Improving Sprint Performance in Road Cycling

The Forward Standing Sprint Position

This thesis is presented for the degree of

Doctor of Philosophy

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MSc

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Declaration

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Acknowledgements

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Abstract

The majority of road cycling races finish with a sprint and as such sprints are a key determinant of success. Surprisingly, the scientific literature on this specific topic is scarce, with limited to few studies describing the characteristics of road cycling sprinters and the demands of road sprinting. Cyclists' sprinting velocity, which is mostly influenced by power output and aerodynamic drag (CdA) is critical to performance outcomes. However, to date, there is very limited research specifically examining how to maximise road sprint velocity. Thus, the overall objective of the four studies outlined in this thesis was to manipulate CdA, physiology, and coaching cues to improve road sprint cycling velocity and performance.

The first study examined the validity of the Velocomp PowerPod, which calculates power output based on opposing/resistive forces experienced. When power output is known (using a direct force power meter), the Velocomp PowerPod is able to calculate a continuous CdA which was the reason why this study was included into this thesis. The research was split in to two separate studies: i) 12 recreational male road cyclists completed a power profile test (5-600 s); and ii) 4 elite male road cyclists completed 13 outdoor cycling training sessions. In both studies, power output of cyclists was continuously measured using both the Velocomp PowerPod and Verve Cycling InfoCrank power meters. The results showed that rolling resistance estimated by the Velocomp PowerPod (0.011 ± 0.0) was higher than what has been previously reported (0.006), which likely occurred due to errors in the subjective selection of road surface type in the device setup. This overestimation of rolling resistance increased the calculated power output, which was significantly greater than the power output measured by the Verve Cycling InfoCrank power meter in both study i and ii (27 to 39% and 16 to 49%, respectively). When rolling resistance was adjusted to previously reported values (0.006), the Velocomp PowerPod power meter was shown to be comparable to the Verve Cycling InfoCrank power meter during a controlled field test (−0.57 to 0.24%) but not dynamic training sessions

(8.94 to 33.14%). Consequently, the Velocomp PowerPod power meter was not used in subsequent studies within this thesis.

The following two studies examined the effect of a seated, standing, and novel forward standing (lower and further forward head and torso) sprint position on performance. In study 2, eleven recreational male road cyclists rode 250 m at approximately 25, 32, and 40 $km \cdot h^{-1}$ and in each of the three positions. Riding velocity, power output, wind direction and velocity, road gradient, temperature, relative humidity, and barometric pressure were measured and used to calculate CdA using regression analysis. Sprinting in a forward standing position resulted in a 23% and 26% lower CdA, when compared with a seated and standing position, respectively. Furthermore, in contradiction with previous research no difference in CdA was observed between a seated and standing position. Additionally, despite no significant difference in CdA between the two test days a poor between-day reliability was observed. In study 3, eleven recreational male road cyclists performed a 14 s sprint in the three different sprint positions before and directly after a 10 min high-intensity lead-up. Peak and mean power output were similar between the forward standing (1126 ± 49 W and 896 ± 33 W, respectively) and both the seated (1043 ± 47 W and 857 ± 29 W, respectively) and standing positions (1175 ± 45 W and 928 ± 29 W, respectively). Collectively the results from studies 2 and 3 indicate that sprinting in the forward standing position may result in an increase in sprint cycling velocity of 5.6-6.5 $km \cdot h^{-1}$ and 2.1-5.1 $km \cdot h^{-1}$, when compared with the seated and standing sprint positions, respectively.

In study 4, 28 recreational road cyclists completed a two-week (3 sessions per week) sprint training intervention during which they received either i) visual and external focused verbal instructions, and positive feedback on their cycling sprint position (intervention group), or ii) neutral verbal instructions and feedback (control group). The combination of these coaching techniques did not enhance the training induced improvement in forward standing sprint performance. While improvements in peak (4%) and mean power output (3%), and peak torque (5%) were observed in both groups, it is unclear if these improvements are entirely due to the training programme because of the absence of a non-sprint training control group.

This thesis has shown that sprinting in the novel forward standing sprint position could result in an increase of cycling velocity by approximately 5 $km \cdot h^{-1}$, when compared with more traditional sprint positions. In unaccustomed cyclists, sprint performance in this position might be further improved by a short two-week sprint training programme, however, further research is needed in this area. The results from this thesis have implications in training and tactical decisions of cyclists, coaches, and support staff aiming to be successful in competitive road cycling sprints.

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2. Merkes PFJ, Menaspà P, Abbiss CR. Reducing Aerodynamic Drag by Adopting a Novel Road-Cycling Sprint Position. *Int J Sports Physiol Perform.* 2019;14(6):733-738. (Chapter 4)
3. Merkes PFJ, Menaspà P, Abbiss CR. Power Output, Cadence, and Torque are Similar Between the Forward Standing and Traditional Sprint Cycling Positions. *Scand J Med Sci Sports.* 2020;30(1):64-73. (Chapter 5)

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1. Merkes PFJ, Menaspà P, Halperin I, Munro LA, Abbiss CR. The Combination of Visual and External Focused Instructions, and Positive Feedback did not Enhance Training-Induced Improvements in Forward Standing Sprint Performance. Science & Cycling Conference; 2019; Brussels. (Chapter 9.1)

Definition of Abbreviations

Abbreviation	Unit or Term
~	Approximately
°	Degree(s)
ANOVA	Analysis of variance
ANT+	Adaptive network topology
A_p	Frontal area
C	Celsius
Cd	Drag coefficient
CdA	Aerodynamic drag
cm	Centimetre(s)
CP	Critical power
CV	Coefficient of variation
D_B	Riding direction
D_W	Wind direction
E	Efficiency of the drive system
e'	Effective vapor pressure
e.g.	*Exempli gratia*
ECU	Edith Cowan University
EMG	Electromyography
END	End of the sprint
END_{Torque}	Torque at end of the sprint
END_{Video}	Video screenshot at end of the sprint
et al.	*Et alia*
f	Exported frequency
F_N	Normal force
h	Hour(s)
H	Hypothesis
hPa	Hectopascal(s)
HRmax	Maximal heart rate
Hz	Hertz
i.e.	*Id est*
ICC	Intraclass correlation coefficient
KE	Kinetic energy
kg	Kilogram(s)
km	Kilometre(s)
$km \cdot h^{-1}$	Kilometre(s) per hour
kph	Kilometre(s) per hour
LoA	Limits of agreement
m	Metre(s)
$m \cdot s^{-1}$	Metre(s) per second
M_a	Apparent molecular weight of dry air

MAP	Maximal Aerobic Power during an incremental exercise test
min	Minute(s)
$mL \cdot kg^{-1} \cdot min^{-1}$	Millilitre(s) per kilogram per minute
mm	Millimetre(s)
P	Power output
P_a	Average power output
P_B	Barometric pressure
PE	Potential energy
PhD	Doctor of Philosophy
PO	Power output increment in W (i.e. 35 W)
PO_{final}	Power output of the last completed stage
POST	14 s sprint after 10 minute lead-up
PRE	14 s sprint before 10 minute lead-up
Q	Research question
R	Universal gas constant
RPE	Rate of perceived exertion
rpm	Revolution(s) per minute
s	Second(s)
SD	Standard deviation
SRM	Schoberer Rad Messtechnik
START	Start of the sprint
$START_{Torque}$	Torque at start of the sprint
$START_{Video}$	Video screenshot at start of the sprint
T	Temperature in degrees Kelvin
t	Time spent in the final (uncompleted) stage in s (< 60 s)
T_i	Time of the stage duration in s (i.e. 60 s)
U19	Under 19
U23	Under 23
UCI	Union Cycliste Internationale
V_a	Wind velocity relative to the cyclist's riding direction
V_g	Ground velocity
$\dot{V}O2max$	Maximal oxygen uptake
vs.	Versus
VT1	First ventilatory threshold
VT2	Second ventilatory threshold
V_W	Absolute wind velocity
W	Watt(s)
$W \cdot A_p^{-1}$	Watt(s) per frontal area
$W \cdot kg^{-1}$	Watt(s) per kilogram
y	Year(s)
Z	Compressibility factor

ϵ	Ratio of the apparent molecular weight of dry air and the apparent molecular weight of vapor water
μ	Global coefficient of friction
ρ	Air density
η_p^2	Partial eta squared

1. Introduction

1.1. Overview

This Doctor of Philosophy (PhD) thesis presents four applied research studies aimed at improving road cycling sprint performance. Specifically, the purpose of this research was to examine the effect of different road cycling sprint positions on aerodynamics and power output. Furthermore, this thesis examines if it is possible to improve sprint performance of recreational cyclists in a novel road cycling sprint position after only two weeks of training using an evidence-based combination of different coaching techniques.

1.2. Background

Road cycling is a physically demanding endurance sport with races ranging from short prologues (5-15 min), to single-day events (1-7 h), and multi-stage races (up to 21 days). Success in these races depends on many different factors, including aerobic and anaerobic capacities of cyclists, biomechanics, technique, tactics, and psychophysiological factors.[11-15] Partly based on these factors, cyclists are often categorised into their area of specialisation (e.g. climbers, sprinters, time trialists, all terrain specialists, and flat terrain specialists).[4,9,16-18] Professional and elite road cyclists are required to have high aerobic capacities (e.g. maximal oxygen uptake [$\dot{V}O_2max$] of 70-80 $mL·kg^{-1}·min^{-1}$ and maximal aerobic power during an incremental exercise test [MAP] >5.5 $W·kg^{-1}$).[19,20]

The outcome of many road races is often decided by a sprint. For example, 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 most World Championships, are decided in either a head-to-head, small group, or mass sprint finish. Only a few studies have examined the capacities needed within road sprint cycling.[2,3,6,7,14,21] Menaspà and colleagues[4] showed that junior sprinters (16.8 ± 0.6 y) can produce a higher mean power output during a 5 s sprint test, when compared with flat terrain and uphill specialists (16.6 vs. 14.9 and 14.4 W·kg^{-1}, respectively). To date, performance in elite and professional road cycling sprints have not been extensively examined.[1,3,6,7,14,21,22] Recently, Menaspà and colleagues[7] and Peiffer and colleagues[22] have collected and examined race data from professional male and female cyclists, respectively. The results of these studies have shown that during the final sprint (duration: 9-17 s males; 10-33 s females), male and female cyclists reached a peak power output of 17.4 and 13.9 W·kg^{-1} (1248 and 886 W, respectively) with a maximum velocity of 66 and 58 km·h^{-1}, and a peak cadence of 114 and 110 revolutions per minute (rpm), respectively. These results are slightly higher than those found in a single 14 s sprint of a male cyclist (1097 W with a maximum velocity of 65 km·h^{-1}).[3] When successful sprints of professional male cyclists were compared with those of Under 23 (U23) cyclists, no differences in power output and total work were found.[6] Unpublished data indicate that sprinters need a high sprint power output to finish in the top five; however, differences in power output do not appear to differentiate final position among the top 5 finishers.[23] These data indicate that success in sprints within professional road cycling is not solely determined by high power outputs. Indeed, a cyclist's sprint velocity is likely to be associated with race outcomes. Cycling velocity can be calculated from power output, aerodynamic drag (CdA), and environmental measurements using Equation (1.1).[24]

$$V_g = \frac{2 \cdot P}{\rho \cdot CdA \cdot V_a^2} \qquad \text{(Equation 1.1)}$$

in which V_g is the ground velocity of the cyclist in m·s^{-1}, P is power output in watts, ρ is air density, CdA is aerodynamic drag, and V_a is wind velocity relative to the cyclist's riding direction in m·s^{-1}.

Depending on the equipment and position of a cyclist on the bicycle, air resistance represents approximately 95% of the total resistive forces experienced when cycling at 65 km·h^{-1}.[25] Reducing a cyclist's CdA is therefore extremely important to road cycling performance. CdA can be measured using a wind tunnel. However, wind tunnels are expensive and scarce.

CdA can also be calculated using mathematical modelling.[24,26,27] However, this method requires several experimental trials to calculate a single CdA value. The ideal situation would be to accurately measure CdA during regular races and training sessions, which may be possible with a newly developed device with integrated anemo-, baro-, and accelerometers (Velocomp PowerPod). In fact, the Velocomp PowerPod continuously measures the opposing forces caused by hills, wind, acceleration, and friction. Based upon these opposing forces and Newton's first law it estimates cycling power output. This differs to the majority of currently available power meters which measure torque using strain gauges instrumented in the crank, pedal, or hub of the bicycle.[28] The Velocomp PowerPod can be paired with a strain gauge-based power meter, like a Schoberer Rad Messtechnik (SRM) or Verve Cycling InfoCrank power meter. When doing this the Velocomp PowerPod can be programmed to continuously calculate CdA, rather than power output. However, the validity of the Velocomp PowerPod to calculate power output and CdA is to date unknown.

Until now sport scientists, coaches, and engineers have predominantly focussed on improving CdA in time trial events, probably due to overall duration and importance of these events in multi-stage races, along with the relatively higher velocity when compared with road races.[29-31] However, in road sprints the velocity is significantly higher than in time trials. Given that the outcomes of a sprint are often decided by very small margins (as little as 0.0002 s[32]) aerodynamics are as, if not more, meaningful to overall performance. A drop in CdA, which changes with a cyclist's posture, might therefore result in a faster sprinting velocity. According to the author's knowledge only four studies to date have investigated the effect of various sprinting positions on CdA.[3,27,33,34] Cyclists are known to sprint in three different road cycling sprint positions: seated, standing, and the more novel forward standing (Figure 1.1). The difference between the seated and the two standing positions is the number of contact points with the bicycle (seated: handlebars, saddle, and pedals vs. standing: handlebars and pedals).

The main differences between the standing and the forward standing position are a lower and further forward torso and head position in the forward standing position. The forward standing position is a novel position in the peloton and has only been adopted by a few cyclists. Changing from a seated to a standing position increases CdA by approximately 16.5%.[3,27,33] However, two of these studies did not focus on comparing different positions.[3,27] Blocken and colleagues[33] used computational fluid dynamics and wind tunnel tests of static models of a cyclist to compare three different seated (i.e. back up, horizontal, and down) and two different standing positions (i.e. regular and low/forward standing). Crouch and colleagues[34] analysed the CdA of five different standing positions of a male and a female cyclist in a wind tunnel. Both studies[33,34] have shown an improvement in CdA of approximately 24% when changing from a standing position to a forward standing position. In addition to increasing one's absolute sprint power output, an improvement in aerodynamics (e.g. sprinting in the forward standing position) should lead to a higher velocity for a given power output and hence increase the likelihood of success in a road cycling sprint.

The posture of cyclists has widely been studied during uphill and flat terrain cycling by comparing seated, standing, and time trial positions. Studies observed significant effects on kinematic, energy cost, and efficiency,[35-39] but rarely during cycling at maximal intensities.[38] Millet and colleagues[38] showed that greater power output can be produced when standing and as a result this is favourable at high intensities, yet a seated position is more efficient at submaximal intensities.[40] However, there are only a few studies that have compared sprint performance differences of seated versus standing cycling.[39,41] Reiser and colleagues[41] showed that a standing position during a 30 s Wingate test resulted in a higher peak and mean power output compared with a seated position (19.4 and 11.0 $W \cdot kg^{-1}$ vs. 17.9 and 10.4 $W \cdot kg^{-1}$, respectively). Likewise, greater average power output was produced during an 8 s sprint in a standing position, compared with a seated position in both recreational (14.0 vs. 12.5 $W \cdot kg^{-1}$, respectively) and elite cyclo-cross cyclists (14.1 vs. 12.4 $W\cdot kg^{-1}$, respectively).[39] How much power output cyclists can produce in the novel forward standing position is unclear.

In the process of learning a new motor skill the instructions and feedback athletes receive from their coach are of high importance. When analysed individually visual instructions, verbal instructions stimulating an external focus of attention, and positive feedback are well known to improve performance, coordination, rate of learning, self-confidence, perception of competence, and self-efficacy.[42-46] Additionally, combining visual or external focused verbal instructions with feedback has been shown to have a positive effect on learning when compared with verbal internal focus instructions.[47] Appropriate instruction and feedback may, therefore, benefit the cyclist's ability to maintain an effective sprinting position and enhance performance during the unaccustomed forward standing sprint position.

A B C

Figure 1.1 — The 3 sprinting positions: (A) seated, (B) standing, and (C) forward standing

1.3. Significance of the Research

The research contained in this thesis will further our understanding of sprinting within road cycling. Assessing the validity of the Velocomp PowerPod cyclists will determine if this device will allow CdA to be easily calculated, even during regular races and training sessions. This would be extremely beneficial when compared with other methods such as wind tunnels (logistically difficult and expensive) and mathematical models (strict testing protocol needed to be applied). By assessing different sprint positions, we will understand if a sprint position recently adopted by some successful professional cyclists (i.e. forward standing position) is more aerodynamic than a seated or standing position. We will also gain a greater understanding of how such positions influence total power output, cadence, and torque distribution. As a result, this thesis will give insight into which sprint position is the fastest based on aerodynamics and power output. Given the important role of velocity in road cycling sprint outcomes, such findings are important and will ultimately improve elite sprint cycling performance. The final research in this thesis will further the knowledge in motor learning by providing insight into the effectiveness of combined coaching techniques on learning a new motor task over a two-week period.

1.4. Purpose of the Research

The purpose of this thesis was to manipulate CdA, physiology, and coaching cues to improve road sprint cycling velocity and performance. Specifically, the purpose of Chapter 3 was to determine the validity of the Velocomp PowerPod power meter during field cycling tests and training in comparison with the Verve Cycling InfoCrank power meter. The aim of Chapter 4 was to determine the influence of seated, standing, and forward standing positions on CdA; and the reproducibility of a field test to calculate CdA in these different positions. Chapter 5 assessed the influence of seated, standing, and forward standing positions on power output, cadence, and torque. Finally, Chapter 6 examined if visual and verbal external focus instructions, in combination with positive feedback, could enhance forward standing sprint performance following six sprint cycling training sessions, when compared with neutral verbal instructions and feedback.

1.5. Research Questions and Hypotheses

The research questions (Q) and corresponding hypotheses (H) for each study are listed below:

1.5.1. Chapter 3

Validity of the Velocomp PowerPod Compared With the Verve Cycling InfoCrank Power Meter

Q1. Does power output measured during seven maximal efforts (i.e. 5-600 s) differ between the Velocomp PowerPod power meter and the Verve Cycling InfoCrank power meter?

H1. The Velocomp PowerPod power meter will provide the same power output values as the Verve Cycling InfoCrank power meter measured during seven maximal efforts.

