. In addition, the mean ± SD timing splits at 125, 187.5 and 250 m of the same opening laps. Filled squared denotes average speed between timing points (m/s); filled circles denotes wheel speed (m/s).

A very large, positive relationship with measured peak speed and final lap time was seen ($r = 0.90/R^2 = 81\%$) as was the relationship between peak speed and time taken to complete 187.7–250 m. In addition, time between 187.5 and 250 m and final 250 m time was $r = 0.88/R^2 = 78\%$. The second half of the lap also showed $r = 0.97/R^2 = 94\%$.

For part two, of the 36 solo standing laps performed, all segments showed very large or near perfect relationships with final lap time. Very large, significant relationships with stationary start time to 15 m ($r = 0.70$) and 65 m ($r = 0.86$) as well as 15–65 m ($r = 0.81$) and 125–250 m ($r = 0.87$). The near-perfect relationships were timed to 125 m displayed near perfect relationship ($r = 0.92$) with final lap time. Accordingly, the time from start to 15 m, 65 and 125 m had R^2 values of 49%, 75% and 86%, respectively (Figure 3 and Table 1).

A partial correlation was run to determine the relationship between rider time to 15 m, 65 and 125 m and the various mechanical independent variables whilst controlling for gear ratio. For time taken to 15 m, very large, negative and significant (all $p < 0.001$) partial correlations were seen with PTO ($r(88) = -0.80$; $n = 90$), PTL ($r(88) = -0.80$; $n = 90$), PPO ($r(88) = -0.74$; $n = 90$) and PPL ($r(88) = -0.79$; $n = 90$). However, zero-order correlations showed that there was a statistically significant, very large relationship between 15 m performance time and PTL ($r = -0.79$) (Figure 4A), PPO ($r = -0.70$) (Figure 4C) and PPL ($r = -0.75$) (Figure 4B) indicating that gear ratio has very little influence of controlling for 15 m performance and PTL and PPO.

Partial correlations to examine performance times to 65 m with the independent variables exhibited near perfect, negative and statistically significant ($p < 0.001$)relationships with PTO ($r(91) = -0.90$; $n = 93$) and PTL ($r(91) = -0.90$; $n = 93$). Very large, negative and statistically significant relationships were seen with 65 m performance time and PPO ($r(91) = -0.87$; $n = 93$), PPL ($r(91) = -0.85$; $n = 93$), PTO ($r(91) = -0.70$; $n = 93$), PTL ($r(91) = -0.73$; $n = 93$) and PPO ($r(91) = -0.77$; $n = 93$). Subsequent zero-order correlations showed that there were statistically significant, negative and very large relationships with 65 m performance time and PTL ($r = -0.81$) (Figure 4D), PPO ($r = -0.80$) (Figure 4F) and PPL ($r = -0.83$) (Figure 4E). Accordingly, the gear ratio had little influence on the relationship between 65 m performance and PTL, PPO and PPL.

Partial correlation analysis to ascertain performance times to 125 m showed a near-perfect and significant relationships with PTL (r (Gardner et al., 2007) = −0.99; $n = 20$) and PPL (r (Gardner et al., 2007) = −0.99; $n = 20$). Very large, negative and significant relationships were observed with 125 m performance and PTO (r (Gardner et al., 2007) = −0.86; $n = 20$), PPO (r (Gardner et al., 2007) = −0.78; $n = 20$), PPL (r (Gardner et al., 2007) = −0.79; $n = 20$), PTL (r (Gardner et al., 2007) = −0.71; $n = 20$) and PPO (r (Gardner et al., 2007) = −0.73; $n = 20$). Zero-order correlations showed very large, negative and significant relationships with PTL ($r = -0.77$) (Figure 4G), PPO ($r = -0.80$) (Figure 4I) and PPL ($r = -0.85$) (Figure 4H). Thus, gear ratios used in this study had little influence on 125 m performance and PTL, PPO and PPL. The summary of results of the mechanical measures and coefficient of determination are in Table 2.

