

*Review Article*

# Sprinting in road cycling – literature review

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**Paul Merkes<sup>1</sup>, Paolo Mensapà<sup>1</sup>, Chris Abbiss<sup>1</sup>.**

<sup>1</sup> Centre for Exercise and Sports Science Research, School of Medical and Health Sciences, Edith Cowan University, Joondalup, WA, Australia

\* Correspondence: Paul Merkes. [p.merkes@ecu.edu.au](mailto:p.merkes@ecu.edu.au)

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**Abstract:** A road cycling sprint can be described as the acceleration which occurs toward the end of competitions in order to reach the finish line in front of other competitors. The ability to sprint in road cycling is important since most races are decided in either a head-to-head, small group, or mass sprint finish. Cycling velocity during sprints is important. Factors influencing cycling velocity include the cyclist's physiology, biomechanics and application of force, resistive forces caused by the environment, and the interaction between cyclists. To perform well in sprints, road cyclists are required to have a very well developed aerobic function but also extremely well established anaerobic capacity. Cyclists can produce higher power outputs while adopting a standing position when compared with a seated position, with professional male and female sprinters producing approximately 14.2 and 10.0 W kg<sup>-1</sup> during road sprints which last 14 and 22 s, respectively. Additionally, lowering the torso and head during the standing sprint position results in an aerodynamic improvement of around 25%. Before starting the sprint, road cycling sprinters can save energy by drafting behind other cyclists. However, being close to the front of the peloton during the last part of the race, together with several supporting teammates, is of high importance for cycling performance outcomes. Road cycling sprinting performance could be improved via increasing power output, reducing aerodynamic drag, and smart positioning in the peloton.

**Keywords:** aerodynamics, power output, performance, cyclist specialisation, sprint



## 1. Introduction

The Union Cycliste Internationale (UCI) hosts twenty World Championships every year, which are separated over seven disciplines (Bicycle Motocross (BMX), cyclo-cross, mountain bike, road, track, trials, and indoor cycling). The majority of these races include some form of sprinting, up to one minute (BMX cross and time trial; mountain bike four cross; and track time trial, keirin, sprint, and team sprint); a possible sprint finish at the end of a mass start event (cyclo-cross, mountain bike cross country and cross country eliminator, road race, and track scratch); or repeated sprints for intermediate sprint lines and the finish line (track points race and madison). As such, sprinting is a major determinant of performance in a range of UCI World Championship events. Given differences in the physical demands and rules between various cycling disciplines, the physiological and performance characteristics of specialised 'sprinters' can be vastly different. Indeed, sprinting is a specialisation common to both track and road cycling and despite similarities in the terminology used to describe these events, the task demands are extremely different and as such their physiological and performance characteristics are different. Despite this, a commonality between sprinters from varying disciplines is their ability to produce high power outputs for short periods, when compared with other cyclists competing in the same setting. Elite track sprinters can generally produce the highest peak power output across all the disciplines of track cycling. Similarly, road sprinters are generally able to produce the highest peak power outputs within the road cycling peloton, making comparisons between these two specialists interesting. Due to neural (i.e. higher peak cadences) and anthropometric characteristics (i.e. greater lower limb muscle mass) differences, professional track sprinters can typically produce considerably higher absolute peak power outputs than road sprinters (peak power:  $\geq 1600$  W and  $\geq 1100$  W, respectively) (Dorel et al., 2005; Gardner, Martin, Martin, Barras, & Jenkins, 2007; Menaspà, Quod, Martin, Peiffer, & Abbiss, 2015; Menaspà, Quod, Martin, Victor, & Abbiss, 2013). Despite

limited published data, it seems that when accounting for body mass the power output is more comparable between road and track sprinters (Menaspà, Martin, et al., 2013). To date, there has been considerably more research examining track sprint cycling (Capelli et al., 1998; Dorel et al., 2005; Gardner et al., 2009; Gardner et al., 2007; McLean & Parker, 1989; Schumacher, Mueller, & Keul, 2001), when compared with road sprinting. This is somewhat surprising since sprints are very common in road cycling, with over half of the mass-start stages during the three grand tours (i.e. Giro d'Italia, Tour de France, and Vuelta a España), as well as several of the recent World Championships decided in either a head-to-head, small group, or mass sprint finish. While there are multiple literature reviews (Atkinson, Davison, Jeukendrup, & Passfield, 2003; Crouch, Burton, LaBry, & Blair, 2017; Faria, Parker, & Faria, 2005a, 2005b; Lucia, Hoyos, & Chicharro, 2001; Rønnestad & Mujika, 2014; Santalla, Earnest, Marroyo, & Lucia, 2012) available examining cycling performance more generally, no study has combined and summarised the growing body of knowledge specifically examining the factors influencing road cycling sprint performance. Therefore, the purpose of this review was to: i) define and describe sprinting in road cycling, ii) provide an overview of the physiological capabilities required to perform at a professional level, iii) describe the interaction between the cyclist and bicycle during a road sprint, and iv) outline the effect of other cyclists on road sprint cycling performance (the interaction between cyclists).

## 2. Sprinting in Road Cycling

Professional road cycling is an extremely demanding sport. To participate at the highest level, male road cyclists ride approximately 22,000 to 35,000 km in training and competitions per year (Metcalf et al., 2017; Nimmerichter, Eston, Bachl, & Williams, 2011; Pinot & Grappe, 2015). The mean weekly training duration for road cyclists is approximately 16 to 25 h (Nimmerichter et al., 2011; Pinot & Grappe, 2015), which is close to twice the amount of training hours per week when compared with marathon runners

(Stellingwerff, 2012). Professional male and female cyclists have been reported to participate in at least 30 and up to 95 races each year (Pro-Cycling-Stats).

Cycling velocity is incredibly important in road cycling competitions, since even during multi-stage events, the cyclist who finishes the race in the shortest time wins. Cycling velocity is influenced by a range of factors including the cyclist's physical capacities (De Pauw et al., 2013; Fintelman, Sterling, Hemida, & Li, 2014; Nimmerichter et al., 2011; Novak & Dascombe, 2014; Pinot & Grappe, 2015); opposing resistances (i.e. gravity, wind, acceleration, and friction (Martin, Gardner, Barras, & Martin, 2006b)); the interaction between cyclist and bicycle (Crouch et al., 2017; Fintelman et al., 2014; Hansen & Waldeland, 2008); and the interaction between cyclists (Blocken et al., 2018; Menaspà, Abbiss, & Martin, 2013). Sprinting is the fastest activity on a bicycle (with the exclusion of some descending) in which male (Menaspà, Quod, et al., 2015) and female (Peiffer, Abbiss, Haakonssen, & Menaspà, 2018b) cyclists reach peak velocities near or in excess of 70 km h<sup>-1</sup>. A road cycling sprint has been defined as 'the acceleration which occurs toward the end of competitions in order to reach the finish line in front of other competitors' (Menaspà, Quod, et al., 2015). Typically, the road cycling sprint takes place after hours of endurance cycling and can be compared with the final acceleration in marathon running. Towards the end of the race power output gradually increases and is followed by a final dash to the finish line (Menaspà, Quod, et al., 2015). The duration of the final sprint ranges between 9 and 17 s for both male professional and under 23 (U23) cyclists (Martin, Davidson, & Pardyjak, 2007; Menaspà, Abbiss, et al., 2013; Menaspà, Quod, et al., 2015; Menaspà, Quod, et al., 2013), and between 10 and 33 s in professional female cyclists (Peiffer et al., 2018b).