Q2. Does power output measured during training sessions of elite cyclists differ between the Velocomp PowerPod power meter and the Verve Cycling InfoCrank power meter?

H2. The Velocomp PowerPod power meter will provide the same power output values as the Verve Cycling InfoCrank power meter measured during training sessions of elite cyclists.

1.5.2. Chapter 4

Reducing Aerodynamic Drag by Adopting a Novel Road Cycling Sprint Position

Q3. Does aerodynamic drag calculated from a mathematical model created by Martin and colleagues[26] differ among three different sprinting positions (i.e. seated, standing, and forward standing)?

H3. The aerodynamic drag calculated from a mathematical model created by Martin and colleagues[26] will differ between sprinting positions (i.e. seated, standing, and forward standing). Standing will have a greater aerodynamic drag coefficient than seated, which will be similar to the forward standing position.

Q4. Is aerodynamic drag calculated from a mathematical model created by Martin and colleagues[26] reliable between two separate test days?

H4. The aerodynamic drag calculated from a mathematical model created by Martin and colleagues[26] will be reliable between two separate test days.

1.5.3. Chapter 5

Power Output, Cadence, and Torque are Similar Between the Forward Standing and Traditional Sprint Cycling Positions

Q5. Does peak or mean power output measured during maximal sprints of 14 s differ between a seated, standing, and forward standing sprinting position?

H5. Peak and mean power output will be the greatest in the standing position and lowest in the seated position.

Q6. Does peak or mean cadence measured during maximal sprints of 14 s differ between a seated, standing, and forward standing sprinting position?

H6. Peak and mean cadence will be highest in the forward standing position and lowest in the seated position

Q7. Does peak and mean torque, torque distribution, or crank angle at peak torque measured during maximal sprints of 14 s differ between a seated, standing, and forward standing sprinting position?

H7. Peak and mean torque will be greatest in the standing position and lowest in the seated position. Crank angle at peak torque will be greatest in the forward standing position and lowest in the seated position.

Q8. What is the fastest sprinting position (i.e. seated, standing, and forward standing) when modelling the interaction between aerodynamic drag and power output?

H8. The fastest sprint position will be the forward standing position and the slowest position will be the seated position.

1.5.4. Chapter 6

The Combination of Video and External Focused Verbal Instructions, and Positive Feedback does not Enhance the Training Induced Improvement in Forward Standing Sprint Performance

Q9. Does the combination of visual instructions, verbal instructions promoting an external focus of attention, and positive feedback enhance cycling sprint performance (i.e. power output and kinematics) following a two-week sprint training intervention when compared with neutral instructions and feedback?

H9. The combination of visual instructions, verbal instructions promoting an external focus of attention, and positive feedback will improve cycling sprint performance to a greater extent than neutral instructions and feedback.

Q10. Does peak or mean power output, and peak or mean cadence measured during maximal 14 s cycling sprints in the novel forward standing position improve after two weeks of sprint training?

H10. Peak and mean power output, and peak and mean cadence measured during maximal 14 s cycling sprints in the novel forward standing position will improve after two weeks of sprint training.

Q11. Does peak torque measured during maximal sprints of 14 s improve after two weeks of sprint training?

H11. Peak torque measured during maximal 14 s cycling sprints in the novel forward standing position will improve after two weeks of sprint training.

2. Review of the Literature

2.1. 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 these sprints is incredibly important. The factors influencing cycling velocity include the cyclist's physiology and capabilities, the cycling biomechanics and application of force, the forces experienced caused by the environment, and the interaction between cyclists. To perform well in these sprints road cycling sprinters are required to have a very well developed aerobic function (e.g. maximal oxygen consumption [$\dot{V}O_2max$] 71.8 ± 4.7 $mL \cdot kg^{-1} \cdot min^{-1}$; maximal aerobic power during an incremental exercise test [MAP] 428.2 ± 32.5 W and 6.3 ± 0.3 $W \cdot kg^{-1}$) but also extremely well established anaerobic capacity. Cyclists can produce higher power outputs when adopting a standing position when compared with a seated position, with professional male and female sprinters producing approximately 14.2 and 10.0 $W \cdot kg^{-1}$ during the sprint, respectively. Additionally, lowering the torso and head during the standing sprint position results in an aerodynamical improvement of around 25%. Before starting the sprint, road cycling sprinters can ride at very low cost in terms of energy before getting to the finish because cycling in a peloton can reduce the CdA down to 5-10% for almost half of the cyclists in the peloton. However, being close to the front of the peloton during the last part of the race, together with several teammates, is of high importance. Road cycling sprinting could be improved based on physiology, biomechanics (aerodynamics), and smart positioning in the peloton.

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

Chapter 2 is not available in this version of the thesis.

3. Validity of the Velocomp PowerPod Compared With the Verve Cycling InfoCrank Power Meter

3.1. Abstract

Purpose: To determine the validity of the Velocomp PowerPod power meter in comparison with the Verve Cycling InfoCrank power meter. ***Methods:*** This research involved 2 separate studies. In study 1, 12 recreational male road cyclists completed 7 maximal cycling efforts of a known duration (2 times 5 s and 15, 30, 60, 240, and 600 s). In study 2, 4 elite male road cyclists completed 13 outdoor cycling sessions. In both studies, power output of cyclists was continuously measured using both the PowerPod and InfoCrank power meters. Maximal mean power output was calculated for durations of 1, 5, 15, 30, 60, 240, and 600 seconds plus the average power output in study 2. ***Results:*** Power output determined by the PowerPod was almost perfectly correlated with the InfoCrank ($r > 0.996$; $P < 0.001$) in both studies. Using a rolling resistance previously reported, power output was similar between power meters in study 1 ($P = 0.989$), but not in study 2 ($P = 0.045$). Rolling resistance estimated by the PowerPod was higher than what has been previously reported; this might have occurred because of errors in the subjective device setup. This overestimation of rolling resistance increased the power output readings. ***Conclusion:*** Accuracy of rolling resistance seems to be very important in determining power output using the PowerPod. When using a rolling resistance based on previous literature, the PowerPod showed high validity when compared with the InfoCrank in a controlled field test (study 1) but less so in a dynamic environment (study 2).

Keywords: cycling, power profile, training, performance, power output

3.2. Introduction

Cycling power meters typically rely on a measurement of crank arm, chain, pedal, or rear hub torque and angular velocity to calculate power output.[28] There are several models of power meters available on the market, with many validated against the SRM power meter (Schoberer Rad Messtechnik, Jülich, Germany)[28,157-161] or a mathematical model of treadmill cycling.[162] The high accuracy of power output data recorded by SRM devices has been previously reported (<1%[163] and 2.3 ± 4.9% error[164]). Both the SRM and the Verve Cycling InfoCrank power meter (Verve Cycling, Perth, Australia) have shown similar mean deviation (trueness) to a mathematical model of treadmill cycling and coefficient of variation (precision; i.e. trueness = −0.5 ± 2.4% and −1.7 ± 1.1%; precision = 0.8 ± 0.4% and 0.6 ± 0.4%, respectively).[162]

The Velocomp PowerPod power meter (Velocomp LLC, Jupiter, FL) is among the cheapest on the market. An advantage of this power meter is that no changes to the bicycle have to be made (e.g. changing crank arms, rear hub, etc.), and it can be easily mounted on to the handlebars of the bicycle. The novel aspect of this power meter is that when paired with a speed sensor, it continuously calculates the opposing forces caused by road gradient, air resistance, acceleration, and friction. These forces are calculated using 9 different measurements: 3 accelerometers to measure displacements in the x, y, and z directions; frontal air pressure using a small port at the front of the device; environmental air pressure; altitude; air temperature; inclination; and wheel speed (using an ANT+ or Bluetooth speed sensor). Based upon these calculated opposing forces and Newton’s first law, the Velocomp PowerPod power meter calculates cycling power output. This differs to most of the currently available power meters in which power output is calculated with the use of strain gages. To date, the validity of power output calculated by the Velocomp PowerPod power meter is unknown. Therefore, the aim of this study was to determine the validity of the Velocomp PowerPod power meter during field cycling tests and training in comparison with the Verve Cycling InfoCrank power meter.

3.3. Methods

3.3.1. Participants

This study was separated into 2 studies. These include a first study in a controlled field test during which a wide range of power outputs was tested and a second study during typical training rides when velocity and power output were dynamic. In study 1, 12 recreational male road cyclists (age 35.0 ± 7.6 y, height 178.2 ± 5.5 cm, body mass 78.9 ± 8.7 kg) completed a power profile test created and validated by Quod and colleagues.[165] At the time of the study, the participants were riding 5.1 ± 1.0 times and for 10.3 ± 3.9 hours per week and were classified as performance level 3 or higher, as per De Pauw et al.[19] In study 2, 4 elite male road cyclists (age 19.1 ± 1.2 y, height 176.2 ± 1.0 cm, body mass 70.3 ± 2.8 kg), racing for a continental cycling team, completed a combined total of 13 training sessions (duration 202.03 ± 69.60 min and distance 95.12 ± 32.35 km) over a period of 5 weeks during the competitive season. At the time of the study, the participants were riding 6 to 7 times and 18 to 20 hours per week, covering over 500 $km \cdot wk^{-1}$. They had more than 5 years of cycling experience and were classified as performance level 5, as per De Pauw et al.[19] In both these studies, the bicycles were equipped with both a Verve Cycling InfoCrank and a Velocomp PowerPod power meter. The Verve Cycling InfoCrank power meter has previously shown similar trueness (−1.7 ± 1.1%) and precision (0.6 ± 0.4%) to a mathematical model of treadmill cycling.[162] Prior to data collection, all participants provided written informed consent in accordance with the Edith Cowan University (ECU) Human Research Ethics Committee and the principles outlined in the Declaration of Helsinki.

3.3.2. Study 1 — Power Profile Test

Participants completed the power profile test individually on a road bicycle, with the saddle height and setback adjusted to replicate the participants' own bicycle. The bicycle was equipped with a Verve Cycling InfoCrank power meter and a Velocomp PowerPod power meter. The Verve Cycling InfoCrank power meter contained 4 strain gages per crank arm.[162] Before data collection, the Velocomp PowerPod power meter was setup in the Isaac software (Velocomp LLC, Jupiter, FL) including the participant's body mass, height, and the sum of body mass and bicycle mass; riding position (i.e. drops); tyre size (i.e. 700 × 23c), type (i.e. clincher), grade (i.e. utility), and pressure (i.e. 7 bars); device mount location (i.e. front mount); road type (i.e. rough asphalt); and calibration ride type (i.e. best accuracy). After the setup, the Velocomp PowerPod power meter was paired to an SRM speed sensor (Schoberer Rad Messtechnik, Jülich, Germany) followed by an "out-and-back calibration ride" of approximately 10 minutes as per manufacturer's manual. Briefly, during the "out-and-back calibration ride," power output was displayed on a Garmin Edge 820 (Garmin, Schaffhausen, Switzerland). Power increased from 0 to 50 W (as in 0 to 50%). When power output was at 50 W, participants stopped for 5 seconds. Turned around and rode the same course but in the opposite direction during which power output increased from 51 to 100 W (as in 51 to 100%). The "out-and-back calibration ride" started and finished at the same location for every participant and was performed on the same open road (outdoor) as the power profile test. The calibration ride was followed by two 5-second sprints at approximately 70 and 80% of self-reported maximal effort to select gear for the first effort of the power profile test.

Three minutes following this procedure, participants began the power profile test[165] on an open road (outdoor; elevation gain = 46 ± 8 m [Garmin Edge 820]). Briefly, all participants completed 7 maximal efforts, including 2 times 5 seconds followed by 15, 30, 60, 240, and 600 seconds.[165] All efforts were performed from a rolling start and at a self-selected gear. During recovery periods between each effort, participants rode at a freely chosen low intensity and were allowed to drink water ad libitum.

Throughout the power profile test, power output data of the Verve Cycling InfoCrank power meter was recorded by the Garmin Edge 820 head unit at 1 Hz. Data of the Velocomp PowerPod power meter was stored on the device itself at 1 Hz. Given the time delay required to calculate power output for the Velocomp PowerPod power meter, data were synchronised by starting each duration (i.e. 5, 15, 30, 60, 240, and 600 s) at the peak power output reached during that effort. Synchronising the data showed a delay in power output data of 2.45 ± 1.85 seconds of the Velocomp PowerPod power meter data compared with the Verve Cycling InfoCrank power meter data. Maximal mean power outputs for durations of 1, 5, 15, 30, 60, 240, and 600 seconds were calculated for the complete power profile test. Data was analysed using the rolling resistance estimated by the Velocomp PowerPod power meter as well as using a rolling resistance observed in previous research (0.006)[26] because rolling resistance estimated by the Velocomp PowerPod was higher than suggested in literature for rough road (0.011 ± 0.0 vs. 0.006,[26] respectively).

3.3.3. Study 2 — Training Sessions

The participants' personal bicycles were equipped with a Verve Cycling InfoCrank and a Velocomp PowerPod power meter. Before their first training session, the Velocomp PowerPod power meter was setup in Isaac software as described in study 1, and the participants performed the "out-and-back calibration ride." Riding position, tyre size, and road type were setup differently compared with study 1 (i.e. hoods, 700 × 25c, and good asphalt, respectively). These settings were kept consistent for all following training sessions. Power output data was analysed as per study 1, with the addition of the average power output per training session. Furthermore, as the rolling resistance estimated by the Velocomp PowerPod power meter was higher than suggested in literature for smooth road (0.005 ± 0.0 vs. 0.004,[26] respectively), the same analysis was performed using a rolling resistance of 0.004 as suggested previously for smooth road.[26]

3.3.4. Statistical Analysis

Two-tailed Pearson correlations were used to determine the strength of the linear relationship between the two power meters, whereby the strength was classified as 0.0 to 0.09 (trivial), 0.10 to 0.29 (small), 0.30 to 0.49 (moderate), 0.50 to 0.69 (large), 0.70 to 0.89 (very large), 0.90 to 0.99 (near perfect), and 1.0 (perfect).[166] Dependent variables for study 1 (i.e. power output per duration: 1, 5, 15, 30, 60, 240, and 600 s) and study 2 (i.e. power output per duration: 1, 5, 15, 30, 60, 240, 600 s, and average) were compared between the Verve Cycling InfoCrank and the Velocomp PowerPod power meters using a two-way analysis of variance (ANOVA). Furthermore, partial eta squared (η_p^2) was calculated. When a main effect of device (i.e. Verve Cycling InfoCrank vs. Velocomp PowerPod power meter) was found, an additional ANOVA was performed as a post hoc test. Bland–Altman plots and 95% limits of agreement (95% LoA)[167,168] were applied to assess the agreement among the two power meters. The level of significance was set at $P \leq 0.05$ for all tests. All statistical analyses were completed using SPSS Statistics software (IBM Inc, Chicago, IL).

3.4. Results

3.4.1. Study 1 — Power Profile Test

The Pearson correlation showed a significant near-perfect correlation between the two devices ($r = 0.998$; $P < 0.001$). Furthermore, a significant main effect of device on power output was observed ($F_{1,22} = 18.982$; $P < 0.001$; $\eta_p^2 = 0.463$; Figure 3.1A). Post hoc comparisons revealed that power output was significantly greater for the Velocomp PowerPod power meter compared with the Verve Cycling InfoCrank power meter for each duration (26.68 to 38.57%). The bias was −197.52 ± 137.51 W (95% LoA = 269.52 W; Figure 3.2A).

When using a rolling resistance of 0.006, a significant perfect correlation between the two devices ($r = 1.000$; $P < 0.001$) was observed. Furthermore, no significant main effect of device on power output was observed ($F_{1,22} = 0.00$; $P = 0.989$; $\eta_p^2 = 0.000$; Figure 3.1B; −0.57 to 0.24%). The bias was 0.50 ± 10.59 W (95% LoA = 20.76 W; Figure 3.2B).

3.4.2. Study 2 — Training Sessions

The Pearson correlation showed a significant near-perfect correlation between the two devices ($r = 0.996$; $P < 0.001$). Furthermore, a significant main effect of device on power output was observed ($F_{1,24} = 6.819$; $P = 0.015$; $\eta_p^2 = 0.221$; Figure 3.1C). Post hoc comparisons revealed that power output was significantly greater for the Velocomp PowerPod power meter compared with the Verve Cycling InfoCrank power meter for maximal mean power outputs at 1, 5, 30, and 240 seconds and for the average power output (15.23 to 47.68%). The bias was −200.20 ± 250.21 W (95% LoA = 490.41 W; Figure 3.2C).

When using a rolling resistance of 0.004, a significant near-perfect correlation between the two devices ($r = .995$; $P < .001$) was observed. Furthermore, a significant main effect of device on power output was observed ($F_{1,24} = 4.496$; $P = 0.045$; $\eta_p^2 = 0.158$; Figure 3.1D). Post hoc comparisons revealed that power output was significantly higher for the Velocomp

PowerPod power meter compared with the Verve Cycling InfoCrank power meter for the maximal mean power output at 1 second but not for the other durations. The bias was −139.03 ± 241.57 W (95% LoA = 473.48 W; Figure 3.2D).