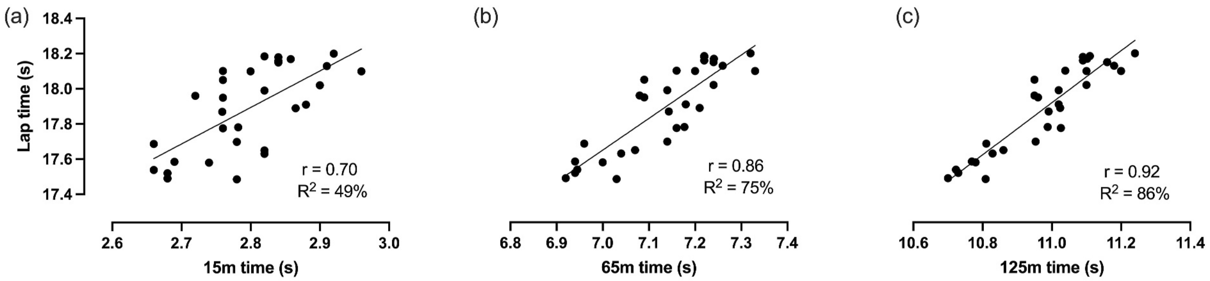

FIGURE 3 The relationship between final opening lap time and (A) time taken to 15 m, (B) time taken to 65 m and (C) time taken to 125 m.

TABLE 1 Relationship (*r*) and relationship strength (R^2) of different timing segments of the opening lap of the starter compared to the final opening lap time.

Timing segment	*r*	Relationship strength	R^2
0–15 m	0.70	Very large	49%
0–65 m	0.86	Very large	75%
0–125 m	0.92	Near perfect	86%
15–65 m	0.81	Very large	65%
65–125 m	0.92	Near perfect	85%
125–250 m	0.87	Very large	76%

4 | DISCUSSION

The overarching findings of this experiment were three-fold. Firstly, that peak speed is a determinant of Starter performance and is achieved within the final quarter of the opening lap. Further analysis suggests that the second half lap split can be used as a surrogate measure for peak speed making it easier to interpret starter lap performance in competitions without the need for instrumenting a bicycle.

Secondly, that the first 15 m (or first 6% of the total event distance) is crucial in the opening lap of a TS and subsequently, TS performance. Lastly, peak power output normalised to system mass is a determinant of the Starter performance. This seems to be underpinned by peak torque of the lead leg normalised to system mass (rather than total peak torque) making cycling specific maximal strength a mechanical determinant of standing lap performance and therefore, TS performance.

To the author's knowledge, this is the first-time data of any kind of the Starter and/or TS performance has been shared in the scientific domain. The data from this study suggests that peak speeds achieved can be in excess of 71 km/h which were all achieved in the last quarter of the opening lap. Peak speed exhibited very large, positive relationships and was highly predictive of opening lap performance. Final quarter and second half times also exhibited very large relationships with peak speed and final lap performance suggesting that the second half lap split which is freely available during racing is a proxy to peak speed and subsequently opening lap performance.

A more detailed performance analysis of the opening lap of the TS suggests that there is a very high degree of predictability from simply taking the 125 m (first half lap) performance time and time from 65 to 125 m. The first half lap performance represents half of the distance and approximately 60% of the time in an all-out, maximal task making it unsurprising that an almost near perfect relationship existed with final lap performance. With regards to 65–125 m time performance (and its near perfect relationship with final lap performance), it represents a far smaller proportion (in terms of time and task) in comparison to first half lap performance. This timing segment represents an acceleration phase of the lap. Therefore, the speed at which the rider enters the segment will strongly determine the final segment time meaning that what precedes this segment largely determines final lap performance. Accordingly, a disproportionately high level of predictability of 15 and 65 m performance to final lap performance is also seen. The data suggests time taken to 15 and 65 m performance (that represent the first 6% and 26% of the lap, respectively) explains almost 50% and 74% of the final opening lap time, respectively. This suggests that the initial acceleration phase from the start gate is crucial to achieve a higher maximal speed in the Starter lap and as such, a faster standing lap time making the first 15 m a crucial determinant of standing lap performance. The better (i.e., faster) performance to 15 and 65 m means that a higher entry speed into the 65–125 m segments leads to the near-perfect relationship of the 65–125 m segment to final lap performance.