In addition, within some road cycling events, cyclists also sprint for intermediate sprints. In fact, during multi-stage races, 'intermediate' and 'King of the Mountain' sprint lines are often placed along the course. At the intermediate sprint lines, cyclists can earn bonus seconds for the general classification

and/or points for a dedicated points jersey (also known as sprint jersey). The King of the Mountain sprint lines are places on top of a hill or mountain. At these lines, cyclists can earn points for the King of the Mountain jersey. There is currently no research available examining these intermediate sprints. Further research is needed to better understand the factors important to success in intermediate sprints and implications of such sprints to overall outcomes on general, sprint, and King of the Mountain classifications. Regardless, the existence of these sprints further highlights the importance of understanding sprinting characteristics within road cycling.

### 3. The Cyclist's Physiology and Capabilities

Road cyclists can fulfil several different roles throughout a race based on tactical decisions, and the athlete's physiological and performance characteristics. One characteristic that discriminates road cycling sprinters from other specialists, is their capacity to produce extremely high power outputs over relatively short durations (Pinot & Grappe, 2011; Sallet, Mathieu, Fenech, & Baverel, 2006). However, road cycling sprinters are also required to reach each intermittent or final sprint at the same time as other competitors to compete in the final dash to the line. As a result, road sprint cyclists are not only required to be able to produce high sprint power outputs but also be able to resist fatigue prior to and during the sprint. The athletic demands of road cycling sprints, road sprint cycling specialisation, and how to measure sprint performance is discussed below.

### 4. Athletic Demands of Road Cycling Sprinting

The energetic demands during road cycling races are predominantly placed on the aerobic metabolism (Lucia et al., 2001; Mujika & Padilla, 2001) and road cycling is therefore often described as an aerobic event (De Pauw et al., 2013; Lucia et al., 2001; Mujika & Padilla, 2001). However, road cycling can be seen as an intermittent sport in which several short and high intensity efforts are repeated (Abbiss, Straker, Quod, Martin, & Laursen, 2010), during which a contribution of

anaerobic metabolism is required (Faria et al., 2005b; Fernandez-Garcia, Perez-Landaluce, Rodriguez-Alonso, & Terrados, 2000; Olds, 2001). For example, short high intensity efforts are required when establishing a breakaway (i.e. riding away from a group of cyclists) (Abbiss, Menaspà, Villerius, & Martin, 2013), climbing a steep hill, or during intermediate and final road cycling sprints (Martin et al., 2007; Menaspà, Abbiss, et al., 2013; Menaspà, Quod, et al., 2015; Menaspà, Quod, et al., 2013). Several studies (Abbiss, Burnett, et al., 2010; Del Coso, Hamouti, Aguado-Jimenez, & Mora-Rodriguez, 2009; Etxebarria, Ingham, Ferguson, Bentley, & Pyne, 2019; Menaspà, Martin, Victor, & Abbiss, 2015; Schabort, Hawley, Hopkins, Mujika, & Noakes, 1998; Sharma, Elliott, & Bentley, 2015) have attempted to replicate the stochastic nature of power output observed during road cycling races (Abbiss, Straker, et al., 2010). The participants in these studies (Abbiss, Burnett, et al., 2010; Del Coso et al., 2009; Etxebarria et al., 2019; Menaspà, Martin, et al., 2015; Schabort et al., 1998) were not classified as sprinters. As such, it is possible that sprint performance of specialised road sprinters (who typically have lower aerobic characteristics when compared with other road cycling specialisations (Menaspà et al., 2012; Sallet et al., 2006)) could potentially be affected by the high-intensity variability of road races. Additionally, some of these studies (Abbiss, Burnett, et al., 2010; Del Coso et al., 2009; Etxebarria et al., 2019; Schabort et al., 1998; Sharma et al., 2015) combined periods of high intensity (e.g. 1 or 4 min) with submaximal cycling but did not account for the high demands of the long lead-up phase of a road cycling race (Menaspà, Quod, et al., 2015; Menaspà, Quod, et al., 2013). Indeed, professional road cycling sprints occur following a long lead-up period during which cyclists are typically riding at or above mean maximal power of 1 h for extended periods (Menaspà, Quod, et al., 2013). Additionally, cyclists will most likely be riding close to or above their critical power (CP) and VO<sub>2</sub>max in the final stages before the final acceleration to the finish line. CP is the highest power output at which oxygen consumption and blood lactate are stable (Poole, Ward, Gardner, & Whipp, 1988). When riding above

CP, cyclists are most critically limited by their finite amount of energy coming from the anaerobic metabolism (Fukuba et al., 2003; Fukuba & Whipp, 1999; Palmer, Dennis, Noakes, & Hawley, 1996). It can be concluded that road cycling sprint performance can be improved by either improving anaerobic capacity or the maximal rate of aerobic metabolism (VO<sub>2</sub>max).

Much of the available research in sprinting has examined performance in a non-fatigued state (Menaspà et al., 2012; Munro, Stannard, Fink, & Foskett, 2017; Sallet et al., 2006; Tofari, Cormack, Ebert, Gardner, & Kemp, 2017). However, there is currently a paucity of research that has specifically examined the metabolic requirements of road sprinting, especially following 1-7 h of cycling. Adenosine triphosphate resynthesises during non-fatigued sprints is heavily reliant on the anaerobic metabolism in particular, phosphocreatine (phosphagen system) and the degradation of muscle glycogen to lactic acid (anaerobic glycolysis) (Bangsbo, Krstrup, Gonzalez-Alonso, & Saltin, 2001; Gaitanos, Williams, Boobis, & Brooks, 1993; Gastin, 2001; Jones et al., 1985; Parolin et al., 1999). It is important to note that a road cycling sprint occurs after hours, and sometimes after multiple days of racing including a long lead-up phase. As a result, road sprint cyclists are somewhat unique and have to be able to rapidly produce high power outputs in multiple states of fatigue. However, it is also important to consider that pacing within the sprint is not dictated solely by metabolic pathways. Indeed, any energy carried over the finish line is essentially wasted energy. Therefore, using this energy to accelerate rapidly is important in road sprint cycling. The rapid increase in power output is often caused by cyclists starting their sprints by standing out of their saddle and getting out of the slipstream of another cyclist in front (Menaspà, Abbiss, et al., 2013) and followed by a quick decline in power output during the rest of the sprint (Martin & Brown, 2009; O'Bryan, Brown, Billaut, & Rouffet, 2014). Current literature has been important in identifying power output during a sprint at the end of a race and in a non-fatigued state. There is currently limited literature



examining the behaviour of opponents which might affect pacing strategies and performance (Konings, Parkinson, Zijdewind, & Hettinga, 2018; Konings, Schoenmakers, Walker, & Hettinga, 2016). Additionally, no studies are available describing the difference in road cycling sprint power output before and at the end of a road cycling race, most likely due to its practical limitations.