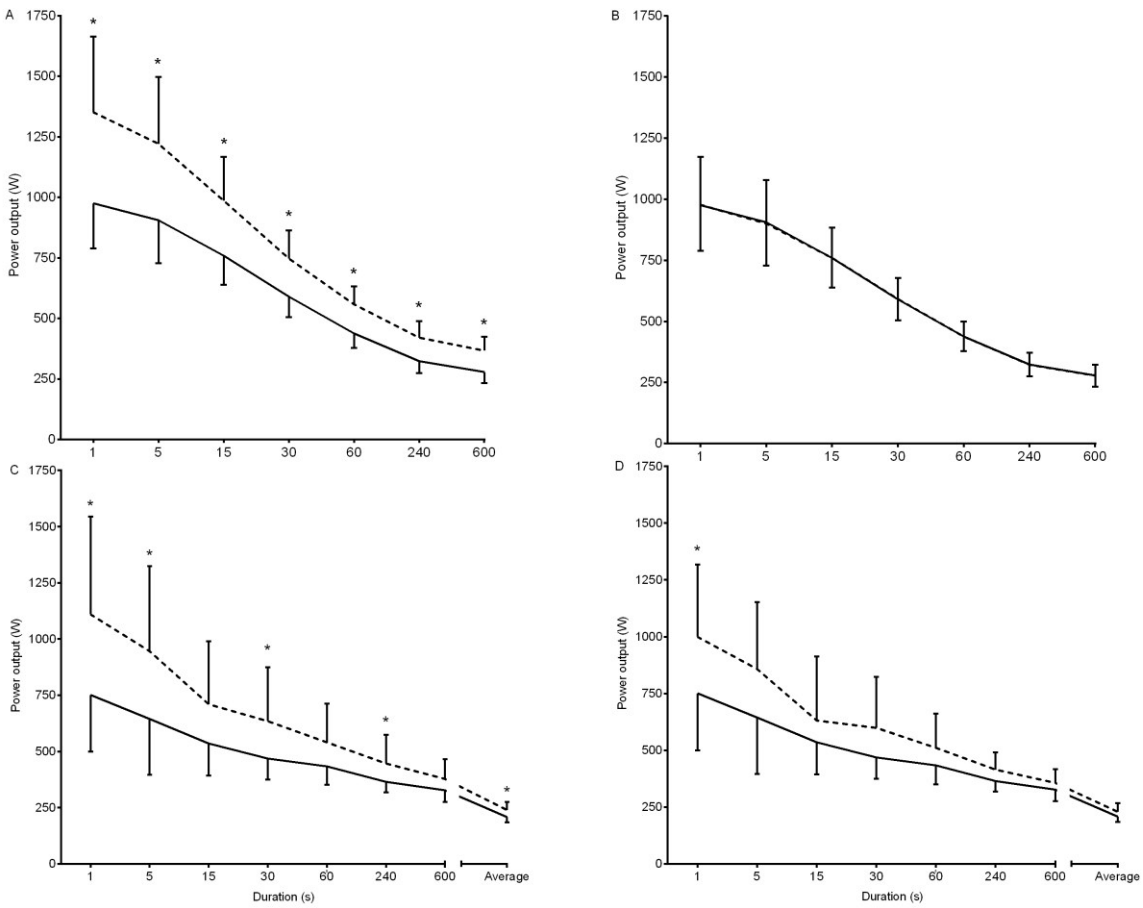

Figure 3.1 — Maximal mean power output per duration for both the Verve Cycling InfoCrank (solid line) and the Velocomp PowerPod power meters (dashed line)

(A) Study 1 — power profile test (n = 12); (B) study 1 — power profile test with adjusted rolling resistance (n = 12); (C) study 2 — 13 training sessions (n = 4); (D) study 2 — 13 training sessions with adjusted rolling resistance (n = 4); * = $P < 0.05$.

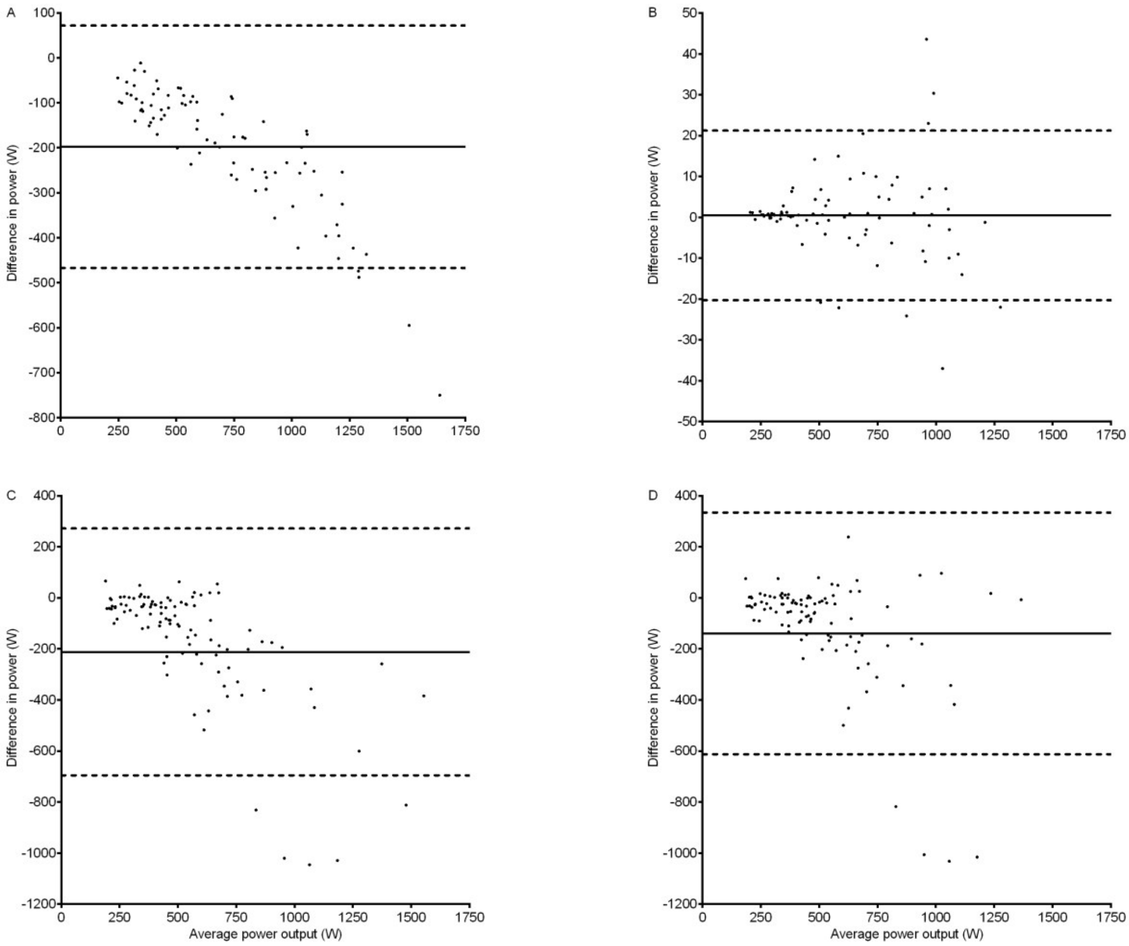

Figure 3.2 — Bland–Altman plots of the difference in power output (in watts) between the Verve Cycling InfoCrank and the Velocomp PowerPod power meters for all data points

(A) Study 1 — power profile test (n = 12); (B) study 1 — power profile test with adjusted rolling resistance (n = 12); (C) study 2 — 13 training sessions (n = 4); (D) study 2 — 13 training sessions with adjusted rolling resistance (n = 4); solid line = mean bias; dashed line = the 95% LoA; LoA = limits of agreement.

3.5. Discussion

The aim of this study was to assess the validity of the Velocomp PowerPod power meter. Both the power profile test data and the training data showed nearly perfect to perfect correlations between the two power meters before and after adjusting rolling resistance (before: r = 0.998 and 0.996; after: r = 1.000 and 0.995, respectively). Using a rolling resistance previously reported in literature,[26] power output was similar between the Verve Cycling InfoCrank and Velocomp PowerPod power meter in study 1 (P = 0.989), but not in study 2 (P = 0.045). Rolling resistance estimated by the Velocomp PowerPod was higher than what has been previously reported in literature,[26] affecting power output readings.

High validity is important in the use of power meters to monitor training and competition performance. When the rolling resistance was adjusted according to previous research,[26] the difference in power measured with the Verve Cycling InfoCrank and Velocomp PowerPod in study 1 (−0.57 to 0.24%), but not during study 2 (8.94 to 33.14%), was comparable with differences previously observed between the SRM power meter and the PowerTap (−3.5 to −0.5%[164]; Saris Cycling Group Inc., Madison, WI) and between Gamin Vector (3.0 to 3.8%[158]; Garmin, Schaffhausen, Switzerland) and Garmin Vector 2 (2.9 to 7.4%[157]; Garmin, Schaffhausen, Switzerland). Without the adjusted rolling resistance, the difference in power measured with the Verve Cycling InfoCrank and Velocomp PowerPod was notably higher (study 1: 27 to 39% and study 2: 16 to 49%). These results indicate that a significant aspect of the difference in power output observed between devices in this study might be associated with the Velocomp PowerPod power meter estimations of rolling resistance. Martin et al.[24] reported that rolling resistance accounted for 10 to 20% of total power output, and the proportion of rolling resistance power output to total power output decreased with increased speed. A change in rolling resistance from 0.0016 to 0.0066 could affect cycling velocity by up to 6%.[24] The amount of force a cyclist has to produce to overcome rolling resistance is related to the cumulative weight of the cyclist and the bicycle; tyre type, grade, and pressure; and road gradient and type.[24]

The Velocomp PowerPod power meter calculates rolling resistance based upon the selected/entered tyre type, grade/quality, and pressure, and road type.[169] Given that the classification of these variables is somewhat subjective (i.e. good asphalt vs. rough asphalt), it is not possible to determine the magnitude of error caused within the present study and should be an area of future research. The error in the estimation of rolling resistance (based upon assumed road and tire quality) is likely to have little influence on the reliability of power output measurements when these variables are consistent (i.e. using the same tyres or similar roads), and therefore, the Velocomp PowerPod power meter should be useful in monitoring changes in workload. However, this needs to be established in future research. In addition, caution should be taken when comparing power output data collected by different cyclists, on different road types, or using different bicycles and tyres. In the current study, no measurements of rolling resistance were made, which might be subject for future research.

The significant difference in power output observed between the Velocomp PowerPod and Verve Cycling InfoCrank power meter in study 2 (Figure 3.1) may be due to the variability in road gradient and wind direction in study 2 compared with study 1. In addition, data in study 2 were collected during participants' regular training rides, including both individual and group rides. From the data files, it was not possible to determine the effect of drafting behind other cyclists or passing traffic. As the participants collected data during their regular training rides and the classification of the settings is subjective, it was not possible to measure road quality and tyre type for each individual training session and to change the Velocomp PowerPod power meter settings if needed. In addition, road type might change between good and rough asphalt within one training session in study 2. As it is not possible to change the settings during the training session, this limitation might give errors in calculating power output. Another difference between study 1 and study 2 is the riding position. In study 1 this was somewhat controlled; all efforts were performed with the hands in the drops. However, other variables like seated and standing, head high or low, or elbows tucked or not were not controlled. These small changes in riding position are likely to affect CdA.[30,123-125,170] The Velocomp PowerPod uses a constant CdA value for its power output calculations, which might result in errors because CdA has a dynamic nature and changes with riding position. [30,123-125,170] For example, changing from a seated position to a standing or forward standing position when riding 60 $km \cdot h^{-1}$ can cost or save you 25 or 190 W, respectively (with cyclist + bicycle weight 80 kg, air density 1.175, gradient 0%, wind velocity parallel to the cyclist 0 $m \cdot s^{-1}$, and rolling resistance 0.004).[170] Hence, changing riding position has a major effect on CdA and therefore on power output. This could explain the higher variability in study 2 compared with study 1 because in study 2, riding position was in no way controlled and might have varied even more than in study 1 (i.e. hands in the drops, hoods, or on top of the handlebars). The effect of these variables (i.e. road gradient, wind direction, drafting, passing traffic, road type, and riding position) on the validity of the Velocomp PowerPod needs further investigation.

It appears from this study that the difference in power output between devices was greatest at higher power outputs (Figures 3.1 and 3.2). Similar findings were shown in studies comparing the Garmin Vector power meter with the SRM power meter.[157,158] Nimmerichter et al.[157] showed a higher typical error during sprint cycling when compared with submaximal trials and time trials in laboratory and field conditions (7.4 and 2.9%, respectively). Furthermore, Novak and Dascombe[158] reported the greatest variance during 5-second efforts compared with longer durations up to 10 minutes. However, in contradiction with the current study, the difference in their study was not significant.

3.6. Practical Applications

The Velocomp PowerPod power meter is easy to mount to different bicycles; when using a rolling resistance previously reported, the Velocomp PowerPod power meter was able to show highly valid measurements in a controlled field test, but not as much in a more dynamic situation. When setting up the Velocomp PowerPod power meter in the Isaac software, coaches and cyclists are assumed to have the knowledge about the effect of tyre type, grade, and pressure, and road type on rolling resistance and therefore on power output. Measuring these variables in real time rather than relying on estimations may drastically improve the accuracy of devices, such as the Velocomp PowerPod, and could be an avenue of future research. In addition, using the Velocomp PowerPod during dynamic high intensity, training sessions/races might lead to an overall overestimation of training load, as the Velocomp PowerPod overestimates power output at higher intensities. Regardless, the Velocomp PowerPod power meter is an interesting advancement in the measurement of power output during cycling, which may have many additional applications (i.e. estimating CdA).

3.7. Conclusion

Accuracy of rolling resistance seems to be very important in determining power output using the Velocomp PowerPod power meter. When using a rolling resistance based on previous literature, the Velocomp PowerPod power meter showed high validity when compared with the Verve Cycling InfoCrank power meter in a controlled field test (study 1) but less so in a dynamic environment (study 2).

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4. Reducing Aerodynamic Drag by Adopting a Novel Road Cycling Sprint Position

4.1. Abstract

Purpose: To assess the influence of seated, standing, and forward standing cycling sprint positions on CdA and the reproducibility of a field test of CdA calculated in these different positions. ***Methods:*** A total of 11 recreational male road cyclists rode 250 m in 2 directions at around 25, 32, and 40 km·h^{-1} and in each of the 3 positions, resulting in a total of 18 efforts per participant. Riding velocity, power output, wind direction and velocity, road gradient, temperature, relative humidity, and barometric pressure were measured and used to calculate CdA using regression analysis. ***Results:*** A main effect of position showed that the average CdA of the 2 days was lower for the forward standing position (0.295 ± 0.059) compared with both the seated (0.363 ± 0.071, $P = 0.018$) and standing positions (0.372 ± 0.077, $P = 0.037$). Seated and standing positions did not differ from each other. Although no significant difference was observed in CdA between the 2 test days, a poor between-days reliability was observed. ***Conclusion:*** A novel forward standing cycling sprint position resulted in 23% and 26% reductions in CdA compared with a seated and standing position, respectively. This decrease in CdA could potentially result in an important increase in cycling sprint velocity of 3.9–4.9 km·h^{-1}, although these results should be interpreted with caution because poor reliability of CdA was observed between days.

Keywords: CdA, aerodynamics, cyclist, sprinting, between-days reliability

4.2. Introduction

The outcome of road cycling races is often decided by a sprint. Indeed, over half of the mass-start stages during the 3 grand tours (i.e. Giro d'Italia, Tour de France, and Vuelta a España), as well as several of the recent World Championships, were decided in either a head-to-head, small group, or mass-sprint finish. To date, road cycling sprints have not been extensively examined.[3,6,7,14,21] It appears that to be competitive in a sprint, male cyclists are required to produce high peak power outputs (e.g., 13.9–20.0 $W \cdot kg^{-1}$,4 989–1443 W[3,7]) over durations of approximately 9 to 17 seconds.[3,7] However, studies have also shown that peak power output is not the only important factor to success.[14] Indeed, a cyclist's velocity is likely to be a much more important factor in the outcome of road cycling sprints. Cycling velocity is the result of power output, CdA, road characteristics, and environmental variables.[27] Therefore, CdA plays an important role in cycling, but is often overlooked, particularly within the sprint. Depending on the equipment and position of a cyclist on the bicycle, aerodynamic resistance represents approximately 95% of the total resistive forces experienced when cycling at 65 $km \cdot h^{-1}$.[25] In addition, the external power required to overcome aerodynamic resistance is a third polynomial of the velocity,[123] making it necessary to increase power output by 2% to increase a cycling velocity by 1% only, when riding at 65 $km \cdot h^{-1}$.[27] Reducing CdA is therefore extremely important to road cycling performance and even more in sprint performance, as sprinting is likely to be 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 is meaningful to overall sprint performances.

The CdA can be determined using a wind tunnel or mathematical modelling.[27] However, wind tunnel testing is relatively expensive and facilities are somewhat scarce. The research in CdA within road sprint cycling is limited, with the majority of the literature focusing on time trials and endurance cycling.[30,123-126] In some of the very few studies to examine CdA in sprinters, it was found that a seated position was more aerodynamic than a standing position. In particular, Martin et al.[27] reported CdA values based on the cycling positions of 3 track sprinters. Sprinting while seated resulted in a CdA of 0.245, whereas a standing position resulted in a CdA of 0.304. In a different study, Martin et al.[3] modelled the difference in CdA between 1 seated (0.288) and 1 standing sprint (0.360). However, comparing different positions was not the focus of these studies.[3,27] From data published on aerodynamics in cycling, it is known that lowering the torso[30,123,125,126] and head[124,125] significantly reduced aerodynamics. Therefore, in this study, a novel cycling sprint position was assessed during which participants adopted a low and forward torso and head position (forward standing position). The aim of this study was to assess the influence of a seated, standing, and forward standing position on CdA and the reproducibility of a field test to calculate CdA in these different positions.

4.3. Methods

4.3.1. Participants

A total of 11 recreational male road cyclists (age 37.1 ± 6.1 y, height 178.7 ± 6.6 cm, and weight 78.9 ± 9.9 kg) volunteered to participate. The participants rode 5.2 ± 1.0 times and for 10.7 ± 4.0 hours per week and were classifiable as performance level 3 or higher, as per De Pauw et al.[19] The participants completed a familiarisation session and 2 identical aerodynamic field tests[24] separated by at least 2 days and a maximum of 7 days. Prior to data collection, the subjects provided written informed consent in accordance with the ECU Human Research Ethics Committee and the principles outlined in the Declaration of Helsinki. All participants were asked to avoid strenuous exercise and refrained from the consumption of caffeine 24 hours prior to testing.

4.3.2. Experimental Design

The familiarisation session started with a 10-minute warm-up at a freely chosen low intensity. Three minutes following the warm-up, participants performed one of the 250-m test sections of the aerodynamic field test (described below) in 3 different positions (i.e. seated, standing, and forward standing; Figure 1.1). During the familiarisation session, participants were assessed by a single investigator using video footage (described below) to determine whether they were capable of maintaining each position. When a participant was not able to ride in each position, he was excluded from the study. In total, 2 participants were excluded from the study. One of the participants was not able to hold the standing and forward standing positions longer than 5 seconds. The video analysis did not reveal a noticeable difference between the standing and the forward standing positions in the other participant.

During the 2 aerodynamic field tests, participants performed the protocol described by Martin et al.[24] in 3 different positions, 3 minutes after a 10-minute warm-up. Specifically, both aerodynamic testing sessions were identical and involved participants riding 250 m in 2 directions at 24 to 26, 31 to 33, and 39 to 41 km·h^{-1} and in each of the 3 positions, resulting in a total of 18 efforts per participant. All efforts were conducted in a randomised and counterbalanced order. Participants were asked to reach constant velocity before entering the 250-m test section and to maintain constant velocity and the selected position within the 250-m test section. A 100-m section of road was provided at the start and end of the 250-m test section to allow the participants to accelerate and decelerate. The participants were required to maintain the required velocity throughout the 250-m test section, which they could view on a Garmin Edge 820 head unit (Garmin, Schaffhausen, Switzerland) attached to the handlebars during the seated and standing positions and the front fork during the forward standing position. A recovery period of 4 minutes was given between each effort.

