

7-1-2019

Reducing aerodynamic drag by adopting a novel road-cycling sprint position

Paul F. J. Merkes
Edith Cowan University, p.merkes@ecu.edu.au

Paolo Menaspa
Edith Cowan University, p.menaspa@ecu.edu.au

Chris R. Abbiss
Edith Cowan University, c.abbiss@ecu.edu.au

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Recommended Citation

Merkes, P. F., Menaspa, P., & Abbiss, C. R. (2019). Reducing aerodynamic drag by adopting a novel road-cycling sprint position. DOI: <https://doi.org/10.1123/ijsp.2018-0560>

[10.1123/ijsp.2018-0560](https://doi.org/10.1123/ijsp.2018-0560)

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This Journal Article is posted at Research Online.
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1 Original Investigation

2
3 **Title:**

4 Reducing aerodynamic drag by adopting a novel road cycling sprint position.

5
6 **Authors:**

7 Paul F.J. Merkes¹, Paolo Menaspà¹, and Chris R. Abbiss¹

8
9 **Affiliations:**

10 ¹Centre for Exercise and Sports Science Research, School of Medical and Health Sciences,
11 Edith Cowan University, Joondalup, WA, Australia

12
13 **Corresponding Author:**

14 Paul F.J. Merkes

15 Centre for Exercise and Sports Science Research

16 Edith Cowan University

17 270 Joondalup Drive, Joondalup, WA

18 Phone: (+61)447826963

19 E-mail address: p.merkes@ecu.edu.au

20
21 **Running title:** Aerodynamic drag in road cycling sprints

22 **Abstract word count:** 228

23 **Text only word count:** 3656

24 **Number of figures:** 3

25 **Number of tables:** 1

26

27 Abstract

28 **Purpose:** To assess the influence of a seated, standing, and forward standing cycling
29 sprint position on aerodynamic drag CdA and the reproducibility of a field test of CdA
30 calculated in these different positions. **Methods:** Eleven recreational male road cyclists rode
31 250 m in two directions at around 25, 32, and 40 km·h⁻¹ and in each of the three positions,
32 resulting in a total of 18 efforts per participant. Riding velocity, power output, wind direction
33 and velocity, road gradient, temperature, relative humidity, and barometric pressure were
34 measured and used to calculate CdA use regression analysis. **Results:** A main effect of position
35 showed that the average CdA of the two days was lower for the forward standing position (0.295
36 ± 0.059), compared with both the seated (0.363 ± 0.071; p = 0.018) and standing positions
37 (0.372 ± 0.077; p = 0.037). Seated and standing positions did not differ from each other. While
38 no significant difference was observed in CdA between the two test days, a poor between day
39 reliability was observed. **Conclusion:** A novel forward standing cycling sprint position resulted
40 in a 23 and 26% reduction in CdA compared with a seated and standing position. This decrease
41 in CdA could potentially result in an important increase in cycling sprint velocity of 3.9-4.9
42 km·h⁻¹, although these results should be interpreted with caution since poor reliability of CdA
43 was observed between days.

44
45 **Keywords** CdA, aerodynamics, cyclist, sprinting, between day reliability.

47 Introduction

48 The outcome of road cycling races is often decided by a sprint. Indeed, over half of the
49 mass start stages during the three grand tours (i.e. Giro d'Italia, Tour de France, and Vuelta a
50 España) as well as several of the recent World Championships, were decided in either a head-
51 to-head, small group, or mass sprint finish. To date, road cycling sprints have not been
52 extensively examined.¹⁻⁵ It appears that to be competitive in a sprint, male cyclists are required
53 to produce high peak power outputs (e.g. 13.9-20.0 W·kg⁻¹;⁴ 989-1443 W^{1.4}) over durations of
54 approximately 9 to 17 s.^{1,4} However, studies have also shown that peak power output is not the
55 only important factor to success.² Indeed, a cyclist's velocity is likely to be a much more
56 important factor in the outcome of road cycling sprints. Cycling velocity is the result of power
57 output, aerodynamic drag (CdA), road characteristics, and environmental variables.⁶ Therefore,
58 CdA plays an important role in cycling, but is often overlooked, particularly within the sprint.

59 Depending on the equipment and position of a cyclist on the bicycle, aerodynamic
60 resistance represents approximately 95% of the total resistive forces experienced when cycling
61 at 65 km·h⁻¹.⁷ Additionally, the external power required to overcome aerodynamic resistance is
62 a third polynomial of the velocity,⁸ making it necessary to increase power output by 2% to
63 increase a cycling velocity by 1% only, when riding at 65 km·h⁻¹.⁶ Reducing CdA is therefore
64 extremely important to road cycling performance, and even more in sprint performance since
65 sprinting is likely to be the fastest activity in road cycling (with the exclusion of some
66 descending). Given that the outcomes of road cycling sprints are often decided by very small
67 margins, aerodynamics are meaningful to overall sprint performances.