## 5. Cycling Specialists and Road Cycling Sprinters

Despite competing in the same races, a significant difference in anthropometric, physiological, and performance characteristics exists between various road cycling specialists (Impellizzeri et al., 2008; Lucia, Joyos, & Chicharro, 2000; Menaspà et al., 2012; Padilla, Mujika, Cuesta, & Goiriena, 1999; Pinot & Grappe, 2011; Sallet et al., 2006). To date, much of the literature has described and compared the physiological characteristics of uphill, flat terrain, all terrain, and time trial specialists (Impellizzeri et al., 2008; Lucia et al., 2000; Padilla et al., 1999; Pinot & Grappe, 2011). Interestingly, only one study has compared the anthropometric and physiological characteristics (Sallet et al., 2006), and two studies have compared the performance characteristics (Pinot & Grappe, 2011; Sallet et al., 2006) of adult road cycling sprinters with other specialists. In one of the studies (Sallet et al., 2006) it has been shown that male road cycling sprinters have similar height ( $175.6 \pm 2.1$  cm), body mass ( $67.3 \pm 2.5$  kg), body fat percentage ( $8.2 \pm 2.3\%$ ),  $VO_{2max}$  ( $71.8 \pm 4.7$  mL  $\cdot$ kg $^{-1}$  min $^{-1}$ ), MAP ( $428.2 \pm 32.5$  W and  $6.3 \pm 0.3$  W  $\cdot$ kg $^{-1}$ ), and gross mechanical efficiency ( $25.4 \pm 1.4\%$ ), when compared with other specialists. These results must be interpreted with caution since this was a cross-sectional study design and only 4 of the 71 participants were classified as road cycling sprinters. In addition, the road cycling sprinters ( $20.2 \pm 2.6$  y;  $n = 4$ ) were significantly younger than the uphill ( $23.6 \pm 3.6$  y;  $n = 24$ ), flat terrain ( $23.5 \pm 3.9$  y;  $n = 32$ ), and all terrain cyclists ( $27.7 \pm 4.8$ ;  $n = 11$ ). Additionally, 45 participants were classified as professional cyclists and 26 as elite cyclists; however, it is unclear how many of the 4 road cycling sprinters were professional or elite cyclists. These limitations could explain why there

were no differences found for the anthropometric, physiological, and performance characteristics. A different study (Menaspà et al., 2012), however, showed that under 19 (U19) male road cycling sprinters were heavier, taller, and had a higher body mass index than uphill cyclists. Additionally, U19 road cycling sprinters had a lower  $VO_{2max}$  and MAP relative to body mass ( $61.9 \pm 4.1$  mL  $\cdot$ kg $^{-1}$  min $^{-1}$  and  $5.5 \pm 0.4$  W  $\cdot$ kg $^{-1}$ ) when compared with uphill cyclists ( $67.5 \pm 5.0$  mL  $\cdot$ kg $^{-1}$  min $^{-1}$  and  $6.2 \pm 0.6$  W  $\cdot$ kg $^{-1}$ ) which could be partly explained by the higher body mass among sprinters. The greater body mass typically observed in road cycling sprinters, when compared with other specialisations, is likely to be the result of the large muscle mass required to produce the high sprint cycling power outputs. Since road cycling sprinters are often competitive during relatively flat races, a gain in power output as a result of greater muscle mass typically outweighs the negative effects caused by relatively greater body mass. Comparatively, a lower body mass is incredibly important in climbing given the high energy cost associated with overcoming gravity (Martin, Milliken, Cobb, McFadden, & Coggan, 1998; Mujika & Padilla, 2001). Competitive female cyclists with greater lower-body lean mass produced greater mean maximal power output (Haakonssen, Martin, Martin, Burke, & Jenkins, 2013). For example, an increase of 1 kg lower-body lean mass resulted in an increase of approximately 9 and 4% in 1 s and 10 min mean maximal power output, respectively (Haakonssen et al., 2013). Additionally, 1 kg of muscle mass was associated with an increase of 35 W during a 30 s sprint (Haakonssen et al., 2013). It should be noted that we are unaware of research specifically modelling the balance between muscle mass, body mass, and cycling performance across a range of course geographies and within a variety of cycling specialisations (e.g. uphill specialists and sprinters), which may be an interesting area for future research.

Through examining the power outputs observed across a range of studies in U19/U23/elite/professional male road cycling sprinters (Table 1) it can be seen that

for the average sprint duration of approximately 14 s (Martin et al., 2007; Menaspà, Abbiss, et al., 2013; Menaspà, Quod, et al., 2015; Menaspà, Quod, et al., 2013) elite/professional male cyclist can produce approximately 14.2 W·kg<sup>-1</sup> (Figure 1). Both case studies (Martin et al., 2007; Menaspà, Quod, et al., 2013) deviate from the trendline, possible due to the small sample size or the participant in these studies was simply a better (Menaspà, Quod, et al., 2013) or worse (Martin et al., 2007) sprinter compared with the sprinters in the other studies. Less studies are available about sprint performance in female road cyclists (Table 2). From the available research, it can be seen that professional female road cyclists can produce a power output of approximately 10.0 W·kg<sup>-1</sup> for an average sprint duration of 22 s (Peiffer et al., 2018b) (Figure 2).

The cadence observed in road sprint cycling is vastly lower than in track cycling. Indeed, the average cadence during male and female road cycling sprints has been shown to be approximately 110 (Menaspà, Martin, et al., 2013; Menaspà, Quod, et al., 2015) and 103 rpm (Peiffer, Abbiss, Haakonssen, & Menaspà, 2018a) with a peak cadence of approximately 114 (Menaspà, Quod, et al., 2015) and 110 rpm (Peiffer et al., 2018a), respectively. Peak and mean cadence in male track cyclists has been shown to be approximately 155 (Craig & Norton, 2001; Gardner, Martin, Barras, Jenkins, & Hahn, 2005) and 135 (Craig & Norton, 2001; Menaspà, Martin, et al., 2013), respectively. This difference in cadence has significant implications for the neural constraints that influence sprint performance in these two disciplines and therefore the training strategies that are likely to result in optimal adaptation and performance. Cadence has an effect on kinetics and kinematics during cycling. For example, increasing cadence has been shown to decrease ankle and knee joint range of motion (Bini, Rossato, et al., 2010; Bini, Tamborindéguy, & Mota, 2010; McDaniel, Behjani, Elmer, Brown, & Martin, 2014; Rauen, Angeloudis, & Falconer, 2012) while hip joint range of motion increased during sprints (McDaniel et al., 2014). Such a decrease in ankle joint range of motion may be

important especially at higher power outputs or when a cyclist is fatigued as it allows the stabilisation of the joint and transfer of high power output from the hip and knee to the pedal (Bini, Tamborindéguy, et al., 2010; McDaniel et al., 2014; Rauen et al., 2012). Indeed, power produced at the hip and knee is transferred to the pedal via the ankle. Conversely, studies have also shown no changes in hip and knee range of motion during submaximal efforts (Bini, Tamborindéguy, et al., 2010). The difference in results between these studies might be explained by the power contribution of each joint at low versus high power outputs. A different effect of an increased cadence on kinetics is that it leads to an increase in knee joint power contribution and a decreased hip joint power contribution during either submaximal or maximal cycling (Elmer, Barratt, Korff, & Martin, 2011; Hoshikawa, Takahashi, Ohashi, & Tamaki, 2007; Mornieux, Guenette, Sheel, & Sanderson, 2007; Sanderson, Mornieux, Guenette, & Sheel, 2008; Skovereng, Ettema, & van Beekvelt, 2017; Strutzenberger, Wunsch, Kroell, Dastl, & Schwameder, 2014). This interaction between hip and knee contribution acts in such a way that they compensate for one another to maintain pedal power. According to the majority of available studies ankle contribution does not change with changes in cadence (Bini, Rossato, et al., 2010; Elmer et al., 2011; Hoshikawa et al., 2007; Mornieux et al., 2007; Sanderson et al., 2008; Skovereng et al., 2017; Skovereng, Ettema, & van Beekvelt, 2016; Strutzenberger et al., 2014), except for one study that reported an increased ankle contribution when changing a cadence from 40 to 70 rpm (from ~3.5 to ~4% of overall power contribution) (Bini, Tamborindéguy, et al., 2010). It is unclear why an increase in ankle contribution was observed in this particular study but it could be due to the low cycling level of the participants (healthy males without experience in cycling competition) and therefore poor pedalling technique (Bini, Tamborindéguy, et al., 2010). It can be concluded that an increased cadence leads to a shift in total power contribution of the hip and knee with the knee providing a greater contribution to the overall power output.