Participants completed the familiarisation session and 2 aerodynamic field tests on a road bicycle, with the saddle height and setback adjusted to replicate the participant's own bicycle. The participants wore their own helmet during the field tests. The bicycle was equipped with a Verve Cycling InfoCrank power meter (Verve Cycling, Perth, Australia) containing 4 strain gauges per crank arm.[162] All tests were completed on a quiet, straight, and flat road. A high-definition camera (Sony, Tokyo, Japan) was placed on the side of the road at the middle of the 250-m test section to film the participant's sagittal plane at 25 Hz. A screenshot was taken when the cyclist was in the middle of the video footage and it was exported to Adobe Illustrator (Adobe Systems, San Jose, CA) afterward. In this software, the front wheel was standardised at 200 pt; then, the distances between the participant's chest and the bottom of the front wheel (vertical) and between the participant's shoulder and the front wheel hub (horizontal) were determined (Figure 4.1). A negative number for the horizontal distance meant the shoulder was positioned in front of the frontal hub. These data were used to ascertain if the participants were adopting the desired position. The distance of the 250-m test section was measured with the Garmin head unit paired with the SRM speed sensor (Schoberer Rad Messtechnik, Jülich, Germany). The SRM speed sensor was used to measure cycling velocity at the beginning (initial) and end (final) of the 250-m test section. The average power output was measured by the Verve Cycling InfoCrank power meter. The gradient of the 250-m test section was measured with the Garmin head unit. Cycling velocity, average power output, and road gradient were recorded by the Garmin head unit at 1 Hz. Absolute wind velocity and direction were measured 2 times during every effort using a wireless weather station (Davis Instruments Corp, Hayward, CA). The turning plane of the anemometer cups was located at approximately the same height as the participant's torso while positioned on the bicycle. A compass (Suunto, Vantaa, Finland) was used to indicate north on the weather station and to assess riding direction. Wind velocity parallel with the road was calculated using Equation (3.1)[24] as follows:

$$V_a = V_W \cdot [COS(D_W - D_B)] \qquad \text{(Equation 3.1)}$$

in which V_a is the wind velocity relative to the participant's riding direction in m·s^{-1}; V_W is the absolute wind velocity in m·s^{-1}; D_W is the wind direction in degrees; and D_B is the riding direction in degrees. Finally, measurements of temperature, relative humidity, and barometric pressure were recorded 4 times during the session with the weather station. The average of these 4 measurements was used to calculate air density using Equation (3.2)[171] as follows:

$$\rho = \frac{P_b \cdot M_a}{R \cdot T \cdot Z} \cdot \left(1 + (\epsilon - 1)\frac{e'}{P_b}\right) \qquad \text{(Equation 3.2)}$$

in which ρ is the air density; P_b is the barometric pressure in pascals; M_a is the apparent molecular weight of dry air; R is the universal gas constant; T is the temperature in degrees Kelvin; Z is the compressibility factor; ϵ is the ratio of the apparent molecular weight of dry air and the apparent molecular weight of vapor water; and e' is the effective vapor pressure.

Based on calculations of Martin et al.,[26] 1 CdA value per position was calculated from 6 trials (i.e. 2 directions at 24–26, 31–33, and 39–41 km·h^{-1}). Briefly, a regression analysis was performed using the mathematical model in Equation (4.1) as follows:

$$P \cdot E - \frac{\Delta PE}{\Delta t} - \frac{\Delta KE}{\Delta t} = CdA \cdot \left(\frac{1}{2}\rho {V_a}^2 V_g\right) + \mu \cdot \left(V_g F_N\right) \qquad \text{(Equation 4.1)}$$

4.3.3. Statistical Analysis

The vertical and horizontal distances found in the screenshots were analysed using a two-way ANOVA to identify differences between the standing and forward standing positions per day. Two-tailed paired sample *t* tests were used to compare environmental data (i.e. air density and wind velocity parallel to the riding direction) and cycling velocity variability (i.e. average standard deviation per day) between days.

The CdA was compared between positions (i.e. seated, standing, and forward standing) and between days using a two-way ANOVA. Furthermore, η_p^2 was calculated. When a main effect of position was found, pairwise comparisons using Bonferroni's corrections were performed. When an interaction effect of position and day was found, an additional ANOVA was performed to identify differences in position for each day. The level of significance was set at $P \leq 0.05$ for all tests. All statistical analyses were completed using SPSS Statistics software (IBM Inc, Chicago, IL).

The intraday reliability was tested using the mean coefficient of variation (CV) and the intraclass correlation coefficient (ICC) for each position derived from log-transformed data.[172] A CV lower than 3.5% was regarded as high test–retest reliability.[173,174]

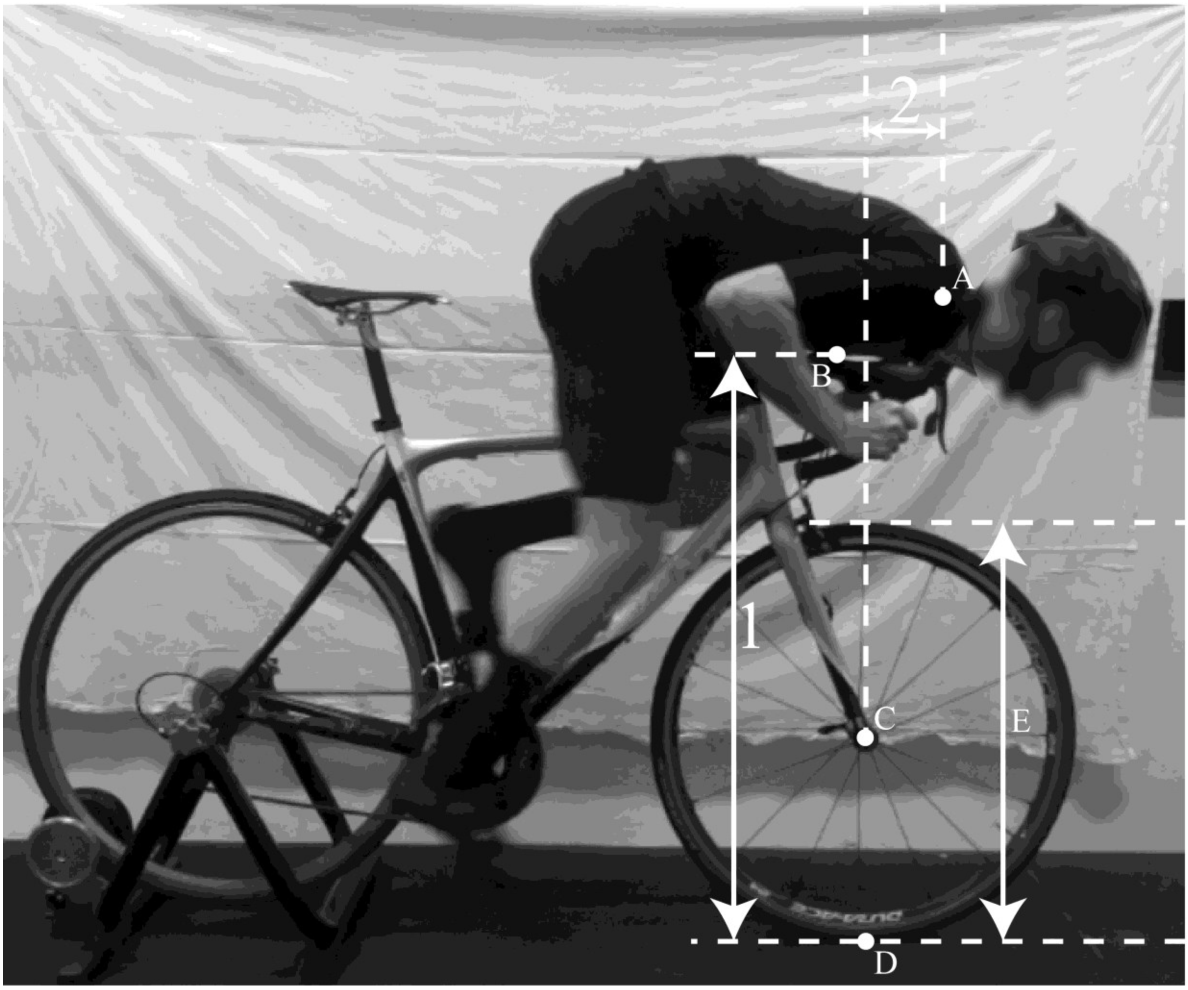

Figure 4.1 — Video analysis overview

(1) vertical; (2) horizontal; (A) shoulder point; (B) chest point; (C) front wheel hub; (D) bottom of the front wheel; (E) calibration distance (i.e. 200 pt).

4.4. Results

Results of the video analysis showed a mean ± SD for vertical and horizontal distances (average of days) of 360.6 ± 13.1 and 26.2 ± 6.4 pt and 311.6 ± 14.06 and −2.7 ± 11.1 pt for standing and forward standing, respectively. The video analysis showed significant differences between the standing and forward standing position in both the vertical and the horizontal direction ($F_{1,10}$ = 107.631; P = 0.001 and $F_{1,10}$ = 109.106; P = 0.001, respectively). No differences were found between days in both the vertical as the horizontal direction ($F_{1,10}$ = 0.083; P = 0.779 and $F_{1,10}$ = 0.775; P = 0.399, respectively). No differences in air density (t_{10} = 0.295; P = 0.774), wind velocity parallel to the riding direction (t_{10} = −0.040; P = 0.969) and cycling velocity variability (t_{32} = −0.939; P = 0.355; 2 tailed) were found between days (Table 4.1).

Table 4.1 — Mean ± SD of variables used for CdA calculations

	Seated	Standing	Forward standing
ρ			
day 1	1.176 ± 0.022	1.176 ± 0.022	1.176 ± 0.022
day 2	1.174 ± 0.017	1.174 ± 0.017	1.174 ± 0.017
V_a, m·s^{-1}			
day 1	0.21 ± 0.51	-1.79 ± 0.44	-0.01 ± 0.65
day 2	-0.23 ± 0.50	-0.14 ± 0.50	-0.07 ± 0.56
V_g variability, km·h^{-1}			
day 1	0.47 ± 0.06	0.60 ± 0.08	0.69 ± 0.17
day 2	0.46 ± 0.10	0.65 ± 0.14	0.71 ± 0.20

Abbreviations: SD = standard deviation; V_a = wind velocity relative to the participant's riding direction; V_g = the ground-velocity variability of the participants; ρ = air density.

A significant main effect was observed for position on CdA ($F_{2,20}$ = 9.234; P = 0.007; η_p^2 = 0.480; Figure 4.2). No main effect of day and interaction effect between position and day on CdA was observed ($F_{1,10}$ = 3.939; P = 0.075; η_p^2 = 0.283). Pairwise comparisons revealed a lower CdA (average of days) for the forward standing position (0.295 ± 0.059) compared with both the seated (0.363 ± 0.071; P = 0.018) and standing positions (0.372 ± 0.077; P = 0.037). No differences in CdA were found between the seated and standing positions (P > 0.99). A lower CdA was observed for the forward standing position compared with the standing positions on day 1 (P = 0.05) but not on day 2 (P = 0.051). CdA was lower for the forward standing position when compared with the seated position on day 2 (P = 0.034) but not on day 1 (P = 0.122). Furthermore, no differences in CdA were observed between the seated and standing positions on both days (P > 0.99 and P > 0.99, respectively).

The CV for the seated, standing, and forward standing positions were 16.0%, 9.1%, and 15.6%, respectively. Large to very large ICC were found for the CdA between days in the seated (r = 0.530), standing (r = 0.840), and forward standing positions (r = 0.600).

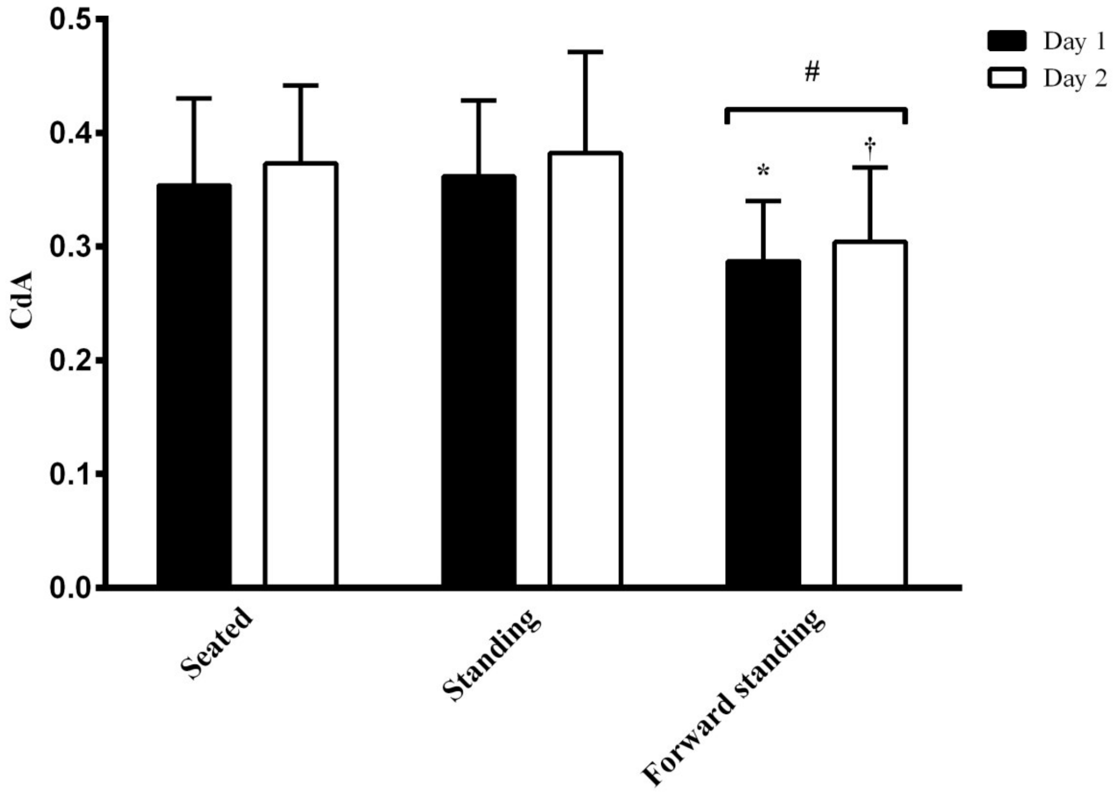

Figure 4.2 — CdA per sprinting position for days 1 and 2

* = $P \leq 0.05$; forward-standing day 1 vs. standing day 1. † = $P < 0.05$; forward-standing day 2 vs. seated day 2. # = $P < 0.05$; forward standing vs. seated and standing (main effect). CdA = aerodynamic drag.

4.5. Discussion

The aim of this study was to assess the influence of a seated, standing, and forward standing position on CdA and the reproducibility of a field test to calculate CdA in these different positions. This research demonstrated that a forward standing position resulted in a significantly lower CdA than a seated or standing position. No difference in CdA was observed between a seated and standing position. Although no significant difference was observed in CdA between the 2 test days, a poor between-day reliability was observed.

Although several studies have examined CdA in road cycling,[30,123-126] very few studies have focused on sprinting.[3,27] To the best of our knowledge, this is the first study assessing CdA of a novel forward standing position. It was found that this position has a 23% and 26% lower CdA compared with a seated and standing position, respectively. Applying a mathematical model to our results and previously reported data, such as average power output during road cycling sprints (865–1140 W[3,7]), a cumulative weight of the bicycle and cyclist of 80 kg, road gradient of 0%, wind velocity parallel to the cyclist of 0 $m \cdot s^{-1}$, and the average air density found in this study ($\rho = 1.175$), an 23% to 26% improvement in CdA would result in an increase of cycling velocity of approximately 3.9 to 4.9 $km \cdot h^{-1}$.[26] This could be a decisive improvement in velocity, given that road cycling races can be decided by very small margins. It is likely that the forward standing position improved CdA due to the lower torso and head position. These changes in body position were likely to affect both the A_p and the Cd. From data published on aerodynamics in cycling other than sprinting, it is known that lowering the torso[30,123,125,126] and head[124,125] significantly reduced CdA[30,123-125] or A_p.[126] Cd is dominated by the turbulence associated with the cyclist's position, shape, size, and surface roughness; as A_p changes, the flow over the cyclist will also change. In other words, decreasing A_p (due to changes in cycling position) does not directly result in a lower CdA. A weak correlation exists between measured

Cd and A_p, in which A_p only accounted for approximately 50% of the variation in CdA between different cycling positions.[122]

In this study, no significant difference in CdA between the seated and standing positions was found. The slightly lower but nonsignificant group mean difference in CdA between the seated and standing positions in this study (~2.5%) is lower than the differences found in other studies: 25%[3] and 24%.[27] Explanations for such discrepancies between studies could be due to differences in the characteristics of the cyclists. In this study, the average height and weight of the participants were 178.7 ± 6.6 cm and 78.9 ± 9.9 kg, respectively. Furthermore, the participants in this study were all amateur male road cyclists. In the study of Martin et al.,[27] 3 world-class track sprint cyclists were tested (1 male sprint specialist: 183 cm, 96 kg; 1 male kilometre time trial specialist: 182 cm, 87 kg; and 1 female 500-m specialist: 165 cm, 68 kg). Differences between studies might also have arisen from the test location and environmental conditions (outdoor vs. indoors[27]) and sample sizes in this study (11 vs. 1[3] and 3[27]). However, in this study, all trials for all 3 positions were performed in a randomised and counterbalanced order on a single day, and therefore it is unlikely that environmental conditions were responsible for the low difference observed between the seated and the standing position. Although no difference in CdA between the seated and the standing positions was observed, it has been previously shown that cyclists are able to generate greater power output in the standing position compared with the seated position.[39,41] The combination of a similar CdA and the possibility to generate greater power output during a standing sprint will result in a higher cycling velocity than a seated sprint. To date, it is unknown if cyclists can produce a similar or different power output in the forward standing position compared with other more traditional positions and may be the subject of future studies. Indeed, although this position was more aerodynamic, it is plausible that changes in body position may influence the movement kinetics compromising or increasing effective pedal forces.