68 CdA can be determined using a wind tunnel or mathematical modelling.⁶ However,
69 wind tunnel testing is relatively expensive and facilities somewhat scarce. The research in CdA
70 within road sprint cycling is limited with the majority of the literature focusing on time trials
71 and endurance cycling.⁸⁻¹² In some of the very few studies to examine CdA in sprinters, it was
72 found that a seated position was more aerodynamic than a standing position. In particular,
73 Martin and colleagues⁶ reported CdA values based on cycling position of three track sprinters.
74 Sprinting while seated resulted in a CdA of 0.245 m², while a standing position resulted in a
75 CdA of 0.304 m². In a different study, Martin and colleagues¹ modelled the difference in CdA
76 between one seated (0.288 m²) and one standing sprint (0.360 m²). However, comparing

77 different positions was not the focus of these studies.^{1,6} From data published on aerodynamics
78 in cycling, it is known that lowering the torso⁸⁻¹¹ and head^{9,12} significantly reduced
79 aerodynamics. Therefore, in this study a novel cycling sprint position was assessed during
80 which participants adopted a low and forward torso and head position (forward standing
81 position). The aim of this study was to assess the influence of a seated, standing, and forward
82 standing position on CdA and the reproducibility of a field test to calculate CdA in these
83 different positions.

84 **Methods**

85 ***Participants***

86 Eleven recreational male road cyclists (age, 37.1 ± 6.1 y; height, 178.7 ± 6.6 cm; weight,
87 78.9 ± 9.9 kg) volunteered to participate. The participants rode 5.2 ± 1.0 times and for $10.7 \pm$
88 4.0 hours per week and were classifiable as performance level 3 or higher, as per de Pauw and
89 colleagues.¹³ The participants completed a familiarization session and two identical
90 aerodynamic field tests¹⁴ separated by at least two days and a maximum of seven days. Prior to
91 data collection, the subjects provided written informed consent in accordance with the Edith
92 Cowan University Human Research Ethics Committee and the principals outlined in the
93 Declaration of Helsinki. All participants were asked to avoid strenuous exercise and refrained
94 from the consumption of caffeine 24 hours prior to testing.

95 ***Experimental design***

96 The familiarization session started with a 10-minute warm-up at a freely chosen low-
97 intensity. Three minutes following the warm-up participants performed one of the 250 m test
98 sections of the aerodynamic field test (described below) in three different positions (i.e. seated,
99 standing, and forward standing; Figure 1). During the familiarization session, participants were
100 assessed by a single investigator using video footage (described below) to determine whether
101 they were capable to maintain each position. When a participant was not able to ride in each
102 position he was excluded from the study. In total two participants were excluded from the study.
103 One of the participants was not able to hold the standing and forward standing positions longer
104 than 5 s. The video analysis did not reveal a noticeable difference between the standing and the
105 forward standing position in the other participant.

106 During the two aerodynamic field tests participants performed the protocol described
107 by Martin and colleagues¹⁴ in three different positions three minutes after a 10-minute warm-
108 up. Specifically, both aerodynamic testing sessions were identical and involved participants to
109 ride 250 m in two directions at 24 to 26, 31 to 33, and 39 to 41 $\text{km}\cdot\text{h}^{-1}$ and in each of the three
110 positions, resulting in a total of 18 efforts per participant. All efforts were conducted in a
111 randomized and counter-balanced order. Participants were asked to reach constant velocity
112 before entering the 250 m test section and to maintain constant velocity and selected position
113 within the 250 m test section. A 100 m section of road was provided at the start and end of the
114 250 m test section to allow the participants to accelerate and decelerate. The participants were
115 required to maintain the required velocity throughout the 250 m test section which they could
116 view on a Garmin Edge 820 head unit (Garmin, Schaffhausen, Switzerland) attached to the
117 handle bars during the seated and standing position, and the front fork during the forward
118 standing position. A recovery period of 4 min was given between each effort.