Table 1 – Power output and cadence during sprints in male road cycling (Mean  $\pm$  SD)

Reference	Level	Type of data collection	n cyclists	n sprints per cyclist	Age (y)	Sprint duration (s)	Power (W·kg <sup>-1</sup> )	Cadence (rpm)
Martin et al., 2007	Professional	Final sprint during a race	1	1	-	14.0	Peak 13.7	-
							Mean 11.6	
Menaspà et al., 2012	U19	Laboratory	25	1	16.9 $\pm$ 0.6	5.0	Mean 16.6 $\pm$ 0.6	Peak 157.0 $\pm$ 5.0
Menaspà, Martin, et al., 2013	Professional	Maximal mean power during races	3	-	26.0 $\pm$ 3.0	1.0	Mean 18.8 $\pm$ 2.1	Peak 109.0 $\pm$ 6.0*
						10.0	Mean 16.3 $\pm$ 1.8	
						20.0	Mean 13.1 $\pm$ 1.1	
						30.0	Mean 11.7 $\pm$ 0.6	
Menaspà, Quod, et al., 2013 (PRO)	Professional	Final sprint during races	1	4	23.0	14.5 $\pm$ 2.4	Peak 19.1 $\pm$ 0.7	-
							Mean 15.6 $\pm$ 0.4	
Menaspà, Quod, et al., 2013 (U23)	U23	Final sprint during races	1	5	18.0	12.8 $\pm$ 1.1	Peak 20.6 $\pm$ 1.0	-
							Mean 17.4 $\pm$ 1.1	
Menaspà, Quod, et al., 2015	Professional	Final sprint during races	6	~3	27.0 $\pm$ 3.8	13.2 $\pm$ 2.3	Peak 17.4 $\pm$ 1.7	Peak 114.0 $\pm$ 5.0
							Mean 14.2 $\pm$ 1.1	Mean 110.0 $\pm$ 5.0
Pinot & Grappe, 2011	-	Maximal mean power during races and training	5	~250	-	1.0	Mean 20.2	-
						5.0	Mean ~18.8	
						30.0	Mean ~11.9	
Sallet et al., 2006	-	Laboratory	4	1	20.2 $\pm$ 2.6	30.0	Peak 19.0 $\pm$ 1.1	Peak 216.0 $\pm$ 8.8

Abbreviations: SD = standard deviation; n = number; PRO = professional; U19 = under 19; U23 = under 23; \* = Cadence at 1 s mean power.

Table 2 – Power output and cadence during sprints in female road cycling (Mean ± SD)

Reference	Level	Type of data collection	n cyclists	n sprints per cyclist	Age (y)	Sprint duration (s)	Power (W·kg <sup>-1</sup> )	Cadence (rpm)
Menaspà et al., 2017 (Top 10)	Professional	Maximal mean power during races	7	~4	28.5 ± 2.9	1.0	Mean 14.3 ± 1.1	-
						5.0	Mean 13.4 ± 1.3	
						10.0	Mean 12.3 ± 1.4	
						20.0	Mean 10.7 ± 1.3	
						30.0	Mean 9.5 ± 1.1	
Menaspà et al., 2017 (non-Top 10)	Professional	Maximal mean power during races	7	~3	28.5 ± 2.9	1.0	Mean 13.9 ± 1.1	-
						5.0	Mean 12.5 ± 1.2	
						10.0	Mean 11.0 ± 1.4	
						20.0	Mean 9.4 ± 1.5	
						30.0	Mean 8.3 ± 1.2	
Peiffer et al., 2018a	Professional	Final sprint during races	7	~4	-	21.8 ± 6.7	Peak 13.9 ± 1.3	Peak 110 ± 9
							Mean 10.6 ± 1.5	Mean 103 ± 8

Abbreviations: SD = standard deviation; n = number.