The second aim of this study was to assess the reproducibility of a field test to calculate CdA in the seated, standing, and forward standing positions. This study showed poor reliability to measure CdA in these positions. Such variability between days can be due to technological, methodological, or biological variability.[175] The technological variability within this study may have arisen from the equipment used (i.e. weather station, scale, stadiometer, power meter, speed sensor, and head unit). According to the manufacturer's guideline, the weather station's accuracy was 1 hPa, 3%, 0.5°C, 3°, and 1 $m \cdot s^{-1}$ for measuring barometric pressure, relative humidity, temperature, wind direction, and wind velocity, respectively. The Verve Cycling InfoCrank power meter showed similar mean deviation (trueness) to a mathematical model of treadmill cycling and CV (precision) compared with the golden standard: the SRM power meter (i.e. trueness = −1.7 ± 1.1 vs. −0.5% ± 2.4%; precision = 0.6 ± 0.4 vs. 0.8% ± 0.4%, respectively).[162] These small measurement errors might have resulted in the variability found in this study. Furthermore, methodological variability in this study could have arisen from the environmental conditions and mathematical modelling. Within this study, tests were conducted outdoors, whereas previous studies utilising this model to calculate CdA have used the mathematic model and field test in velodromes.[27] Regardless, no differences in environmental conditions between the 2 days were observed in this study. Furthermore, the mathematical model and field test have previously been validated.[27] In this study, the greatest biological variability would likely have been the ability of the participant to either maintain the required position or an even velocity over the entire 250-m test section. Although both cycling velocity variability and the analysis of the screenshots from the videos did not show a difference between the 2 days, it is plausible that minor fluctuations in velocity and position occurred, which might have influenced the outcomes of this study. In addition, a single camera next to the 250-m test section might not have been sufficient to identify these small fluctuations. Regardless of this, this study was still able to identify differences between the forward standing and both the seated and standing positions, highlighting the large effect that the forward standing position has on CdA. To reduce biological variability, only well-trained cyclists were recruited in this study. Furthermore, to ensure that the participants were able to maintain the required position over the test section, the participants performed 1 week of training and 1 familiarisation session. In this study, 2 participants were not able to maintain the requested positions and were excluded from this study after the familiarisation session. It is plausible that this familiarisation was not sufficient,[176-178] and more practice is needed before adopting the forward standing position for performance. Future research should examine the influence of training on the consistency of adopting such abnormal sprint positions. Other factors that might have led to these exclusions are anthropometric characteristics, poor balance and coordination, or poor bike-handling skills. However, the anthropometric characteristics of the participants in this study suggest that cyclists within a wide range in height and weight are able to adopt and may benefit from the forward standing position. Further research is needed to identify the effect of additional familiarisation or training sessions, differences in anthropometric characteristics, balance and coordination, and bike-handling skills on the reliability of this field test to identify CdA in different positions.

4.6. Practical Applications

Lowering the torso and head during a road cycling sprint results in a decrease in CdA by 23% and 26% when compared with traditional seated and standing positions. This decrease in CdA could result in an increase of cycling sprint velocity by approximately 3.9 to 4.9 $km \cdot h^{-1}$. Caution should be taken when testing the CdA of sprint positions in a field test. Future research should compare the power production between different positions (i.e. seated, standing, and forward standing).

4.7. Conclusion

A novel forward-standing cycling sprint position resulted in 23% and 26% reductions in CdA compared with seated and standing positions, respectively. This decrease in CdA could result in an increase of approximately 3.9 to 4.9 km·h^{-1} in cycling sprint velocity. However, these results should be interpreted with caution because poor reliability of CdA was observed between days. Further research is required to determine factors influencing the poor reliability observed. It is plausible that more than 1 week of training and a single familiarisation session is required to ensure reliability of CdA in these sprint positions.

5. Power Output, Cadence, and Torque are Similar Between the Forward Standing and Traditional Sprint Cycling Positions

5.1. Abstract

Purpose: Compare power output, cadence, and torque in the seated, standing, and forward standing cycling sprint positions**.** ***Methods:*** On three separated occasions (i.e. one for each position) 11 recreational male road cyclists performed a 14 s sprint before and directly after a high-intensity lead-up. Power output, cadence, and torque were measured during each sprint. ***Results:*** No significant differences in peak and mean power output were observed between the forward standing (1125.5 ± 48.5 W and 896.0 ± 32.7 W, respectively) and either the seated or standing positions (1042.5 ± 46.8 W and 856.5 ± 29.4 W; 1175.4 ± 44.9 W and 927.5 ± 28.9 W, respectively). Power output was higher in the standing, compared with the seated position. No difference was observed in cadence between positions. At the start of the sprint before the lead-up, peak torque was higher in the standing position vs. the forward standing position; and peak torque occurred later in the pedal revolution for both the forward standing and standing positions when compared with the seated position. At the start of the sprint after the lead-up, peak torque occurred later in the forward standing position when compared with both the seated and standing position. At the end of the sprint no difference in torque was found between the forward standing and standing position either before or after the lead-up. ***Conclusion:*** Sprinting in the forward standing sprint position does not impair power output, cadence, and torque when compared with the seated and standing sprint positions.

Keywords: cyclist, sprinting, fatigue, performance, seated and standing position

5.2. Introduction

The outcome of road cycling races is often decided by a sprint. A growing number of studies has examined factors important to successful road cycling sprinting.[3,6,7,14,21,33,170] From current research it appears that to be competitive in a sprint, cyclists are required to produce high peak power outputs (e.g. male: 13.9-20.0 $W \cdot kg^{-1}$;[7] 989-1443 W[3,7] and female: 10.8-16.2 $W \cdot kg^{-1}$;[22] 716-1088 W[22]) over durations of approximately 9 to 17 s in males[3,7] and 10 to 30 s in females.[22] However, studies have also shown that peak power output is not the only important factor to success.[14] A cyclist's velocity is likely to be an important factor in the outcome of road cycling sprints. Cycling velocity is the result of power output, CdA, road characteristics, and environmental variables.[27] CdA plays a very important role in cycling, but has been overlooked for years, particularly within the sprint. Over the past decade things have changed in both the field (e.g. cyclists started adopting an aerodynamic position and wearing aerodynamic clothing) and academia.[33,170]

In a recent study[33] and Chapter 4[170] it was found that adopting a lower and further forward position on the bicycle during a standing sprint (forward standing position) resulted in a 23-26% reduction in CdA compared with a seated and a standing sprint. Chapter 4[170] showed that adopting the forward standing position might result in an increase of up to approximately 1.4 $m \cdot s^{-1}$ (5 $km \cdot h^{-1}$) when cyclists are able to produce the same power output in each mentioned position. While the forward standing position was more aerodynamic[33,170] it is plausible that changes in body position may influence the movement kinetics compromising effective pedal forces. From studies in endurance and uphill cycling it is known that the body position is different between a seated and a standing position due to a loss in saddle support and an increase in lateral sway.[115] Compared with a seated position, in the standing position the centre of gravity is shifted further forward[116] which increased the degrees of freedom due to an increase in hip angle.[112] This altered muscle recruitment patterns, and it increased muscle activation in both upper and lower body muscles.[37,112,117,118] As a result of this, cyclists can produce higher power outputs in the standing position when compared with a seated position in both endurance/uphill cycling[40,114,118] and sprinting.[39,41] For example, greater mean power output was observed during 8 s sprints in a standing position, compared with a seated position in both recreational (966.7 vs. 867.0 W, respectively) and elite cyclo-cross cyclists (1010.5 vs. 891.8 W, respectively).[39] Likewise, Reiser and colleagues[41] showed that a standing position during a 30 s Wingate test resulted in a higher peak and mean power output compared with a seated position (19.4 and 11.0 $W \cdot kg^{-1}$ vs. 17.9 and 10.4 $W \cdot kg^{-1}$, respectively). By adopting the forward standing position, the centre of gravity is shifted further forward and lower when compared with the standing position. Moving forward would result in a greater hip angle. However, lowering the torso by flexing the arms would most likely reduce this angle. Additionally, lowering the torso might negatively affect the lateral sway and therefore power output. Hence, it is hypothesised that cyclists can produce more power output in the forward standing position compared with the seated position but lower when compared with the standing position.

Cycling power output can be calculated from angular velocity (calculated from cadence), torque, and crank arm length.[179] During road cycling races and training, crank arm length can be considered as a constant and it has therefore no effect on sprint performance.[142,147,148,180-182] Two studies have shown a higher peak and mean cadence in the standing position when compared with the seated position during 8[41] (i.e. 4.7 and 5.0%, respectively) and 30 s[39] sprints (recreational 3.9 and 5.5%, and elite 3.7 and 3.4, respectively). Until today it is unclear what the effect of cycling sprint position is on torque production and distribution. To the best of our knowledge only two studies have examined the effect on torque during seated versus standing endurance/uphill cycling.[116,118] Both Chen and colleagues[118] and Caldwell and colleagues[116] showed higher torque values in the standing position compared with the seated position during 2 min trials at 50 rpm and 10 min trials at 80% of maximal oxygen consumption. Additionally, Caldwell and colleagues[116] showed that peak torque occurred later during the pedal revolution in the standing position when compared with the seated position.

The forward standing position has shown to improve aerodynamics compared with both the seated and standing sprint position. However, to the best of our knowledge no study has yet examined the power output cyclists can produce within the forward standing position. Therefore, the aim of this study was to assess the influence of different road cycling sprint positions on power output, cadence, and torque.

5.3. Methods

5.3.1. Participants

Eleven recreational male road cyclists participated in this study (mean ± SD: age, 41 ± 7 y; height, 176.5 ± 7.1 cm; weight, 83.1 ± 8.1 kg; $\dot{V}O_2max$, 54.5 ± 5.2 $mL \cdot kg^{-1} \cdot min^{-1}$; MAP, 375 ± 12 W; maximal heart rate (HRmax), 172 ± 3.0 bpm). At the time of the study the participants were riding 5 ± 2 times per week and for 8 ± 2 hours per week and were classifiable as performance level 3 or higher, as per de Pauw and colleagues.[19] Prior to data collection, the subjects provided written informed consent in accordance with the ECU Human Research Ethics Committee. All participants were asked to avoid strenuous exercise and refrained from the consumption of caffeine 24 hours prior to testing.

5.3.2. Experimental Design

The participants visited the laboratory on four separate occasions. During the first visit they completed an incremental cycling test followed by a familiarisation session. The participants were instructed to practice the three different sprint positions (Figure 1.1) for the following week during their own regular training rides. On three separate occasions the participants then performed three experimental trials (each of the three sprint positions) following an incremental high-intensity protocol as described by Menaspà and colleagues.[21] The three experimental trials were conducted in a randomised cross over fashion, separated by two days and completed in ten days.

Incremental Cycling Test

An incremental cycling test was performed at a self-selected cadence (>60 rpm) on a Velotron cycle ergometer (RacerMate Inc., Seattle, USA). The test started with a 6 min warm-up at 70 W after which power output increased by 35 W each minute until exhaustion. The test was terminated when the cadence dropped below 60 rpm. The participants had to remain seated during the full duration of the incremental cycling test. Heart rate was measured using a Polar heart rate monitor (Polar Electro, Kempele, Finland) at a frequency of 1 Hz. Gas exchange was measured every five seconds using a metabolic cart (Parvo Medics, Sandy, USA).[183] The metabolic cart was calibrated as per manufacture's guidelines before each test. $\dot{V}O_2max$ was defined as the highest oxygen uptake recorded over a 30 s average. HRmax was determined as the highest heart rate during the test. Maximal aerobic power at $\dot{V}O_2max$ (MAP) was calculated using Equation (5.1):[12]

$$PPO = PO_{final} + \frac{t}{T_i * PO} \qquad \text{(Equation 5.1)}$$

in which PO_{final} is the power output of the last completed stage in W; t is the time spent in the final (uncompleted) stage in s (< 60 s); T_i is the time of the stage duration in s (i.e. 60 s); and PO is the power output increment in W (i.e. 35 W). MAP was used to quantify intensity of the familiarisation and experimental sessions (described below).

Familiarisation Session

Fifteen minutes after completing the incremental cycling test, participants were familiarised with the incremental high-intensity protocol, as described by Menaspà and colleagues[21] (outlined below).

Experimental Sessions

During each of the three experimental sessions, participants completed a 10 min warm-up at 50% of MAP, followed by 3 min of rest (30% of MAP). Participants then performed a maximal 14 s sprint (PRE) in one of three sprint positions (i.e. seated, standing, and forward standing; Figure 1.1). The 14 s sprint was used to replicate the sprint duration observed in professional male road cycling sprints.[3,6] The participants were asked to perform the 14 s sprint maximally, as if sprinting for a road race victory. Following the sprint, the participants then performed 10 min of incremental high-intensity cycling (lead-up) immediately followed by a final 14 s sprint in the same position (POST). The intensity of the 10 min lead-up effort was progressively increased (during familiarisation: 0 until 5th min: 50% of MAP; 6th until 9th min: 65% of MAP; 10th min: 80% of MAP; and during experimental sessions: 0 until 5th min: 55% of MAP; 6th until 9th min: 70% of MAP; 10th min: 90% of MAP) to simulate the demands observed in the final 10 min of road races ending in a sprint.[6]

All experimental sessions were performed on an SRM ergometer (Schoberer Rad Messtechnik, Jülich, Germany) with the saddle height and setback adjusted to replicate the participants own bicycle. During the sprints, the ergometer was set to the 'open ended' setting and at gear 13 of the Rohloff gearing system and to the 'hyperbolic' setting during the lead-up. The ergometer was equipped with a multi length scientific SRM crank set power meter incorporating eight strain gauges (Schoberer Rad Messtechnik, Jülich, Germany).[163] Crank arm length was the same for each experimental session (i.e. 172.5 mm), since crank arm length can affect power output.[142,147,148,180-182]

Throughout the sprints an SRM power meter (Schoberer Rad Messtechnik, Jülich, Germany) measured torque at 200 Hz and calculated cadence once per pedal revolution. This data was then converted to power output by a PowerControl IV head unit (Schoberer Rad Messtechnik, Jülich, Germany) and send to SRMWin software (Schoberer Rad Messtechnik, Jülich, Germany). The SRMWin software recorded power output and cadence at 2 Hz. The zero offset of the SRM ergometer was checked before each test session as per manufacturer guidelines.[163] For all sprints peak and mean power output were calculated. Peak power output was calculated as the highest power for one complete revolution and mean power output was calculated as the average power output for the complete 14 s.

During the sprints torque and crank angle were measured with an SRM Torque Analysis System (Schoberer Rad Messtechnik, Jülich, Germany) and sampled per crank revolution at 200 Hz. The SRM Torque Analysis software exports data as a frequency signal. This frequency was converted in Excel (Microsoft Corporation, Redmond, USA) to torque data based on the SRM power meter calibration (slope) and the zero offset (Equation 5.2):

$$Torque = \frac{f - \text{Zero } offset}{Slope} \qquad \text{(Equation 5.2)}$$

in which Torque is in Nm, f is the exported frequency, zero offset is the zero offset value determined before every session, and slope is the calibration factor of the SRM power meter (i.e. 30.1). After this, torque data was converted using linear interpolation to synchronise the number of samples for each pedal revolution. All torque data was then averaged over five completed pedal revolutions starting at the 3rd pedal revolution after the start of the sprint ($START_{Torque}$) and the last five completed pedal revolutions of the sprint (END_{Torque}). Peak and mean torque were defined as the highest and the average toque during the averaged five pedal revolutions (Figure 5.1). Furthermore, torque at a crank angle of 0, 45, 90, 135, and 180° were calculated. Additionally, crank angle at peak torque was determined for each sprint.

A high definition camera (Sony, Tokyo, Japan) was placed to film the participant's left sagittal plane at 25 Hz. Screenshots were taken at approximately 3 ($START_{Video}$) and 11 s (END_{Video}) after the start of sprint when the left pedal was at bottom dead centre. The screenshots were exported to Adobe Illustrator (Adobe Systems, San Jose, USA). In this software, the height of the horizontal saddle adjusting stem of the SRM ergometer was standardized at 20 pt (Figure 5.2). After which the distance was determined between the participant's chest and the top of the SRM logo (vertical) and between the participant's shoulder and the corner in the ergometer's frame (horizontal). This data was determined for three full pedal revolutions of the PRE and POST sprints.

After each sprint, rating of effort was given by the participants on a Category Ratio scale by answering the question: '*How much did you give?*'[184] Directly after each session, participants were asked to rate the intensity of the sessions using the 6-20 rate of perceived exertion scale (RPE).[185] The participants were familiarized with these scales during the familiarisation session.

5.3.3. Statistical Analysis

Based on previous reported power output data[39] it was calculated that a minimum of 9 individuals was required with alpha level at 0.05 to achieve statistical power of 0.8 (GPOWER, Bonn, Germany). The vertical and horizontal distances found in the screenshots were analysed using multiple two-way ANOVA to identify differences between the standing and forward standing position at the $\text{START}_{\text{Video}}$ and $\text{END}_{\text{Video}}$ of the sprint, and between PRE and POST. Peak and mean power output, peak and mean cadence, and rating of effort were compared between sprint positions (i.e. seated, standing, and forward standing) and between PRE and POST sprints using multiple two-way ANOVAs. When a main effect of position was found, pairwise comparisons using Bonferroni's corrections were performed. Additional one-way ANOVAs were performed to identify differences in position between sprints. Peak and mean torque; torque at a crank angle of 0, 45, 90, 135, and 180°; and crank angle at peak torque were compared between sprint positions (i.e. seated, standing, and forward standing) and at the $\text{START}_{\text{Torque}}$ and $\text{END}_{\text{Torque}}$ of the sprint, and between PRE and POST using multiple two-way ANOVAs. When a significant main or interaction effect was found, additional one-way ANOVAs were performed to identify differences in position per start and end of the sprint or between sprints and paired sample *t* tests to identify differences between $\text{START}_{\text{Torque}}$ and $\text{END}_{\text{Torque}}$ or PRE and POST per position. RPE was compared between experimental sessions (i.e. seated, standing, and forward standing) using a one-way ANOVA. The level of significance was set at $P \leq 0.05$ for all tests. η_p^2 effect sizes were reported when appropriate. The magnitudes of these effect sizes were classified as trivial (0–0.19), small (0.20–0.49), moderate (0.50–0.79) and large (0.80 and greater) using the scale advocated by Cohen.[186] All statistical analyses were completed using SPSS (IMB SPSS Inc. Statistics, Chicago, USA).