119 Participants completed the familiarization session and two aerodynamic field tests on a
120 road bicycle, with the seat height and saddle setback adjusted to replicate the participant's own
121 bicycle. The participants wore their own helmet during the field tests. The bicycle was equipped
122 with a Verve Cycling InfoCrank power meter (Verve Cycling, Perth, Australia) containing four
123 strain gauges per crank arm.¹⁵ All tests were completed on a quiet, straight, and flat road. A
124 high definition camera (Sony, Tokyo, Japan) was placed on the side of the road at the middle
125
126

127 of the 250 m test section to film the participant's sagittal plane at 25 Hz. A screenshot was taken
 128 when the cyclists was in the middle of the video footage and exported to Adobe Illustrator
 129 (Adobe Systems, San Jose, USA) afterwards. In this software, the front wheel was standardized
 130 at 200 pt; then, the distances between the participant's chest and the bottom of the front wheel
 131 (vertical) and between the participant's shoulder and the front wheel hub (horizontal) were
 132 determined (Figure 2). A negative number for the horizontal distance meant the shoulder was
 133 positioned in front of the frontal hub. This data was used to ascertain if the participants were
 134 adopting the desired position. The distance of the 250 m test section was measured with the
 135 Garmin head unit paired with the SRM speed sensor (Schoberer Rad Messtechnik, Jülich,
 136 Germany). The SRM speed sensor was used to measure cycling velocity at the beginning
 137 (initial) and end (final) of the 250 m test section. The average power output was measured by
 138 the Verve Cycling InfoCrank power meter. The gradient of the 250 m test section was measured
 139 with the Garmin head unit. Cycling velocity, average power output, and road gradient were
 140 recorded by the Garmin head unit at 1 Hz. Absolute wind velocity and direction were measured
 141 two times during every effort using a wireless weather station (Davis Instruments Corporation,
 142 Hayward, USA). The turning plane of the anemometer cups was located at approximately the
 143 same height as the participant's torso while positioned on the bicycle. A compass (Suunto,
 144 Vantaa, Finland) was used to indicate north on the weather station and to asses riding direction.
 145 Wind velocity parallel with the road was calculated using equation 1:¹⁴

$$146 V_a = V_W \cdot [\text{COS}(D_W - D_B)] \quad (\text{Equation 1})$$

147 in which V_a is wind velocity relative to the participant's riding direction in $\text{m}\cdot\text{s}^{-1}$; V_W is absolute
 148 wind velocity in $\text{m}\cdot\text{s}^{-1}$; D_W is wind direction in $^\circ$; and D_B is riding direction in $^\circ$. Finally,
 149 measurements of temperature, relative humidity, and barometric pressure were recorded four
 150 times during the session with the weather station (Davis Instruments Corporation, Hayward,
 151 USA). The average of these four measurement was used to calculate air density using equation
 152 2.¹⁶

$$153 \rho = \frac{P_b \cdot M_a}{R \cdot T \cdot Z} \cdot \left(1 + (\epsilon - 1) \frac{e'}{P_b}\right) \quad (\text{Equation 2})$$

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

158 Based upon calculations of Martin and colleagues¹⁷ one CdA value per position was
 159 calculated from six trials (i.e. two directions at 24 to 26, 31 to 33, and 39 to 41 $\text{km}\cdot\text{h}^{-1}$). Briefly,
 160 a regression analysis was performed using the mathematical model in equation 3:

$$161 P \cdot E - \frac{\Delta PE}{\Delta t} - \frac{\Delta KE}{\Delta t} = CdA \cdot \left(\frac{1}{2} \rho V_a^2 V_g\right) + \mu \cdot (V_g F_N) \quad (\text{Equation 3})$$

162 in which P is average power output in Watts; E is efficiency of the drive system (assumed to
 163 be 97.7%¹⁴); PE is potential energy; KE is kinetic energy; CdA is aerodynamic drag; ρ is air
 164 density; V_g is the ground velocity of the participants in $\text{m}\cdot\text{s}^{-1}$; μ is a global coefficient of friction
 165 (i.e. 0.006 for rough road¹⁷); and F_N is the normal force exerted by the bicycle tires on the
 166 rolling surface (essentially weight of the bicycle and participant).

167 168 **Statistical analysis**

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

174 CdA was compared between positions (i.e. seated, standing, and forward standing); and
 175 between days using a two-way analysis of variance (ANOVA). Furthermore, partial eta squared

176 was calculated. When a main effect of position was found, pairwise comparisons using
177 Bonferroni's corrections were performed. When an interaction effect of position and day was
178 found an additional ANOVA was performed to identify differences in position for each day.
179 The level of significance was set at $p \leq 0.05$ for all tests. All statistical analyses were completed
180 using SPSS (IMB SPSS Inc. Statistics, Chicago, USA).