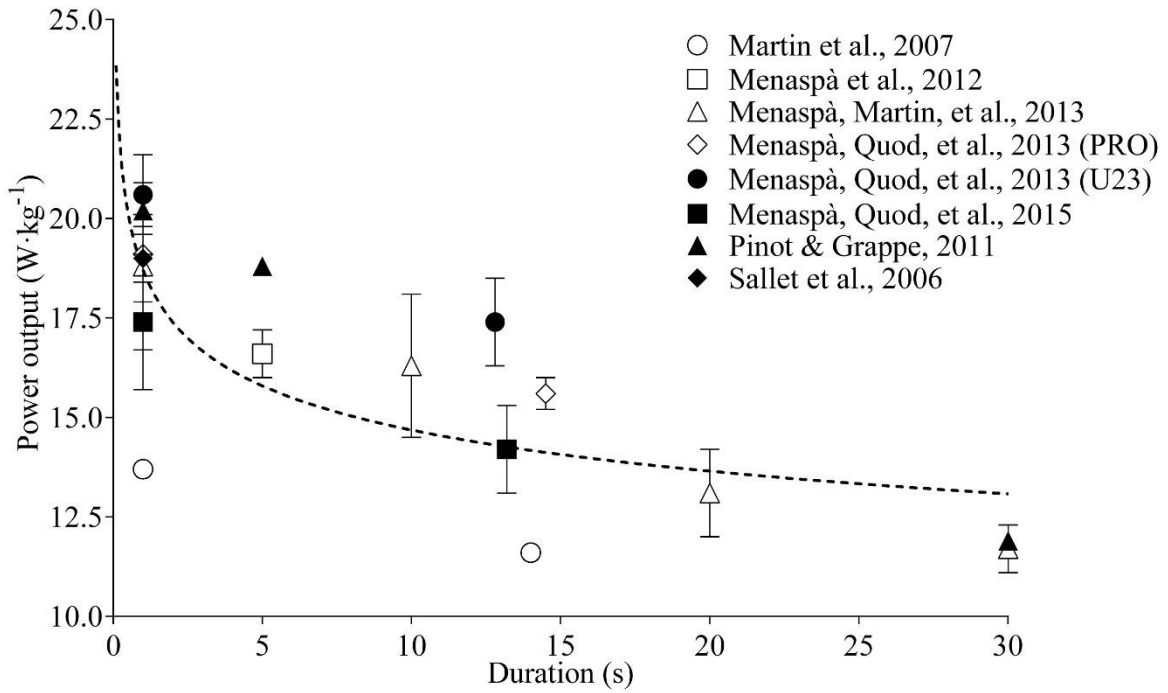


Figure 2 — Power output and sprint duration in male road cyclists

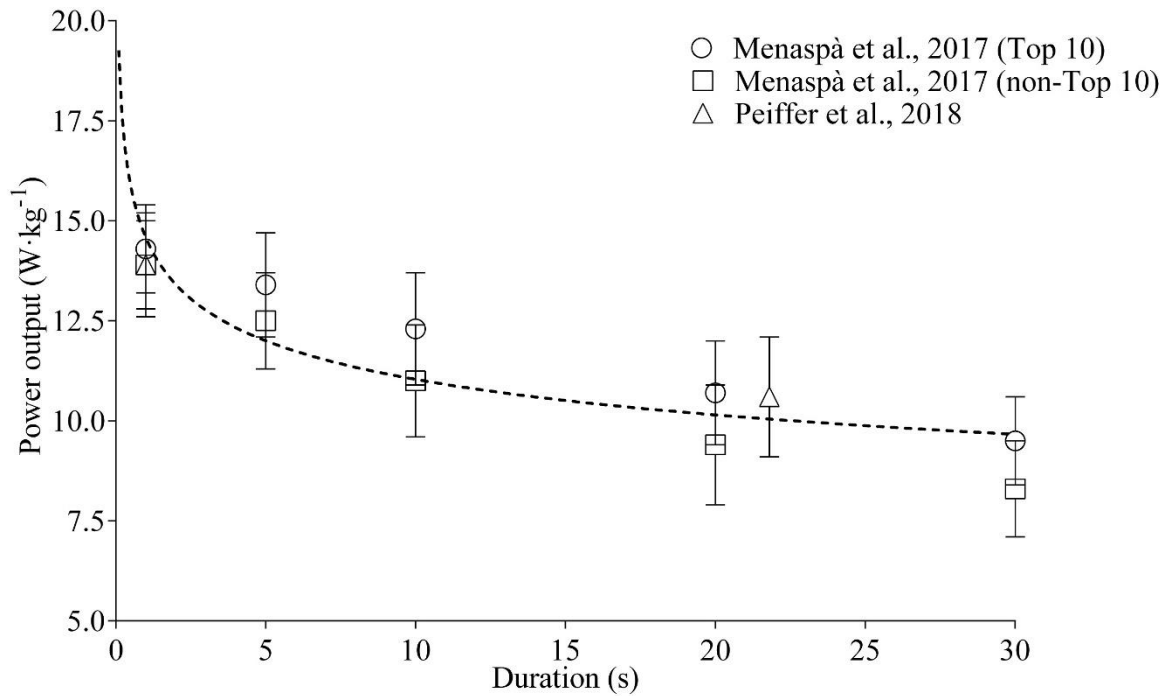


Figure 1 — Power output and sprint duration in female road cyclists

## 6. Measuring Sprint Power Output in Cycling

To date, studies have examined the power output during the sprint in a laboratory setting (Barratt, Korff, Elmer, & Martin, 2011; Del Vecchio *et al.*, 2019; Harnish, King, & Swensen, 2007; McLester, Green, & Chouinard, 2004; Moura, Luis Moro, Rossato, de Lucas, & Diefenthaler, 2017; Mujika, Rønnestad, & Martin, 2016; Padulo, Laffaye, Bertucci, Chaouachi, & Viggiano, 2014; Reiser, Maines, Eisenmann, & Wilkinson, 2002) and during professional road cycling races (Martin *et al.*, 2007; Menaspà, Martin, *et al.*, 2013; Menaspà, Quod, *et al.*, 2015; Menaspà, Quod, *et al.*, 2013). An important consideration when comparing laboratory and field-based cycling is that laboratory-based ergometers often have limited lateral movement (lateral sway) (Bertucci, Tiaar, & Grappe, 2005). This is especially important in sprinting because lateral sway might lead to a higher power output as a result of a higher global upper limb activity when compared with no use of lateral sway (Duc, Bertucci, Pernin, & Grappe, 2008). However, it is worth noting that it is often difficult to obtain accurate and reliable data on muscle activity (Duc *et al.*, 2008; Li & Caldwell, 1998) and other factors important to sprint cycling (e.g. torque development (Watsford, Ditroilo, Fernandez-Pena, D'Amen, & Lucertini, 2010) and optimal cadence (Martin *et al.*, 2007)) during field-based testing. Additionally, the advantage of testing in a laboratory is that environmental conditions (e.g. temperature and wind) can be kept consistent, and allow accurate assessment of a range of factors and their effect on cycling performance including a training intervention (Del Vecchio *et al.*, 2019; Mujika *et al.*, 2016), bicycle setup (Barratt *et al.*, 2011; Moura *et al.*, 2017), or body position (Harnish *et al.*, 2007; McLester *et al.*, 2004; Merkes, Menaspà, & Abbiss, 2020; Padulo *et al.*, 2014; Reiser *et al.*, 2002). To date, it is unclear if there are any differences in power output between sprinting in the laboratory and on the road. It has been reported that track sprinters can produce similar torque and power-peddalling rate relationships in laboratory and track-based tests (Gardner *et al.*, 2007). Additionally, peak

power output, maximal force, and time to obtain peak power output were higher (~1, 69, and 13%, respectively) during a 55 m sprint from a standing start in a gymnasium when compared with a laboratory test (Bertucci *et al.*, 2005). Future research could investigate the difference in the sprint performance of cyclists when sprinting on the road compared with the laboratory.

The analyses of field-based road cycling performance have, to date, typically focussed on the explosive power output throughout the dash towards the finish line (Martin *et al.*, 2007; Menaspà, Martin, *et al.*, 2013; Menaspà, Quod, *et al.*, 2015; Menaspà, Quod, *et al.*, 2013) and the lead-up phase (Menaspà, Quod, *et al.*, 2015; Menaspà, Quod, *et al.*, 2013). These studies have predominantly focused on the duration, and peak and mean power output achieved during the lead-up phase and the dash towards the finish line. To date, no detailed analysis exists including the effect of geography and stage profile on sprint performance; the rate of development of power output during the sprint; or the metabolic requirements and fatigue development during both lead-up phase and sprint.

## 7. Interaction between Cyclist and Bicycle

Cycling is a complex multi-joint movement, involving several important considerations which influence the delivery of force from the cyclist to the bicycle and from the bicycle to the road. This is critically important in road sprints given the maximal demands placed upon the cyclist, whereby effective maximal force transfer plays a major role in sprinting due to the maximal nature of the activity. Furthermore, road sprinting is often performed in a range of different body positions (e.g. seated and standing), which influences muscle activation and force production, the number of contact points between the bicycle and the cyclist, and the aerodynamic drag. As a result, direct comparison of cycling biomechanics, performance, and limits to performance during seating and sprint cycling is flawed. Similarly, the majority of research examining cycling while standing has focussed on uphill

cycling and direct comparison with sprint road cycling is problematic.

## 8. Cyclist's Body Position during Road Cycling Sprinting

During prolonged road cycling, cyclists adopt a range of different body positions (e.g. seated or standing), but generally the majority of the time is spent cycling in a seated position (Arkesteijn, Jobson, Hopker, & Passfield, 2016; Bouillod & Grappe, 2018; Bouillod et al., 2018; Hansen & Waldeland, 2008; Millet, Tronche, Fuster, & Candau, 2002). To date, the majority of the literature available on this topic has examined the influence of body position on performance, fatigue, and movement economy during cycling on the flat and uphill. In a standing position there is a loss in saddle support, more lateral sway (Bertucci et al., 2005; Bouillod et al., 2018), and a forward shift in the cyclist's centre of gravity, when compared with a seated position (Caldwell, Li, McCole, & Hagberg, 1998). This increases the degrees of freedom for segmental movements (Li & Caldwell, 1998). Changing from a seated to a standing position alters muscle recruitment patterns, increasing muscle activation in both upper and lower body muscles (Chen, Wu, Chan, Shih, & Shiang, 2016; Duc et al., 2008; Li & Caldwell, 1998; Turpin, Costes, Moretto, & Watier, 2017), and increasing transfer of power across the hip (Davidson et al., 2005). As a result of this, cyclists can produce greater power outputs in the standing position, when compared with a seated position during both prolonged cycling (Bouillod & Grappe, 2018; Chen et al., 2016; Hansen & Waldeland, 2008) and sprinting (Bertucci et al., 2005; Bertucci, Taiar, Toshev, & Letellier, 2008; Merkes et al., 2020; Millet et al., 2002; Reiser et al., 2002; Rohsler et al., 2020). During uphill cycling, shifting from a seated to a standing position typically results in a lower cadence (Harnish et al., 2007), with a shift in the direction and an increase in the magnitude of the resultant pedal force (Caldwell, Hagberg, McCole, & Li, 1999; Caldwell et al., 1998). Furthermore, the forward hip and knee positions induce changes in the hip (increase of ~25%), knee (increase of ~44%), and ankle joint moments (increase of ~38%) with a modified contribution of muscular and non-muscular

forces (i.e. gravity) (Caldwell et al., 1999; Caldwell et al., 1998).