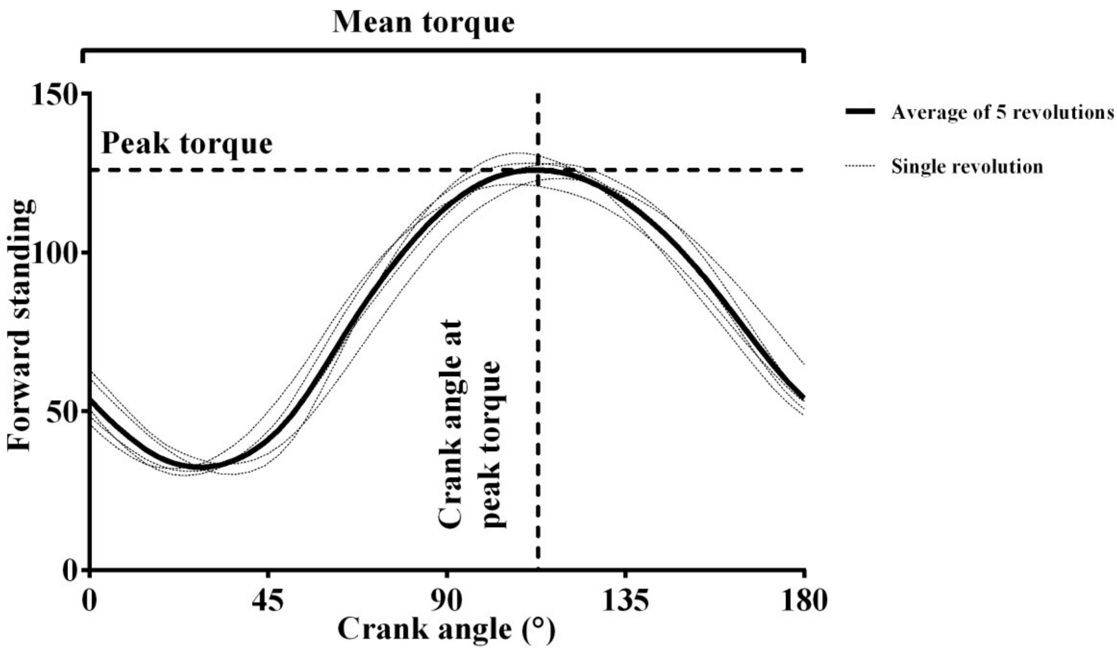

Figure 5.1 — Peak and mean torque, and crank angle at peak torque calculations.

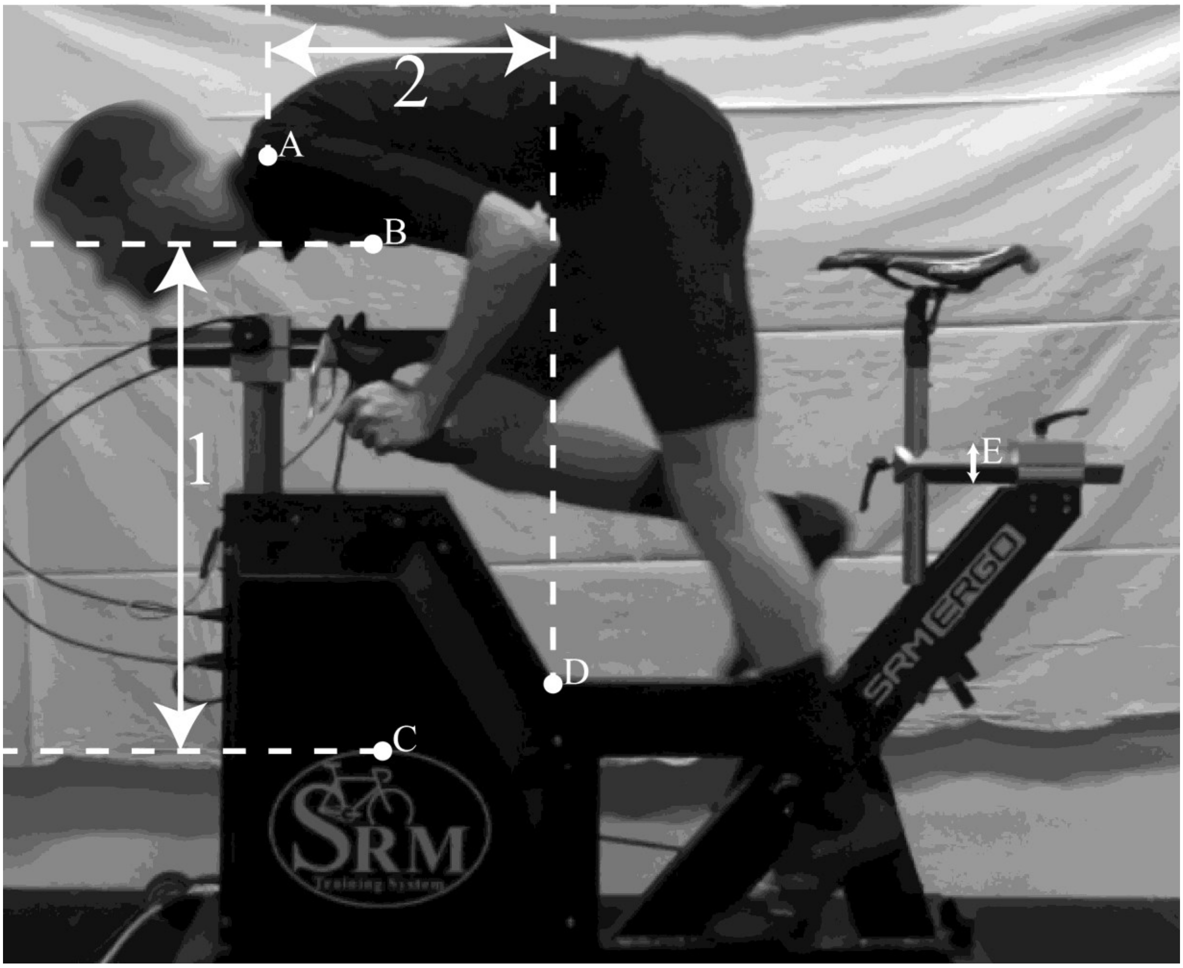

Figure 5.2 — Video analysis overview

(1) vertical; (2) horizontal; (A) shoulder; (B) chest; (C) top of SRM logo; (D) corner in the ergometer's frame; (E) calibration distance (i.e. 20 pt).

5.4. Results

The video analysis showed that the torso was lower, and the shoulder was further forward in the forward standing position compared with the standing position at the $START_{Video}$ and END_{Video} of the sprint and during the PRE and POST sprint ($P < 0.001$). Furthermore, at PRE a main effect was observed in vertical position for $START_{Video}$ vs. END_{Video} ($P = 0.025$). Pairwise comparisons showed that the torso was further up at $START_{Video}$ when compared with END_{Video} during a standing sprint. No other differences in both vertical and horizontal direction were found between $START_{Video}$ and END_{Video}, and PRE and POST.

Significant main effects were observed in peak ($F_{2,20} = 11.338$; $P = 0.001$; $\eta_p^2 = 0.53$) and mean power output ($F_{2,20} = 6.007$; $P = 0.009$; $\eta_p^2 = 0.375$) between sprint position (Figure 5.3). Pairwise comparisons showed that the participants produced a higher peak and mean power output (average PRE and POST) in a standing position, when compared with the seated position. The peak and mean power output in the forward standing position was not significantly different from either the seated or standing position. No significant main effect was observed in peak and mean cadence, and rate of effort between positions ($F_{2,20} = 2.287$; $P = 0.127$; $\eta_p^2 = 0.186$, $F_{2,20} = 0.525$; $P = 0.600$; $\eta_p^2 = 0.050$, and $F_{2,20} = 0.317$; $P = 0.732$; $\eta_p^2 = 0.031$, respectively). Higher peak and mean power output, and higher peak and mean cadences were observed during PRE when compared with POST ($F_{1,10} = 71.227$; $P < 0.001$; $\eta_p^2 = 0.877$, $F_{1,10} = 25.250$; $P = 0.001$; $\eta_p^2 = 0.716$, $F_{1,10} = 104.982$; $P < 0.001$; $\eta_p^2 = 0.913$, and $F_{1,10} = 33.936$; $P < 0.001$; $\eta_p^2 = 0.772$, respectively).

At $START_{Torque}$ a main effect was found for peak and mean torque; torque at a crank angle of 0, 45, 90, 135, and 180°; and crank angle at peak torque between positions ($P \leq 0.05$) (Table 5.1). Furthermore, a main effect was found for mean torque; and torque at a crank angle of 0, 45, 90, 135, and 180° between PRE and POST ($P \leq 0.05$). An interaction effect was found for peak torque; and torque at a crank angle of 45 and 135° between positions and between PRE and POST ($P \leq 0.05$). At $\mathrm{END_{Torque}}$ a main effect was found for torque at a crank angle of 0, 45, 90, and 180° between positions ($P \leq 0.05$). Furthermore, a main effect was found for peak and mean torque; and torque at a crank angle of 90 and 135° between PRE and POST ($P \leq 0.05$). An interaction effect was found for peak and mean torque; and torque at a crank angle of 0, 90, 135, and 180° between positions and between PRE and POST ($P \leq 0.05$).

During PRE a main effect was observed for peak torque; torque at a crank angle of 0, 45, 90, 135, and 180°; and crank angle at peak torque between positions ($P \leq 0.05$). Furthermore, a main effect was observed for peak and mean torque; torque at a crank angle of 0, 45, 90, 135, and 180°; and crank angle at peak torque between $\mathrm{START_{Torque}}$ and $\mathrm{END_{Torque}}$ ($P \leq 0.05$). An interaction effect was observed for peak and mean torque; torque at a crank angle of 0, 45, 135, and 180°; and crank angle at peak torque between positions and between $\mathrm{START_{Torque}}$ and $\mathrm{END_{Torque}}$ ($P \leq 0.05$). During POST a main effect was observed for peak and mean torque; and torque at a crank angle of 0, 45, 135, and 180° between positions ($P \leq 0.05$). Furthermore, a main effect was found for peak and mean torque; and torque at a crank angle of 90 and 135° between $\mathrm{START_{Torque}}$ and $\mathrm{END_{Torque}}$ ($P \leq 0.05$). An interaction effect was found for peak and mean torque; and torque at a crank angle of 0, 45, 135, and 180° between positions and between $\mathrm{START_{Torque}}$ and $\mathrm{END_{Torque}}$ ($P \leq 0.05$).

Rating of effort was significant higher during POST when compared with PRE ($F_{1,10} = 23.502$; $P = 0.001$; $\eta_p^2 = 0.702$) but was not different between positions ($F_{2,20} = 0.385$; $P = 0.691$; $\eta_p^2 = 0.079$). No significant difference was found for RPE ($F_{2,20} = 0.595$; $P = 0.561$; $\eta_p^2 = 0.056$).

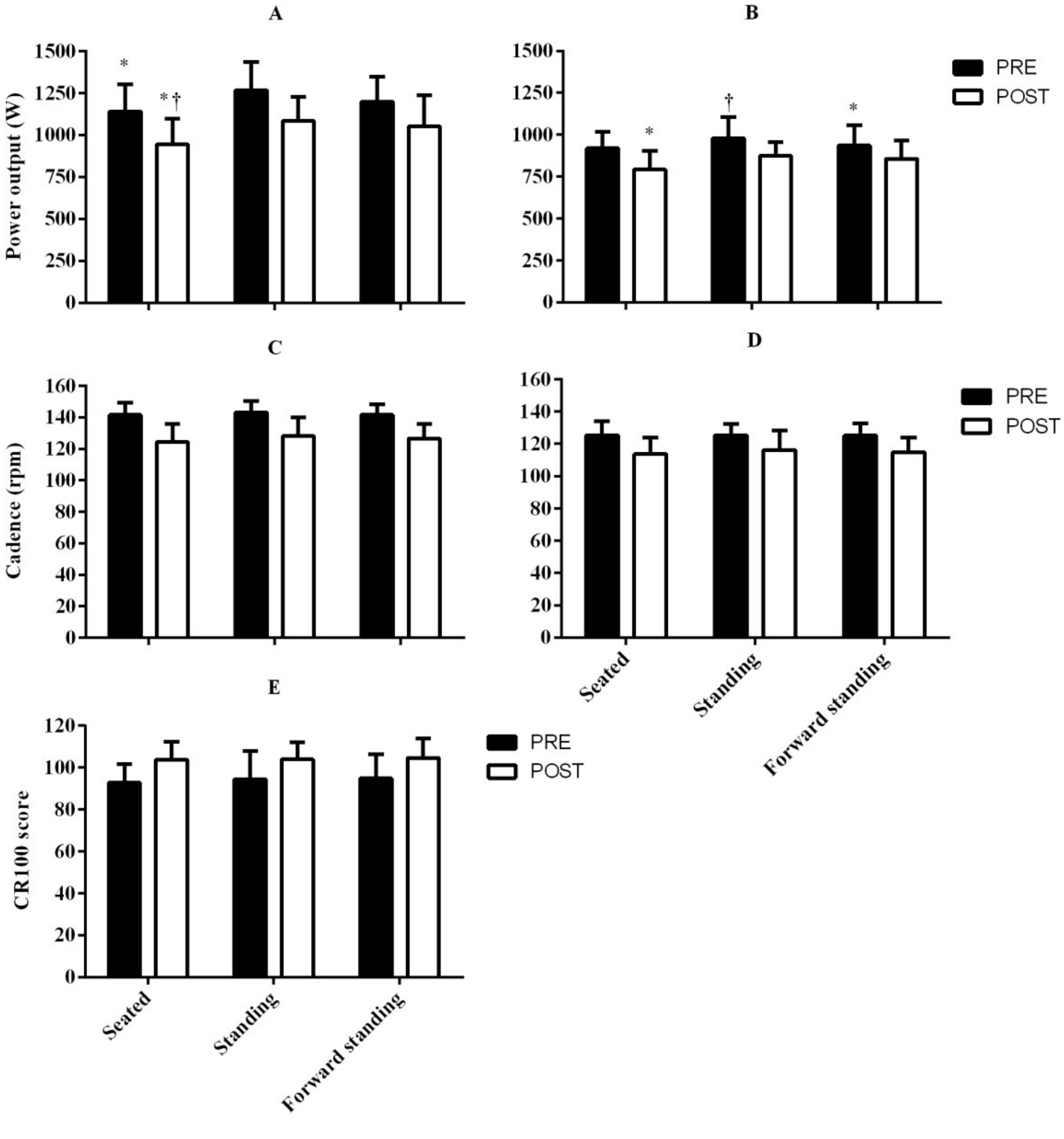

Figure 5.3 — Power output, cadence, and rating of effort differences between sprint positions before and after 10 min lead-up

(A) Peak power output (W); (B) mean power output (W); (C) peak cadence (rpm); (D) mean cadence (rpm); (E) rating of effort; * = $P \leq 0.05$ vs. standing; † = $P \leq 0.05$ vs. forward standing.

Table 5.1 — Torque differences between sprint positions at $START_{Torque}$ and END_{Torque} during PRE and POST (Mean ± SD)

PRE	$START_{Torque}$				END_{Torque}			
	Seated	Standing	Forward standing	η_p^2	Seated	Standing	Forward standing	η_p^2
PT (Nm)	119.7 ± 16.3	133.9 ± 20.9†	124.6 ± 18.4*	0.348	63.5 ± 8.8$^{¥}$	62.9 ± 12.0$^{¥}$	59.8 ± 7.3$^{¥}$	0.087
MT (Nm)	79.2 ± 10.5	86.39 ± 14.2	81.0 ± 13.2	0.248	44.4 ± 5.3$^{¥}$	40.3 ± 8.7$^{¥}$	39.8 ± 6.5$^{¥}$	0.220
T at 0° (Nm)	40.2 ± 8.9*†	56.0 ± 14.8	61.4 ± 17.5	0.696	39.2 ± 8.3	42.1 ± 7.5$^{¥}$	43.7 ± 10.0$^{¥}$	0.210
T at 45° (Nm)	65.2 ± 17.3*†	45.0 ± 11.3†	38.0 ± 8.6*	0.771	24.7 ± 7.6$^{*¥}$	15.5 ± 9.2$^{¥}$	17.6 ± 7.7$^{¥}$	0.391
T at 90° (Nm)	115.1 ± 17.3†	115.2 ± 19.7†	102.4 ± 18.3*	0.343	54.7 ± 10.5$^{*\dagger¥}$	43.8 ± 14.4$^{¥}$	41.5 ± 10.2$^{¥}$	0.472
T at 135° (Nm)	97.9 ± 14.6*†	127.6 ± 21.0	121.1 ± 17.9	0.640	60.5 ± 7.5$^{¥}$	60.4 ± 13.2$^{¥}$	58.5 ± 6.9$^{¥}$	0.027
T at 180° (Nm)	39.6 ± 9.0*†	56.0 ± 17.3†	61.7 ± 18.6*	0.734	36.0 ± 8.0$^{¥}$	42.1 ± 10.3$^{¥}$	39.6 ± 10.4$^{¥}$	0.347
Crank angle at PT (°)	104.0 ± 11.0*†	120.6 ± 9.6	125.0 ± 7.7	0.849	128.0 ± 18.6$^{¥}$	136.4 ± 22.0$^{¥}$	127.0 ± 8.3	0.135

POST	$START_{Torque}$				END_{Torque}			
	Seated	Standing	Forward standing	η_p^2	Seated	Standing	Forward standing	η_p^2
PT (Nm)	105.6 ± 15.8$^{*\$}$	124.9 ± 16.8$^{\$}$	122.5 ± 19.0	0.453	67.9 ± 8.7$^{¥}$	76.0 ± 14.0$^{¥\$}$	74.9 ± 11.5$^{¥\$}$	0.252
MT (Nm)	67.6 ± 10.3$^{*\$}$	77.2 ± 9.8$^{\$}$	75.3 ± 12.6	0.420	45.0 ± 4.4$^{¥}$	47.9 ± 6.3$^{¥\$}$	47.5 ± 6.5$^{¥\$}$	0.130
T at 0° (Nm)	32.2 ± 7.8$^{*\dagger\$}$	48.4 ± 12.1$^{\dagger\$}$	54.8 ± 13.8*	0.850	33.6 ± 6.7$^{*\dagger\$}$	46.0 ± 6.7$^{\$}$	46.7 ± 9.9$^{¥}$	0.650
T at 45° (Nm)	51.9 ± 14.5$^{*\dagger\$}$	37.2 ± 10.1$^{\dagger\$}$	32.8 ± 8.3*	0.751	23.7 ± 8.2$^{¥}$	16.0 ± 7.2$^{¥}$	17.0 ± 5.5$^{¥}$	0.383
T at 90° (Nm)	101.4 ± 14.8$^{\$}$	100.5 ± 16.6$^{\$}$	92.0 ± 19.5	0.246	59.9 ± 8.9$^{¥\$}$	56.0 ± 12.6$^{¥\$}$	54.6 ± 10.0$^{¥\$}$	0.143
T at 135° (Nm)	85.6 ± 16.2$^{*\dagger\$}$	120.6 ± 15.5	120.2 ± 18.5	0.761	63.0 ± 8.8$^{\dagger¥}$	74.6 ± 14.2$^{¥\$}$	73.7 ± 11.9$^{¥\$}$	0.415
T at 180° (Nm)	31.6 ± 8.1$^{*\dagger\$}$	49.9 ± 13.7$^{\dagger\$}$	56.5 ± 15.9*	0.876	32.0 ± 6.2$^{*\dagger\$}$	43.8 ± 7.9	45.0 ± 10.2$^{¥\$}$	0.714
Crank angle at PT (°)	103.7 ± 9.0*†	124.1 ± 8.4†	128.5 ± 8.4*	0.904	117.2 ± 14.4	126.8 ± 8.6	117.2 ± 39.6	0.043

PT = peak torque; MT = mean torque; T = torque.
* = $p \leq 0.05$ vs. Standing; † = $p \leq 0.05$ vs. Forward standing; ¥ = $p \leq 0.05$ vs. $START_{Torque}$; \$ = $p \leq 0.05$ vs. PRE; η_p^2 = partial eta squared.