This begs the question, if time to 15 m (and 65 m) is crucial, then should all the training focus be on getting the Starter to the 15 m (and 65 m) as fast as the solitary goal? The promptest way of doing this would be to reduce the gear ratio (i.e., the difference between the numbers of teeth on the front chain ring relative to the rear sprocket in the drive chain). Reducing the gear ratio would make it more likely to achieve a faster 15 and 65 m time. Therefore, PPO is achieved earlier and there would be a need to complete more pedal revolutions to get the same or a faster time. Increasing the number of pedal revolutions (or consecutive muscle contractions) increases fatigue (Tomas et al., 2010; Weyand et al., 2006) and peak speed is achieved much earlier in the lap meaning that the deceleration would have a negative impact on the TS and the opening lap.

It is worth nothing that the coefficient of variance of the time of second of the lap in part two of the study had a much higher

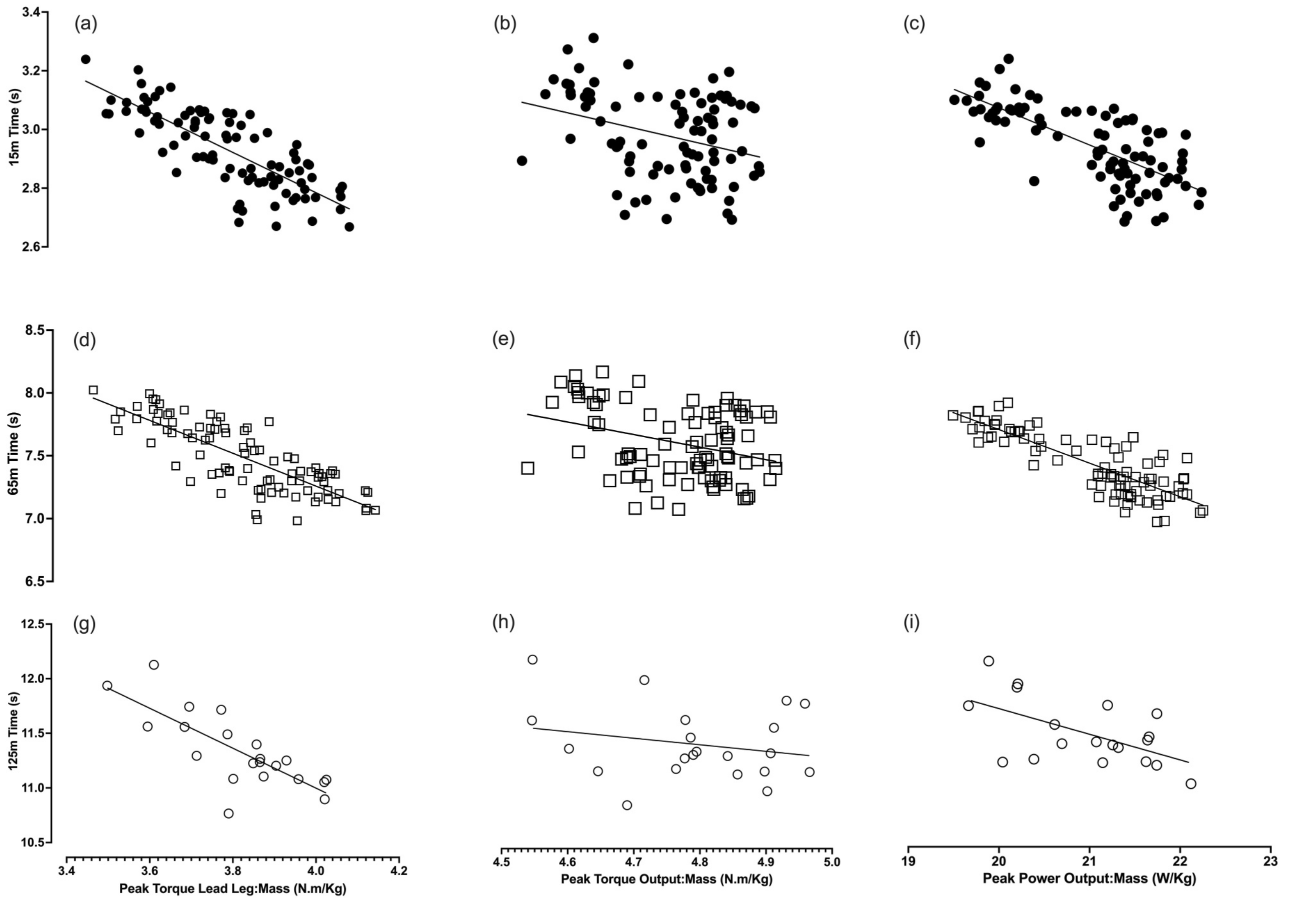

FIGURE 4 The relationships between peak torque of lead leg normalised to system mass with the first (A) 15 m (r = –0.79), (D) 65 m (r = –0.81) and (G) 125 m (r = - 0.77) times; peak torque output normalised to system mass of the first (B) 15 m (r = –0.32), (E) 65 m (r = –0.35) and (H) 125 m (r = –0.23). The peak power output normalised to system mass of the first (C) 15 m (r = –0.70), (F) 65 m (r = –0.80) and (I) 125 m (r = –0.74).

TABLE 2 The relationship strength (R^2) of the different mechanical measures relative to time taken to complete the first 15, 65 and 125 m.

	R^2		
	15 m	65 m	125 m
Peak torque output: Mass	0.10	0.12	0.05
Peak torque of lead leg: Mass	0.62	0.65	0.60
Peak torque of trail leg: Mass	0.29	0.29	0.24
Peak power output: Mass	0.49	0.64	0.55
Peak power of lead leg: Mass	0.56	0.70	0.72

level of predictability than the publicly sourced competition data shown in Figure 1 (76% vs. 44%). There is not an obvious explanation for this however, we can speculate that: some Starters are not specialised starters, potentially different gear choices and differing equipment which could impact resistive forces (e.g., rolling resistance). Also, the competition times are inclusive to both the time spent in the start gate when the timing starts as well as the time it takes to get to the checkpoint which could also have had an effect.