These changes in cycling biomechanics are associated with altered muscle recruitment as evidenced by alterations in the intensity and timing of electromyographic (EMG) activity of the hip and knee extensors (Caldwell et al., 1998; Li & Caldwell, 1998; Turpin et al., 2017). For example, Turpin and colleagues (Turpin et al., 2017) reported that a standing position is favourable in terms of EMG at power outputs greater than 500 W due to position-dependent modulations of muscle activation levels. In addition to greater power output, cycling in a standing position has been shown to elicit greater heart rates, ventilatory responses (Millet et al., 2002), and mechanical cost (Bouillod & Grappe, 2018; Bouillod et al., 2018; Hansen & Waldeland, 2008). A greater mechanical cost (or decrease in efficiency) may be of concern during prolonged cycling in a standing position, such as observed during uphill cycling. However, it should be noted that when cycling at submaximal workloads a decrease in efficiency is not always critical to performance. Indeed, a short term increase in oxygen consumption when cycling submaximally uphill may not be problematic, when exercising below CP. This is especially true if the change in position allows activation of different muscle groups (Arkesteijn et al., 2016), reducing localised neuromuscular fatigue. However, an increase in oxygen consumption resulting from a less efficient cycling position at the end of the lead-up phase, when at or near  $\dot{V}O_{2max}$  (Menaspà, Quod, et al., 2015), may have significant implications for sprint performance. To the author's knowledge no study has yet compared movement efficiency during different cycling sprint positions following a fatiguing bout of exercise which replicates the lead-up phase of a final sprint in road cycling.

Standing while sprinting has a positive effect on power output when compared with a seated position (Bertucci et al., 2005; Bertucci et al., 2008; Merkes et al., 2020; Millet et al., 2002; Reiser et al., 2002; Rohsler et al., 2020). For example, Reiser and colleagues (Reiser et al., 2002) observed a 6 to 8% improvement in peak and mean power output while standing (19.4 and 11.0 W·kg<sup>-1</sup>, respectively) during a

30 s Wingate, compared with sitting (17.9 and 10.4 W·kg<sup>-1</sup>, respectively). By adopting a lower and more forward torso and head position to reduce aerodynamic drag (e.g. forward standing position) (Blocken, van Druenen, Toparlar, & Andrienne, 2019; Crouch et al., 2019; Merkes, Menaspà, & Abbiss, 2019a), the centre of gravity is presumably shifted forward and lower when compared with a more traditional standing position. Research has shown that during a 14 s sprint in a laboratory, recreational cyclists produce similar power outputs in the forward standing position compared with the standing position (Merkes et al., 2020). However, to date, no study has analysed the effect of a forward standing position on power output, muscle activation, force transfer, and performance in the field and might be an avenue for future research.

## 9. Aerodynamics of Road Cycling Sprinters

When cycling on level ground, air resistance is the main opposing force to the motion (Martin et al., 2006b). Indeed, air resistance represents up to approximately 95% of the total resistive forces experienced when cycling at 65 km·h<sup>-1</sup> (di Prampero, Cortili, Mognoni, & Saibene, 1979). This resistance is dictated by air density, the airspeed of the bicycle, and the aerodynamic drag (CdA). The CdA is the product of the drag coefficient (Cd, dimensionless) and the combined projected frontal area of the cyclist and bicycle (Ap, in m<sup>2</sup>). The Cd is used to model all the complex factors of shape, position, and air flow conditions relating to the cyclist, and typically ranges from approximately 0.6 during a time trial to over 0.8 while riding on the hoods (Gibertini & Grassi, 2008). In addition, Ap represents the proportion of an object (i.e. cyclist + bicycle) that can be seen by an observer placed exactly in front of that object (also known as the frontal area); that is the projected surface normal to the fluid displacement. It has previously (Martin et al., 1998) been suggested to combine Cd and Ap into a single variable, CdA, as Cd is dominated by the turbulence associated with the cyclist's position, shape, size, and surface roughness; as Ap changes the flow over the cyclist will also change. In other words, decreasing Ap (due to changes in cycling

position) does not directly result in a lower CdA. A correlation exists between measured Cd and Ap, in which Ap accounts for approximately 50% of the variation in drag between different cycling positions (Bassett, Kyle, Passfield, Broker, & Burke, 1999).

External power required to overcome air resistance is a third polynomial of the velocity (Underwood, Schumacher, Burette-Pommay, & Jermy, 2011), making it necessary to increase power output by 2% to increase cycling velocity by 1% only, when riding at 65 km·h<sup>-1</sup> (Martin et al., 2006b). Reducing CdA is therefore of high importance to road cycling performance, and even more in sprint performance since sprinting is the fastest activity in road cycling (with the exclusion of some descending). Given that the outcomes of road cycling sprints are often decided by very small margins, aerodynamics are extremely important to overall sprint performances. However, to date the majority of research into aerodynamics and cycling position have focused predominately on the time trial or prolonged cycling performance (Barry, Burton, Sheridan, Thompson, & Brown, 2014; Barry, Burton, Sheridan, Thompson, & Brown, 2015; Fintelman, Sterling, Hemida, & Li, 2015; Garcia-Lopez et al., 2008; Underwood et al., 2011).

Changing from a seated to a standing position increases maximal power output but has a negative effect on CdA, which increases by approximately 16.5% (Blocken et al., 2019; Martin et al., 2007; Martin et al., 2006b; Merkes et al., 2019a). From data published on aerodynamics in cycling, it is known that lowering the torso (Barry et al., 2014; Fintelman et al., 2015; Garcia-Lopez et al., 2008; Underwood et al., 2011) and head (Barry et al., 2014; Barry et al., 2015), riding with the hands on the hoods compared with the drops (with the arms bend) (Barry et al., 2014), and bringing the arms inside the silhouette of the hips (Barry et al., 2014), all improved aerodynamics. Three recent studies using different measuring techniques (i.e. computational fluid dynamics and wind tunnel tests of static models of a cyclist (Blocken et al., 2019); wind tunnel tests (Crouch et al., 2019), and field tests (Merkes et al., 2019a)) have shown that lowering the



torso and head (Blocken et al., 2019; Crouch et al., 2019; Merkes et al., 2019a), and moving the elbows inwards (Crouch et al., 2019) reduced CdA by approximately 25% during road cycling sprints in both males (Blocken et al., 2019; Crouch et al., 2019; Merkes et al., 2019a) and females (Crouch et al., 2019). An improvement in aerodynamics, due to changing cycling position, should lead to a higher velocity for a given power output, and will therefore increase the likelihood of success in a road cycling sprint.

To date, performance within cycling literature is typically reported based upon power output data (i.e. W or W·kg<sup>-1</sup>). However, it has been suggested that allometrically scaling power output (i.e. W·kg<sup>-0.32</sup> and W·kg<sup>-0.79</sup>) may provide a better indicator of flat and uphill cycling performance, respectively (Faria et al., 2005b; Mujika & Padilla, 2001; Padilla et al., 1999; Swain, 1994). This makes sense given the importance of body mass within cycling particularly when required to overcome gravity (i.e. uphill); however, it is unclear why it has not been used in more recent research. Additionally, as shown above, the main resistive force to overcome in a sprint is air resistance and not gravity. Although a number of studies have accounted for this by reporting power output relative to frontal area (W·Ap<sup>-1</sup>) (Menaspà, Quod, et al., 2013; Mujika & Padilla, 2001; Padilla et al., 1999), decreasing Ap (due to changes in cycling position) does not directly result in a lower CdA, as noted above. Therefore, in future research it might be interesting to see if power output relative to CdA is a better indicator of road cycling success. This has been discussed in high performance cycling (Cycling-Power-Lab, 2014) but has not been reported in scientific literature to date.