5.5. Discussion

The aim of this study was to compare power output, cadence, and torque between different road cycling sprint positions. To the best of our knowledge, this is the first study assessing the power output, cadence, and torque in the forward standing position. No significant differences in power output were found in the current study between the forward standing and either the seated or standing position. Additionally, this study showed that cyclists can produce a higher peak and mean power output in a standing position when compared with the seated position. Higher peak and mean power outputs were observed during the 14 s sprints before the 10 min lead-up (PRE) compared with the sprint after the lead-up (POST). Furthermore, no difference was observed in peak and mean cadence between sprint positions. Peak torque was higher in the standing position, when compared with the forward standing position at start of the sprint (START) during PRE. At START during POST both peak and mean torque were higher in the standing position compared with a seated position. No other differences were found in peak and mean torque between positions at both START and end of the sprint (END). It was observed that the torque distribution during the pedal revolution differed between all three positions, when compared between positions at START (e.g. Figure 5.4). At END the seated position still showed differences in torque distribution when compared with both the standing and forward standing position. However, no differences between the standing and forward standing position were observed in torque distribution. Additionally, peak torque was reached later during the pedal revolution for both the standing and the forward standing position when compared with the seated position. No other differences in crank angle at peak torque were observed between positions.

Applying a mathematical model to our power output results and using previously reported data, a cumulative weight of the bicycle and cyclist of 80 kg; road gradient of 0%; wind velocity parallel to the cyclist of 0 $m \cdot s^{-1}$; average air density (ρ = 1.175);[170] a CdA of

0.363, 0.372, and 0.295[170] and a power output of 597-1035, 747-1135, and 671-1149 W for seated, standing and forward standing position, respectively, would result in an increase of cycling velocity of approximately 1.6-1.8 (5.6-6.5 $km \cdot h^{-1}$) and 0.6-1.4 $m \cdot s^{-1}$ (2.1-5.1 $km \cdot h^{-1}$) in the forward standing position compared with the seated and standing position, respectively.[26] This could be a decisive improvement in velocity given that road cycling races can be decided by very small margins.

It was hypothesised that cyclists would be able to produce higher power outputs in the forward standing position when compared with the seated position. Indeed, this study and previous research[39,41] have shown that cyclists are able to produce higher power outputs in a standing position when compared with a seated position. The lack of statistical difference in power output between the forward standing and the seated positions observed in this study is likely to be due to the low and forward torso position in the forward standing position. The low and further forward position could have limited the transfer of power across the hip (a reason why more power output is produced in the standing position when compared with the seated position[119]) and increased muscle activation in the upper body due to the shift of weight further forward and therefore lowered power output. How the forward standing position affects joint specific kinetics and kinematics, and muscle activation was not analysed in the current study and could be a subject for future research. An alternative explanation could be that the participants in the current study were less experienced in this new forward sprint position, when compared with the seated and standing position, and therefore not able to produce maximal power output during the sprint in the forward standing position. To ensure that the participants were able to maintain the required position during the 14 s sprint the participants performed, one week of training (unsupervised) and one familiarisation session. Yet it is still plausible that this familiarisation was not sufficient to learn how to sprint and produce maximal power output in this position,[176-178] and that more practice is needed. Future research should examine the influence of training on the consistency of adopting such non-regular sprint positions. Other factors which might affect sprint performance in the forward standing position are anthropometric characteristics, poor balance and coordination, poor cycling handling skills, or bicycle setup. Regardless, the anthropometric characteristics of the participants in the current study suggests that cyclists within a wide range in height and weight are able to adopt the forward standing position. However, since the experimental sessions were performed on a heavy SRM ergometer the sprints performed in the current study were not limited by the participant's balance and/or bicycle handling skills. It is plausible that the relatively new forward standing position requires more balance and cycling handling skills than the regular standing position because of the change in centre of gravity and new motor skill and may be an avenue of future research. Changing bicycle setup to optimise sprint performance in the forward standing position might negatively influence cycling efficiency and therefore overall cycling performance.

The current study showed that cyclists can produce a higher peak and mean power output in a standing position when compared with the seated position. This is in line with previous studies.[39,41] Bertucci and colleagues[39] found that greater mean power output was produced during 8 s sprints in a standing position, compared with a seated position in both recreational (966.7 vs. 867.0 W, respectively) and elite cyclo-cross cyclists (1010.5 vs. 891.8 W, respectively). Furthermore, Reiser and colleagues[41] showed that a standing position during a 30 s Wingate test resulted in a higher peak and mean power output compared with a seated position in 12 recreational cyclists (19.4 and 11.0 $W \cdot kg^{-1}$ vs. 17.9 and 10.4 $W \cdot kg^{-1}$, respectively). Changing from a seated to a standing position alters recruitment patterns, and it increases muscle activation in both upper and lower body muscles.[37,112,117,118] For example, Li and colleagues[112] showed an increase in EMG magnitude of the rectus femoris, gluteus maximus, and the tibialis anterior in the standing position. Furthermore, the gluteus maximus, rectus femoris, and vastus lateralis were longer activated during the pedal stroke. Additionally, Duc and colleagues[37] found higher intensities and durations in muscle activity of the gluteus maximus, vastus medialis, rectus femoris, biceps femoris, and biceps brachii in the standing position while semimembranosus activity showed a slight decrease. These studies have been conducted in endurance and uphill cycling.

To the best of the authors' knowledge this is the first study to analyse the effect of sprint position on torque and torque distribution. A previous study has examined the effect on torque during seated versus standing endurance/uphill cycling.[118] At the start of the 14 s sprint (START) after the 10 min lead-up (POST) both peak and mean torque were higher in the standing position compared with a seated position. This can be explained by the higher magnitude and longer muscle activation[37,112,117,118] or the further forward centre of gravity providing leverage over the crank arm in the standing position.[187] The latter would suggest that the torque in the forward standing position would be even higher. However, in the current study the opposite was found. Peak torque was higher in the standing position when compared with the forward standing position during at START before the 10 min lead-up (PRE). This could be an indication that the participants were not completely accustomed to the new forward standing position and more training in this position is needed. No other differences were found in peak and mean torque between position. Hence, when a cyclist is fatigued (i.e. end of the sprint (END)) they produced similar torque in each position.

It was observed that the torque distribution during the pedal revolution at START differed between all three positions (e.g. Figure 5.4). For example, peak torque was reached later during the pedal revolution for both the standing and the forward standing position when compared with the seated position. The earlier peak torque during the seated position compared with the standing and forward standing position is likely due to a greater contribution from hip and knee extensors and flexors. Indeed, previous studies in endurance/uphill cycling have shown that the rectus femoris, gluteus maximus, vastus lateralis and medialis and biceps femoris shown higher EMG magnitude.[37,112] The results in the current study also showed a higher torque at the beginning but lower at the end of the pedal stroke in the standing position compared with the forward standing position at START. This could be explained by the forward shift in the forward standing position which resulted in a later torque production. At END the seated position still showed differences in torque distribution during the pedal revolution when compared with both the standing and forward standing position, but no more differences were found between the standing and forward standing position. An explanation could be the lower torso at END when compared with START as shown in the video during the standing sprint. However, there was still a significant difference in vertical position between the standing and forward standing position at END.

Peak and mean cadence did not change with cycling sprint position in the current study (i.e. 1.9 and 1.0%, respectively.). This is in contradiction with the studies of Reiser and colleagues[41] (i.e. 4.7 and 5.0%, respectively) and Bertucci and colleagues[39] (recreational 3.9 and 5.5%, and elite 3.7 and 3.4, respectively). In both these studies resistance applied to the bicycle/ergometer was based on the cyclist's body mass. In the current study the resistance was set to gear 13 on the Rohloff gearing system of the SRM ergometer. This might have limited the cyclist's ability to optimise their cadence and therefore their maximal power output. Future research could examine optimal cadence and maximal power output over a range of different resistances in the studied positions.

Despite a higher rate of effort during POST a lower peak and mean power output was observed when compared with PRE. This indicates that the 10 min lead-up induced fatigue during the POST sprint which can also be seen in the lower cadence during POST. This is inconsistent with the finding of Menaspà and colleagues[21] who observed no differences in 12 s sprint performance before vs. after a 10 min lead-up. An explanation for this inconsistency could be the level of cyclists. In the current study the cyclists were classifiable as level 3 or higher as per De Pauw and colleagues[19] while Menaspà and colleagues[21] tested professional cyclists in level 5. In the study of Etxebarria and colleagues[71], well-trained cyclists performed a 30 s sprint before and after 1 h of cycling. A slight decrease in peak and mean power output, and peak cadence (0.5±6.4, 0.3±5.4, and 0.1±10.7%, respectively) was observed after 1 h of cycling at a constant power output. Additionally, the study showed a higher decrease in peak and mean power output, and peak cadence (5.6±7.3, 6.1±8.6, and 4.1±10.8, respectively) after 1 h of cycling with variable power outputs.[71] What the effect on sprint performance is of the full length of a cycling race (up to ~7 hours) is unclear.

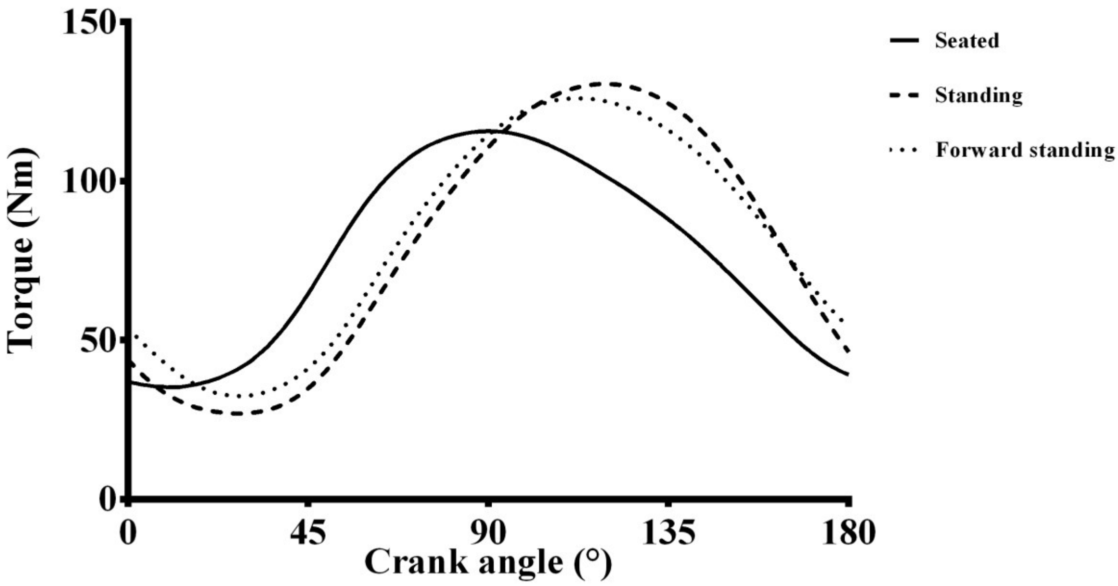

Figure 5.4 — Example of torque distribution for each sprint position

5.6. Practical Applications

Sprinting in the forward standing sprint position has previously shown its aerodynamic benefits when compared with more regular seated and standing sprint positions.[33,170] This research has shown that it does not impair power output, cadence, and torque when compared with the seated and standing sprint positions. This combination of equal power output production and aerodynamic benefits can result in an improvement of cycling velocity by 1.6-1.8 (5.6-6.5 $km \cdot h^{-1}$) and 0.6-1.4 $m \cdot s^{-1}$ (2.1-5.1 $km \cdot h^{-1}$) when compared with the seated and standing sprint position, respectively. This improvement in cycling velocity can be the difference between winning and losing a cycling race especially since most sprints are won by very small margins. How the results from this laboratory-based study transfers to actual road sprints stays unclear.

5.7. Conclusion

In conclusion, this study showed that power output, cadence, and torque are not impaired when sprinting in the forward standing sprint position when compared with the seated and standing sprint positions.

6. The Combination of Video and External Focused Verbal Instructions, and Positive Feedback does not Enhance the Training Induced Improvement in Forward Standing Sprint Performance

6.1. Abstract

Purpose: Determine if the provision of visual and external focused verbal instructions, and positive feedback would enhance the training effects of two weeks forward standing sprint training. ***Methods:*** Prior to and after 6 sprint training sessions 28 recreational male road cyclists performed a 14 s cycling sprint before and directly after a high-intensity lead-up. Power output, cadence, torque, and kinematics (sub-group of 16 participants only) were recorded during each sprint. The participants were separated into 2 groups. During the training sessions, one group received visual and external focused verbal instructions, and positive feedback, while the other group received neutral verbal instructions and feedback. ***Results:*** Peak and mean power output, and peak torque were significantly greater post-training, when compared with baseline in both groups. The combination of the three coaching techniques did not further enhance performance. Knee and hip range of motion were higher during post-training when compared with baseline in the sub-group. ***Conclusion:*** The combination of visual and external focused verbal instructions, and positive feedback did not enhance the training effects of two weeks forward standing sprint training.

Keywords: cycling, external focus, motor learning, positive feedback, verbal instruction, visual instruction

Chapter 6 is not available in this version of the thesis.

7. General Discussion

7.1. Summary and Practical Implications

Road cycling races are physically demanding events during which sprint ability is a key determinant of success. Indeed, most professional races finish in a head-to-head, small group, or bunch sprint. Despite the importance of sprinting in road cycling, scientific literature is limited to a few studies describing the physical and physiological demands of a road cycling sprint and the lead-up phase.[2,3,6,7,14,21] Therefore, this PhD thesis focused on improving sprint performance in road cycling through improving our understanding of cycling aerodynamics, physiology, and coaching techniques. A total of four applied research studies were conducted and presented in Chapters 3 to 6. The main findings of this thesis were that: i) when using a rolling resistance previously reported in literature,[26] the Velocomp PowerPod power meter is a valid device to measure power output during a controlled field test but invalid during more dynamic training sessions; ii) sprinting in the novel forward standing position results in an improvement of CdA by 23% and 26%, when compared with a seated and standing position, respectively; iii) sprinting in the forward standing sprint position did not impair power output, cadence, and torque, when compared with the seated and standing sprint positions; iv) sprinting in the forward standing position might result in an improvement of cycling velocity by approximately 5 $km \cdot h^{-1}$, when compared with more traditional sprint positions; v) the combination of visual and external focused verbal instructions, and positive feedback does not enhance the training induced improvement in forward standing sprint performance after a two-week training programme.

The purpose of Chapter 3 was to determine the validity of the Velocomp PowerPod power meter during field cycling tests (study 1) and training (study 2) in comparison with the Verve Cycling InfoCrank power meter. Rolling resistance estimated by the Velocomp PowerPod was higher than what has been previously reported in literature,[26] resulting in an overestimation of power output. Therefore, adjustments were made to the rolling resistance in the Isaac software to examine if the power output measured by the Velocomp PowerPod was comparable to the Verve Cycling InfoCrank power meter. Both study 1 and 2 showed high correlations between the two power meters before and after adjusting rolling resistance. Additionally, when applying a rolling resistance previously reported in literature,[26] power output was similar between the Verve Cycling InfoCrank and Velocomp PowerPod power meter in study 1 (−0.57 to 0.24%) but not in study 2 (8.94 to 33.14%). This difference between study 1 and 2 could have arisen from a higher variability in drafting, passing traffic, riding position, road gradient and type, and wind direction in study 2 when compared with study 1. Additionally, using the Velocomp PowerPod power meter during dynamic high intensity, training sessions/races might lead to an overall overestimation of training load, as it overestimates power output at higher intensities. The Velocomp PowerPod power meter was one of the first available devices to calculate power output from opposing resistances (i.e. acceleration, air resistance, friction, and road gradient) and is an interesting advancement in the measurement of power output during cycling, which may have some additional applications like estimating CdA. Indeed, when the Velocomp PowerPod power meter is paired with a direct force power meter (e.g. SRM or Verve Cycling InfoCrank) it can estimate CdA. It is for this reason that we planned to use this device for the aerodynamic measurements in Chapter 4. However, according to the developers of the Velocomp PowerPod power meter the device needs at least 8 min of data to give accurate CdA values. Since we tested the Velocomp Powerpod power meter for its validity, the company has launched updated versions of the device and the newly developed AeroPod that have yet to be tested for their validity to measure power output and CdA, respectively. Given the results of Chapter 3 and that updates for the Velocomp PowerPod did not exist at the time of data collection of this thesis, the Velocomp PowerPod power meter was not used for the CdA measurements in Chapter 4.