The data from part three of this experiment examined the mechanical data and its relationship with start times over a period of 4 months. The findings suggest that PTL and PPO normalised to system mass are significant determinants of 15 m, 65 and 125 m performance. This suggests that PTL and PPO can be monitored to ascertain physiological changes in standing start performance. Recently, there has been a debate of the weighting of importance of PPO and simply focussing on improving maximal mechanical output in track sprint cycling especially in the individual “non-TT” events such as the match sprint or keirin (Douglas, 2021; Ferguson et al., 2021). However, the data in this study and previous studies suggests that maximal mechanical measures are important determinants sprint cycling performance in at least the timed-events such as the TS and flying 200 m TT (Dorel et al., 2005). This complements other studies that point towards PPO to be considered a mechanical measure that can predict or is related to sprint cycling ability and performance (Dorel et al., 2005; Kordi et al., 2020; Martin et al., 2006). Power is the product of torque and cadence; peak torque in output of the lead leg is the pedal revolution that generates the highest torque in any crank cycle of the start and peak torque output underpins PPO (Gardner et al., 2007; Kordi et al., 2020; Martin et al., 1997). It is somewhat surprising it is PTL rather than

PTO that determines stationary start performance. No data in the literature has examined the mechanical or physiological factors that determine standing lap performance in track sprint cycling. However, in a study examining starts in BMX riders suggested that the lead PTL is important to "finish the first two pedal strokes" but it was not in the scope of the study to understand why (Janssen et al., 2017). Similarly, we cannot come up with a plausible explanation as to why PTO is not a significant predictor other than speculation.

5 | CONCLUSION

This study shows for the first time that peak speed that is achieved within the last quarter of a Starter gives a very degree of predictability to the performance of (a) the opening lap of the TS and (b) the TS. The time taken to 15 m which only accounts for 6% of the distance and approximately 15% of the final time gives a high level of predictability of the Starters performance in the TS. Additionally, on a mechanical level, peak power output normalised to system mass that is largely underpinned by peak torque output normalised to system mass are significant determinants of 15 m, 65 and 125 m performance. The findings of this study could be used by coaches, practitioners and athletes to monitor their physical performance as well as helping them monitor and optimise the training.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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