## 10. Measuring CdA in Cycling

Aerodynamics are typically determined using either a wind tunnel or mathematical modelling. In a wind tunnel air flow is created with a fan in front of the cyclist-bicycle system. The assessment of CdA is determined based on ground reaction forces through force plate measurements (Debraux, Grappe, Manolova, & Bertucci, 2011). Cyclists are placed on the bicycle on either a stationary

force plate (passive) or on an ergometer on a force plate (active). The wind tunnel is the most valid and reliable technique to measure aerodynamics, and it can be used to assess different cycling postures, handlebars, frames, clothing, helmets, and wheels at different yaw angles (Barry et al., 2015; Chabroux, Barelle, & Favier, 2012; Debraux et al., 2011; Garcia-Lopez, Ogueta-Alday, Larrazabal, & Rodriguez-Marroyo, 2014; Garcia-Lopez et al., 2008; Oggiano, Troynikov, Konopov, Subic, & Alam, 2009; Underwood, Jermy, Eloi, & Cornillon, 2015; Underwood et al., 2011). Despite the high validity, reliability, and sensitivity, wind tunnel testing is relatively expensive and facilities are somewhat scarce. Practical field-based methods to assess CdA have therefore been established (Martin et al., 2006b; Martin et al., 1998).

Martin and colleagues developed (Martin et al., 1998) and updated (Martin et al., 2006b) a mathematical model which accounts for 97% of the variability in steady-state cycling power output when all the model parameters are known (CdA, rolling resistance, drive train resistance, and changes in kinetic and potential energy). When power output is known (using a power meter) this model can be used for CdA calculations. These two mathematical models were shown to be valid methods for calculating CdA on the road (Martin et al., 2006b) and in the velodrome (Garcia-Lopez et al., 2014) when compared with a wind tunnel. The updated model uses Equation (2.1):

$$P_a \cdot E - \Delta PE / \Delta t - \Delta KE / \Delta t = C_d A \cdot (1/2 \rho [(V_a)]^2 V_g) + \mu \cdot (V_g F_N)$$

(Equation 2.1)

in which P<sub>a</sub> is the average power output in Watts; E is the efficiency of the drive system (assumed to be 97.7% (Martin et al., 1998)); PE is the potential energy; KE is the kinetic energy; CdA is the aerodynamic drag; ρ is the air density; V<sub>g</sub> is the ground velocity of the participants in m·s<sup>-1</sup>; μ is a global coefficient of friction (i.e. 0.004 or 0.006 for smooth and rough road, respectively (Martin, Gardner, Barras, & Martin, 2006a)); and F<sub>N</sub> is the normal force exerted by the bicycle tyres on



the rolling surface (essentially total weight of the bicycle and participant). Using a mathematical model is cheaper and practically more available than the wind tunnel; however, multiple efforts of approximately 200 metres at different velocities are needed to calculate a single CdA value and therefore it is more time consuming.

The ideal solution would be to accurately measure CdA during regular races and training sessions. There are several companies who have developed or are developing devices to measure CdA in the field (e.g. Alphamantis Track Aero System (Bouillod, Pinot, Froncioni, & Grappe, 2015), the Notio Konect Sensor array (Valenzuela *et al.*, 2020), and the Velocomp PowerPod power meter). However, the Alphamantis Track Aero System is currently only usable in a velodrome, while the Notio Konect has not been validated for road sprints and the Velocomp PowerPod cannot be used for measuring aerodynamics during short efforts like sprinting (Merkes, 2020). The latter two devices measure opposing forces caused by changes in elevation, wind, acceleration, and friction (Merkes, Menaspà, & Abbiss, 2019b; Valenzuela *et al.*, 2020). Based upon these opposing forces CdA is calculated using algorithms. Real time calculation of CdA is an incredibly exciting area for cycling research; however, further work is required to determine the accuracy, reliability, and practicality of these devices.

## 11. Bicycle Setup for Road Cycling Sprinting

The interaction between the cyclist and bicycle is affected by numerous factors such as bicycle geometry and setup, crank length, and handlebar size. Establishing the best bicycle setup for a sprint is important but might differ to that of the rest of a race given that modifying bicycle setup can alter mechanical and energy cost (Peveler, 2008), CdA (Oggiano, Sætran, Leirdal, & Ettema, 2008), and lower extremity kinematics (Rankin & Neptune, 2010). Additionally, something like optimal gear ratios for a cyclist aiming to contest for a sprint during a hilly road race is problematic given the need to have appropriate gearing for steep climbs but also

for a very fast sprint finish. A number of aspects related to bicycle geometry can be altered, of which saddle height and set back (distance of the tip of the saddle behind the bottom bracket) have been most frequently examined in research, given their impact on positioning and hence kinematics and kinetics of performance (Bini, 2011; Menard, Domalain, Decatoire, & Lacouture, 2016).

Saddle height has an impact on both prolonged cycling and seated sprinting (Bini, 2011; Peveler & Green, 2011). However, most road cycling sprints are performed in a standing position and therefore not affected by saddle height. Therefore, saddle height should be chosen to optimise prolonged cycling for multiple hours including a high-intensity lead-up phase. Peak power output during a 30 s seated sprint was greater when saddle height was set to result in a knee angle of 25° compared with a saddle height at 109% of inseam (Figure 3) (Peveler & Green, 2011). Additionally, both these saddle heights with a knee angle of 25° (~3%) and at 109% of inseam (~1%) showed greater mean power outputs during the 30 s seated sprint when compared with a saddle height with a knee angle of 35°. Use of a saddle height with a 25° knee angle was found to be more economical in relation to a saddle height with a 35° knee angle and 109% of inseam (Bini, 2011; Peveler & Green, 2011). This is in line with the literature recommending a saddle height with a knee angle of 25 to 30° to minimise oxygen uptake (Bini, 2011).

The length of the crank arm has implications on joint range of motion and therefore affects the length-tension relationship of the working muscle. Furthermore, crank arm length affects the pedal speed at given cadences (Martin & Spirduso, 2001) and therefore can potentially have an effect on muscle-shortening velocities, which have been shown to have optimal ranges (Hautier, Linossier, Belli, Lacour, & Arzac, 1996). The literature contains some inconsistent results on the effect of crank arm length on power output during maximal efforts (Barratt *et al.*, 2011; Inbar, Dotan, Trousil, & Dvir, 1983; Macdermid & Edwards, 2010; Martin, Malina, & Spirduso, 2002; Martin & Spirduso, 2001; Tomas, Ross, & Martin, 2010; Too & Landwer, 2000). Some

studies indicate that cyclists can produce higher power outputs with intermediate crank arm lengths (range 145-180 mm), when compared with extreme crank arm lengths (<140 and >200 mm) (Inbar et al., 1983; Martin & Spirduso, 2001; Too & Landwer, 2000). More recent findings seem to agree that crank arm length does not affect peak power output (Barratt et al., 2011; Macdermid & Edwards, 2010; Martin et al., 2002; Tomas et al., 2010). The latter studies account for changes in cadence, which strongly affects peak power output (Abbiss, Peiffer, & Laursen, 2009; Dorel et al., 2005; Rylands, Roberts, Hurst, & Bentley, 2017). Most of the studies available investigated large changes in crank arm lengths (>15 mm); however, these kinds of extreme crank arms lengths are not available on the market and are unlikely to be practical in road sprint cycling, particularly in technical race finishes with multiple sharp corners prior to the final sprint. To date, there are no studies available testing smaller changes (<5 mm) in crank arm lengths, which would be practically more relevant. Furthermore, most cycling sprints take place in a standing position and the effect of crank arm length on seated versus standing sprint performance has yet to be investigated.