Chapters 4 and 5 examined the effect of three different road cycling sprint positions on overall sprint performance. The main purpose of Chapter 4 was to determine the influence of seated, standing, and forward standing sprint positions on CdA. It was found that sprinting in the forward standing position results in a 23% and 26% lower CdA, when compared with a seated and standing position, respectively. The CdA was calculated from six submaximal efforts (i.e. approximately 25, 32, and 40 $km \cdot h^{-1}$ in two directions) and it is still unknown what the CdA would be during a maximal sprint. Measuring aerodynamics during a cycling movement is complex and even more so during a maximal effort. This is a limitation in all aerodynamic research within cycling. The effect of the three sprint positions on power output, cadence, and torque was assessed in Chapter 5. In this Chapter it was found that power output, cadence, and torque were similar between the three sprint positions. The results of Chapters 4 and 5 were used in a mathematical model[26] to calculate the potential cycling velocity in each of the three sprint positions. The results of similar power output found in Chapter 5 and the beneficial aerodynamic effect found in Chapter 4 were calculated to result in an improvement of cycling velocity in the forward standing position of up to approximately 6.5 and 5.0 $km \cdot h^{-1}$, when compared with the seated and standing sprint position, respectively. Throughout the average duration of a typical road cycling sprint (i.e. 14 s) this would result in a gain up to approximately 25 and 20 m, when compared with the seated and standing sprint position, respectively. Since cycling velocity is a critical variable in overall outcome of a cycling sprint these results are clearly important in improving success of road cycling sprinters.

A secondary aim of Chapter 4 was to determine the reproducibility of a field test to calculate CdA in the three different positions. No significant difference in CdA was observed between the two test days; however, a poor between-day reliability was observed. The poor between-day reliability might have arisen from technological (i.e. used equipment), methodological (i.e. environmental conditions and mathematical model), or biological variability (i.e. the cyclists ability to keep the position or velocity for 250 m).[175] It is most likely that the poor between-day reliability has arisen from biological variability since valid and reliable equipment was used; there were no differences in environmental conditions observed; and the mathematical model has previously been shown to be a valid method to calculate CdA.[27] To reduce biological variability, the participants in Chapter 4 performed one week of unsupervised training and one familiarisation session. However, two participants were excluded from this research following familiarisation as they were not able to maintain the requested positions. Also, in Chapter 5 the participants completed one week of unsupervised training and one familiarisation session to learn how to sprint in the three different positions. This chapter adds to the body of literature[38,40] indicating that cyclists can produce greater power output in the standing than the seated position. However, interestingly no difference in power output was observed between the seated and forward standing positions. It is plausible that the familiarisation was not sufficient to learn how to sprint and produce maximal power output in the forward standing position,[176-178] and might be the reason why no differences in power output were observed between the forward standing and seated position. More practice may be needed before adopting the forward standing position for performance.

Chapter 6 examined if visual and verbal external focus instructions, in combination with positive feedback, could enhance forward standing sprint performance, when compared with neutral verbal instructions and feedback. The combination of the three coaching techniques did not improve forward standing sprint performance, neither did it alter kinematics. However, a significant body of the literature has shown that when analysed individually these coaching techniques are well known to improve performance, coordination, rate of learning, self-confidence, perception of competence, and self-efficacy.[41-46,187-191,193,194,203-207] This may be because, to the best of our knowledge, this was the first study to combine visual and external focused instructions, and positive feedback which might have interacted differently, when compared with research analysing these variables individually. Importantly, these variables were combined in an attempt to maximise any potential beneficial effects and best replicate real world coaching practices, which are not restricted to one form of instruction/feedback. Furthermore, we are unaware of other research analysing these three coaching techniques in a longitudinal study rather than a cross-sectional design. It is plausible that the acute benefits of instructions and feedback on performance observed in prior literature[41-46,187-191,193,194,203-207] are overshadowed by the training induced changes that both groups experienced in this study. Importantly, regardless of instructions and feedback, in this study an improvement in peak (~4%) and mean power output (~3%), and peak torque (~5%) was observed following training, indicating the intervention may improve sprint performance in the newly adopted forward standing sprint position. However, it should be noted that given the study design, we did not have a control group that performed no sprint training and so such results should be interpreted with caution. However, the improvement in performance is in line with previous short-term sprint training studies which have shown improvements in sprint power output.[210-212] Implementing such a short-term training programme before major events/goals during a cycling season could potentially result in more wins.

7.2. Directions for Future Research

This thesis outlines some potential new areas of research. Chapter 3 examined the validity of the Velocomp PowerPod. To correctly setup the device, coaches and cyclists are assumed to have the knowledge about the effect of tyre type, grade, and pressure, and road type on rolling resistance and therefore on power output. Measuring these variables in real time rather than relying on estimations may drastically improve the accuracy of devices, such as the Velocomp PowerPod, and could be an avenue of future research. The Velocomp PowerPod power meter may have some additional applications next to estimating power output (i.e. estimating CdA). Furthermore, Velocomp has further developed the PowerPod and released upgraded versions and a new device to measure CdA, the AeroPod. The validity and reliability of these applications, upgraded versions, and the new device have yet to be studied. In Chapter 4 the effect of three different sprint positions on CdA was analysed. Further research is needed to identify the effect of differences in anthropometric characteristics, balance and coordination, and bike-handling skills on the reliability of the field test to identify CdA in different positions. In Chapter 5 we observed similar power output, torque, and cadence between the three analysed sprint positions during laboratory-based sprints. The effect of sprint position on power output, torque, and cadence during field-based sprints is still unknown and could be subject for future research. Improvements in performance after a short-term training programme were found in Chapter 6, however no control group was implemented. Furthermore, the research outlined in this thesis did not focus on the underlying mechanisms (i.e. metabolic, perceptual, or neuromuscular perturbations) that are responsible for improvements in performance and is an important area for future research.

7.3. Conclusion

This thesis has shown the benefits of sprinting in the novel forward standing sprint position when compared with more traditional sprint positions. This thesis also examined the validity of one of the first opposing force power meters. This thesis concludes the following:

i) The Velocomp PowerPod power meter is a valid device to measure power output during a controlled field test but invalid during more dynamic training sessions (correction of rolling resistance is necessary).

ii) The forward standing sprint position is 23% and 26% more aerodynamic than the seated and standing sprint positions, respectively.

iii) Power output, cadence, and torque are not impaired while sprinting in the forward standing sprint position when compared with the seated and standing sprint positions.

iv) The combination of an improvement in aerodynamics and similar power output, when compared with more traditional sprint positions might lead to an improvement of cycling velocity by approximately 5 $km \cdot h^{-1}$.

v) The combination of visual and external focused verbal instructions, and positive feedback does not enhance the training induced improvement in forward standing sprint performance after a two-week training programme.

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9. Appendices

9.1. Appendix 1 — Science & Cycling 2019 Conference Presentation

The Combination of Visual and External Focused Instructions, and Positive Feedback did not Enhance Training-Induced Improvements in Forward Standing Sprint Performance

Paul F.J. Merkes, Paolo Menaspà, Israel Halperin, Lynne A. Munro, and Chris R. Abbiss

9.1.1. Introduction

Peak velocity is likely to be an important factor in the outcome of road cycling sprints. Cycling velocity is dependent on the balance of power output and resistive forces including, CdA, gravity, rolling resistance and mechanical inefficiencies.[27] With air resistance known to present the greatest resistive force, the trade-off between power output and CdA is a critical aspect of cycling. Chapter 4[170] and Blocken et al.[33] have shown that adopting a forward standing cycling sprint position (Figure 1.1C) reduces CdA by approximately 23-26 % when compared with a seated and standing position. This reduction in CdA can result in an increase of up to 5 $km \cdot h^{-1}$ in sprint cycling velocity.[170] However, the impact of the forward standing position on the ability to generate power output is currently unclear. Yet, research from our group observed poor intra-day reliability in measurements of CdA, possible due to the cyclist's inability to consistently maintain the required position.[170]

In the process of learning a new motor skill the instructions and feedback an athlete receives from his/her coach are of high importance. When analysed individually visual instructions, instructions stimulating an external focus of attention, and positive feedback are well known to improve performance, coordination, rate of learning, self-confidence, perception of competence, and self-efficacy.[42-45,205] Additionally, combining visual and external focused verbal instructions with feedback has been shown to have a positive effect on learning.[47]

Appropriate instruction and feedback may, therefore, benefit the cyclist's ability to maintain effective sprinting position and enhance power output during the unaccustomed forward standing sprint position. Therefore, the purpose of this study was to determine if the provision of visual and external focused instructions, and positive feedback would enhance the training effects of short-term (6 sessions) forward standing sprint training sessions, when compared with neutral verbal instructions and feedback.

9.1.2. Methods

Twelve trained amateur male cyclists (mean ± SD: age, 44 ± 9 y; height, 180.8 ± 5.7 cm; weight, 90.5 ± 8.4 kg; $\dot{V}O_2max$, 50.4 ± 5.8 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$; MAP, 386 ± 27 W; HRmax, 173 ± 9 bpm, performance level 3 or higher[19]) were divided into two equally matched groups based on height and MAP. Both groups performed 2 weeks of sprint training (6 sessions) in the forward standing sprint position including 2-3 sets of 2-4 repetitions of maximal effort sprints ranging 5-20 s. One group received visual (once at the start of each session) and external focused verbal instructions (30 s before each sprint) as well as positive feedback (after each completed set) about their cycling sprint position (intervention group). The other group only received a neutral verbal instructions and feedback (control group). Prior to (baseline) and following training (post-training) both groups performed a high-intensity sprint performance protocol. The sprint protocol has been described elsewhere,[21] and includes 14 s sprints performed both prior to (non-fatigued) and following (fatigued) a 10 min lead-up, from which peak and mean power output and cadence were measured.

9.1.3. Results

No effect of training group on performance was found. An increase in mean power output was observed during the non-fatigued sprint during post-training when compared with baseline (P = 0.047; η_p^2 = 0.580). Pairwise comparisons revealed an increase in mean power output in the control group (1012 ± 128 vs. 1095 ± 121 W) but not in the experimental group (1042 ± 157 vs. 1064 ± 227 W; Figure 9.1). No differences were observed in cadence.

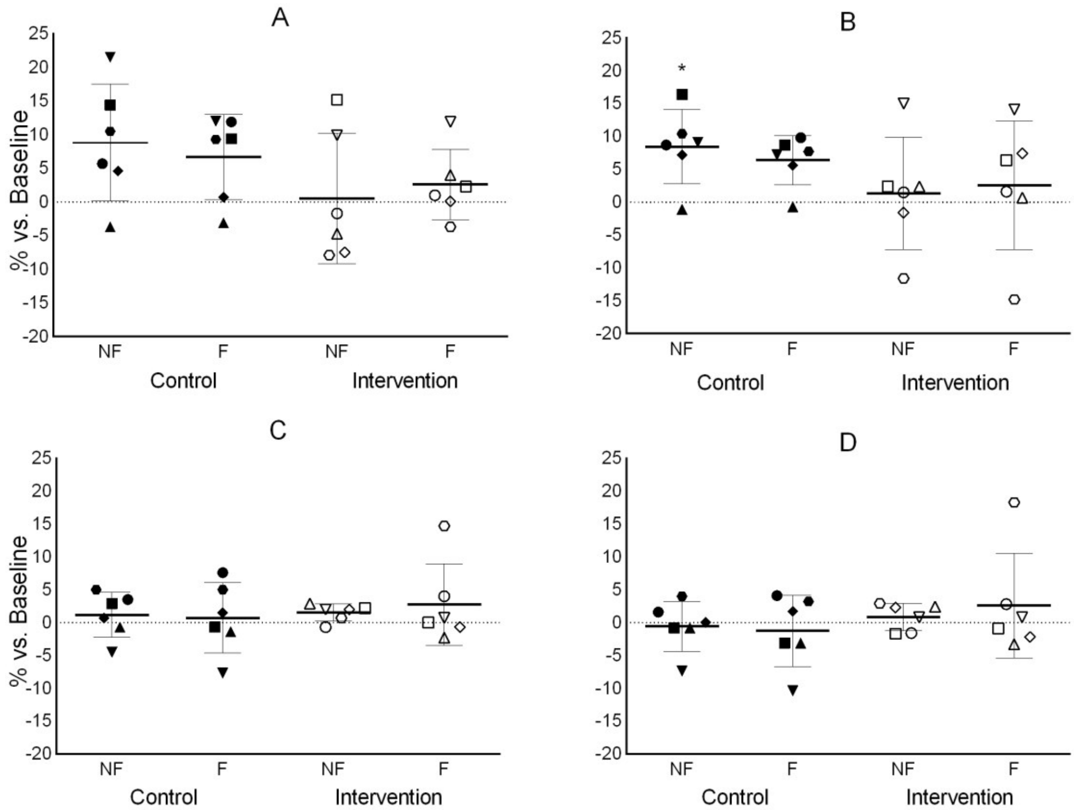

Figure 9.1 — Power output and cadence expressed in percentages versus baseline

(A) Peak power output (W); (B) mean power output (W); (C) peak cadence (rpm); (D) mean cadence (rpm); NF = non-fatigued; F = fatigued; * = $P \leq 0.05$ baseline vs. post-training

9.1.4. Discussion

The combination of visual and external focused instruction, and positive feedback within this study did not improve forward standing sprint performance. While some studies in elite athletes did not found a difference in performance after external vs. internal focused instructions[204] and positive vs. neutral and negative feedback,[194] most studies however, did show an improvement in performance among amateur athletes with visual and external focused instructions, and positive feedback.[42-45,205] It is plausible that the combination of visual and external focused instructions, and positive feedback might have interacted differently, when compared with research analysing these variables individually. Additionally, in most motor learning studies the participants complete a novel task in which they have little to no experience. While the forward standing position is a novel task for most cyclists, the participants in the current study were familiar with sprinting in a regular standing position. It is also possible that the duration of this pilot study was not long enough to induce sufficient learning of the motor task. More training sessions may be required to allow for the combined interventions to lead to a meaningful learning effect compared with the control group.

This pilot study showed an improvement in mean power output during 14 s non-fatigued sprints is possible after only 2 weeks of sprint training in the forward standing position. However, no other improvements in power output or cadence were observed. The 2-week training period might not have been long enough to improve these variables. Furthermore, total training volume and overall content of the training week was not monitored during this study and could have impacted sprint performance. Figure 9.1 shows a significant amount of variability between the cyclists. While some cyclists improved after 2 weeks of training (up to 21.5%) others showed a decrease in performance (up to -14.8%). Greater performance inconsistency is also observed in amateurs when compared with elite athletes.[217] Although power output and cadence were unaffected, it may be that other metrics may be more discriminatory, for example CdA and biomechanical variables. This presents opportunity for future research. The results might also be underpowered by the small number of participants and a power analysis should be conducted prior to future study.


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Figure 9.2 — Certificate of presentation Science & Cycling conference

9.2. Appendix 2 — The Conversation Publication

Your Riding Position Can Give You an Advantage in a Road Cycling Sprint

<u>Link to the publication</u>

Many professional road cycling events are hundreds of kilometres long, but the final placings are often decided by what happens in the last few seconds of any race stage. New research shows that a rider can gain up to an extra 5kph advantage in those final sprint seconds, and it all depends on how they position themselves on their bicycle. That can be enough to make the difference between winning or losing a race.

9.2.1. Race to the Finish

If you've ever watched a professional road cycling event, either live or on television, you know they can go on for several days or even weeks. But more than half of the stages during the Santos Tour Down Under and the Tour de France, as well as some of the recent World Championships, were won in either a head-to-head, small group, or mass sprint finish. The average speed during professional road cycling sprints is 63.9kph (53.7-69.1kph) sustained for between 9 and 17 seconds for men,[7] and 53.8kph (41.6-64kph) for 10-30 seconds for women.[2] During the sprint, men produce peak power outputs between 13.9 and 20.0 Watts per kilogram (989-1,443 Watts), and women 10.8-16.2 Watts per kilogram (716-1,088 Watts). But peak power output is not the only important factor to win the sprint, with tactics playing a significant role.[14] Our new research, published this month in the International Journal of Sports Physiology and Performance,[170] shows that adopting a forward standing position during a sprint could give riders a speed boost of up to 5kph.

9.2.2. The Drag on a Cyclist

Cycling speed is affected by several factors, including power output, CdA, road characteristics, and environmental variables. During the sprint, roughly 95% of the total resistive forces working against the rider is caused by aerodynamic resistance. Therefore, it is important to reduce aerodynamic drag in road cycling, particularly during the sprint which is the fastest activity on the bicycle (with the exclusion of some downhill riding during a race). Given that the outcomes of road cycling sprints are often decided by very small margins – in one race stage down to just 0.0003 seconds[32] – the aerodynamics are meaningful to overall sprint performances. Studies on flow dynamics in cycling have shown that lowering the head and torso significantly reduces wind resistance.[125] That is why several cyclists have, over the past few years, begun to adopt a forward standing cycling sprint position. This novel sprint position has already shown to be successful at the highest level of professional cycling, in events such as the Giro d'Italia and Vuelta a España and in Australia's biggest road cycling race, the Santos Tour Down Under.

9.2.3. Body Position to the Test

To better understand why this forward standing position may give riders an advantage, we compared it with the more traditional seated and standing sprint positions. During the study, participants rode 250 metres in two directions at 25kph, 32kph and 40kph and in each of the three positions, resulting in a total of 18 efforts per participant. During these efforts we measured cycling velocity, power output, road gradient, wind velocity and direction, temperature, humidity, and barometric pressure. We then used these variables, together with the weight of the cyclist and bicycle, and constants for rolling resistance and the efficiency of the drive system, in a mathematical model to calculate the aerodynamic drag. This model has previously been shown to give valid measurements compared with a wind tunnel.[27]

9.2.4. The Results are in

We found the forward standing cycling sprint position resulted in a 23-26% reduction in aerodynamic drag compared with a seated and standing position, respectively. This decrease in drag could potentially result in an important increase in cycling sprint velocity of 3.9-4.9kph. Throughout the average duration of a typical road cycling sprint (about 14 seconds) this would result in a gain of 15-19 metres, which is why it could mean the difference between winning and losing a race. While this novel position was more aerodynamic, it is plausible that changes in body position may influence a rider's movement kinetics, and therefore increasing or decreasing power output. This is currently under investigation in this PhD project. But cyclists who want to improve their sprint performance might want to start practising the forward standing position. It takes time to learn how to sprint in that position, but you could gain those aerodynamic benefits, and potentially win more races.

9.3. Appendix 3 — Other Media

9.3.1. Interview

An interview with Matt de Neef from CyclingTips.com: *Why everyone should be sprinting like Caleb Ewan.*

Link to the interview

9.3.2. Podcast

A podcast with Jeremiah Peiffer from Science from the Source: *Episode#12: Position, aerodynamics and sprint speed - Paul Merkes PhDc.*

Link to the podcast

9.3.3. Radio Interview

A radio interview with Patrick Lodiers and Roelof de Vries from De Proloog on NPO Radio 1 (Dutch national radio station).

Link to the radio interview (Dutch only)

9.3.4. Other Mentions

CyclingTips.com	Link 1 Link 2
Global Cycling Network podcast	Link from minute 16:10
PEZCyclingNews.com	Link
SBS.com.au	Link