Some road and track cyclists use narrower handlebars to improve aerodynamics (Delaney, 2018; Hurcom, 2015). Narrower handlebars may improve aerodynamics, but they might also have a negative effect on bicycle handling, upper body contribution to the sprint, and the capacity for the upper body to contribute to lateral sway. Therefore, it is just as plausible that it may be detrimental to real race performances. Further research is needed to determine the impact of handlebar width on aerodynamics and performance. In conclusion, what constitutes an optimal bicycle setup for road cycling sprinting is currently unclear and requires further research.

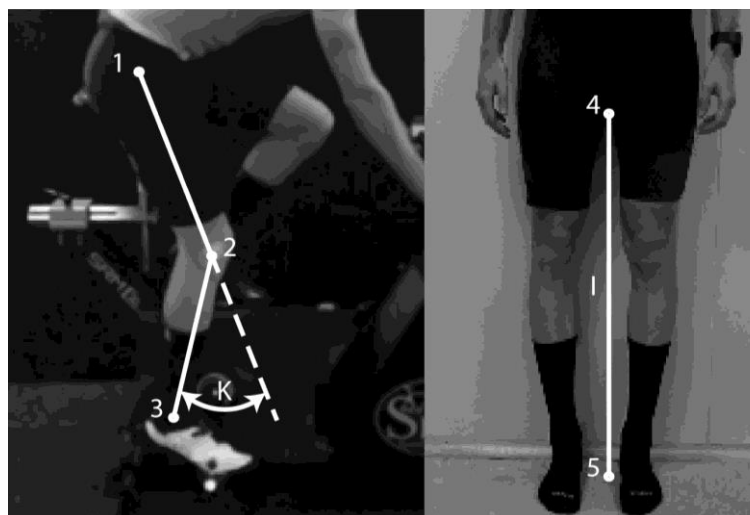


Figure 3 — Overview of how knee angle and inseam are measured in cycling research (Bini, 2011; Peveler & Green, 2011) K = knee angle; I = inseam; 1 = greater trochanter; 2 = lateral femoral epicondyle; 3 = lateral malleolus; 4 = ischium; 5 = floor.

## 12. The Interaction Between Cyclists

In most professional road cycling races, there are over 100 cyclists participating. Therefore, the interaction between cyclists is likely to be an important consideration in performance. The biggest advantage of riding with other cyclists over riding solo, is that cyclists can shelter behind one another (drafting).

## 13. Drafting

The possibility of a cyclist drafting behind other cyclists, and thereby reducing their own CdA, is one of the defining aspects of most races (except individual time trials). A wind tunnel study using 121 models of cyclists has estimated that cycling in a peloton can reduce the CdA down to 5-10% of an isolated cyclist for approximately 40-47% of the cyclists (depending on the density of the peloton) (Blocken et al., 2018). A reduction in CdA also happens when cycling in a smaller group (e.g. breakaway). The second cyclist in line experiences a reduction of approximately 30-50% in CdA when compared with their individual CdA. The next cyclist experiences a reduction of approximately 35-55% compared with baseline. The area behind the first cyclist in line shows a reduction in pressure. Also, the high-pressure in front of the cyclist trailing them reduces the pressure

differential. Both these pressure differences further contribute to the total reduction in pressure drag. The drag of the lead cyclist declines by 5% when another cyclist drafts behind him. This reduction is caused by the high-pressure in front of the trailing cyclist increasing the pressure behind the lead cyclist, thereby reducing pressure drag on the lead cyclist (Barry *et al.*, 2015; Blocken, Defraeye, Koninckx, Carmeliet, & Hespel, 2013; Crouch *et al.*, 2017; Defraeye *et al.*, 2014).

Due to a reduction in aerodynamic drag, trailing cyclists do not have to produce as much power output as the leading cyclist. A reduction in CdA down to 5-10% of an isolated cyclist corresponds to a cycling velocity of approximately 3.2-4.5 times lower than the peloton velocity (Blocken *et al.*, 2018). Furthermore, a reduction in mean power output of 29% was observed when cycling in second position, and a reduction of 36% when cycling in third position compared with the leading cyclist (Broker, Kyle, & Burke, 1999). A different study (Heimans & Dijkshoorn, 2015) showed an even larger reduction in mean power for position two (34%) and three (43%). Velocity reported in both studies was similar (~60 km h<sup>-1</sup>); however, Broker and colleagues (Broker *et al.*, 1999) used an outdoor track with efforts of 2000 m, while Heimans and colleagues (Heimans & Dijkshoorn, 2015) used an indoor track with efforts of 3000 m. On the outdoor track CdA and therefore power output could have been affected by wind velocity and direction (Martin *et al.*, 2006b). Additionally, the longer distance might affect fatigue and the ability to hold the same position for the full length. It can be concluded that a sprinter can save energy by drafting behind single and/or multiple cyclists during the whole race including the lead-up phase and the sprint itself.

#### 14. Team Tactics

Road cycling is an individual sport (with exception of the team time trials and the recently introduced Hammer Series); however, team tactics are of great importance for performance outcomes. With multiple teams trying to win the race with their designated sprinter, it is highly plausible that

cyclists can get in each other's way and the sprinters might not be able to sprint. This plays a major role in race outcomes and therefore teams often attempt an organised lead-out train in the final kilometres of a road race. Menaspà and colleagues (Menaspà, Abbiss, *et al.*, 2013) analysed the number of teammates remaining at 60, 30, and 15 s before the finish line and the position in the bunch of one sprinter during won and lost mass sprint finishes. In this case study, the cyclist had one or two teammates leading him out at 60 s from the finish (~last km) during won races, while rarely any teammates were in front of the subject in lost sprints. The support of the teammates was maintained until the final 15 s when, on average, one teammate was still in front of the cyclist. This team organisation may be responsible for the cyclist's positioning and smooth progression through the bunch in the last minute of each stage. At 60 s from the finish in won stages, the cyclist was significantly closer to the front of the bunch compared with stages resulting in a loss (i.e. 5th-6th vs. 9th-10th position). This study showed that team tactics can be of significant importance to winning professional cycling races finishing with a bunch sprint. Although the above results seem confirmed by anecdotal evidence and practical experiences, more studies confirming this and describing team tactics in different categories and in female road cycling would be needed.

#### 15. Conclusion

A road cycling sprint can be described as 'the acceleration which occurs toward the end of competitions in order to reach the finish line in front of other competitors' (Menaspà, Quod, *et al.*, 2015). During the sprint, male and female cyclists can reach high velocities, up to 70 km h<sup>-1</sup>. Performance outcomes in these sprints are affected by several variables including the cyclist's physiological capabilities, the interaction between the cyclist and their bicycle, and the interaction between cyclists. Professional male and female road cyclists produce a power output of approximately 14.2 and 10.0 W kg<sup>-1</sup> over an average sprint duration of approximately 14 and 22 s, respectively. It is well known that during a road cycling sprint, cyclists can

generate more power output in a standing position than in a seated position. However, the standing position has a negative effect on aerodynamics compared with the seated position. Since air resistance is the highest resistance to overcome during a sprint, changing the standing position itself (e.g. lowering the torso and/or head) might result in better aerodynamics and therefore performance. Cycling in a peloton can reduce the CdA down to 5-10% for nearly half of the cyclists in the peloton. This means that a sprinter could ride at a very low cost in terms of energy before getting to the sprint. However, being close to the front of the peloton during the last part of the race, together with several teammates, seems to favour successful performance.

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