181 The intra-day reliability was tested using the mean Coefficient of Variation (CV) and
182 the Intra-class Correlation Coefficient (ICC) for each position derived from log-transformed
183 data.¹⁸ A CV lower than 3.5% was regarded as high test-retest reliability.^{19,20}

184

185 **Results**

186 Results of the video analysis showed a mean \pm standard deviation for vertical and
187 horizontal distances (average of days) of 360.6 ± 13.1 and 26.2 ± 6.4 pt, and 311.6 ± 14.06 and
188 -2.7 ± 11.1 pt for standing and forward standing, respectively. The video analysis showed
189 significant differences between the standing and forward standing position in both the vertical
190 and the horizontal direction ($F(1,10) = 107.631$; $p = 0.001$, and $F(1,10) = 109.106$; $p = 0.001$,
191 respectively). No differences were found between days in both the vertical as the horizontal
192 direction ($F(1,10) = 0.083$; $p = 0.779$, and $F(1,10) = 0.775$; $p = 0.399$, respectively). No
193 differences in air density ($t(10) = 0.295$; $p = 0.774$); wind velocity parallel to the riding direction
194 ($t(10) = -0.040$; $p = 0.969$); and cycling velocity variability ($t(32) = -0.939$; $p = 0.355$; two-
195 tailed) were found between days (Table 1).

196 A significant main effect was observed for position on CdA ($F(2,20) = 9.234$; $p = 0.007$;
197 Partial $\eta^2 = 0.480$) (Figure 3). No main effect of day and interaction effect between position
198 and day on CdA was observed ($F(1,10) = 3.939$; $p = 0.075$; Partial $\eta^2 = 0.283$). Pairwise
199 comparisons revealed a lower CdA (average of days) for the forward standing position (0.295
200 ± 0.059), compared with both the seated (0.363 ± 0.071 ; $p = 0.018$) and standing positions
201 (0.372 ± 0.077 ; $p = 0.037$). No differences in CdA were found between the seated and standing
202 positions ($p = 1.00$). A lower CdA was observed for the forward standing position compared
203 with the standing positions on day 1 ($p = 0.05$), but not on day 2 ($p = 0.649$ and $p = 0.073$,
204 respectively). CdA was lower for the forward standing position when compared with the seated
205 position on day 2 (0.034), but not on day 1 ($p = 0.051$). Furthermore, no differences in CdA
206 were observed between the seated and standing positions on both days ($p = 1.00$ and $p = 1.00$,
207 respectively).

208 CV for the seated, standing, and forward standing positions were 16.0, 9.1, and 15.6%,
209 respectively. Large to very large ICC were found for the CdA between days in the seated ($r =$
210 0.530), standing ($r = 0.840$), and forward standing positions ($r = 0.600$).

211

212 **Discussion**

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

219 While several studies have examined CdA in road cycling,⁸⁻¹² very few have focused on
220 sprinting.^{1,6} To the best of our knowledge, this is the first study assessing CdA of a novel
221 forward standing position. It was found that this position has a 23 and 26% lower CdA
222 compared with a seated and standing position, respectively. Applying a mathematical model to
223 our results and previously reported data, such as average power output during road cycling
224 sprints ($865-1140 \text{ W}^{1,4}$); a cumulative weight of the bicycle and cyclist of 80 kg; road gradient
225 of 0%; wind velocity parallel to the cyclist of $0 \text{ m}\cdot\text{s}^{-1}$; and the average air density found in this

226 study ($\rho = 1.175$), an 23-26% improvement in CdA would result in an increase of cycling
227 velocity of approximately 3.9-4.9 km·h⁻¹.¹⁷ This could be a decisive improvement in velocity
228 given that road cycling races can be decided by very small margins. It is likely that the forward
229 standing position improved CdA due to the lower torso and head position. These changes in
230 body position were likely to affect both the frontal area (A_p , in m²) and the drag coefficient (Cd,
231 dimensionless). From data published on aerodynamics in cycling other than sprinting, it is
232 known that lowering the torso⁸⁻¹¹ and head^{9,12} significantly reduced CdA^{8-10,12} or A_p .¹¹ Cd is
233 dominated by the turbulence associated with the cyclist's position, shape, size, and surface
234 roughness; as A_p changes, the flow over the cyclist will also change. In other words, decreasing
235 A_p (due to changes in cycling position) does not directly result in a lower CdA. A weak
236 correlation exists between measured Cd and A_p , in which A_p only accounted for approximately
237 50% of the variation in CdA between different cycling positions.²¹

238 In the present study, no significant difference in CdA between the seated and standing
239 position was found. The slightly lower but non-significant group mean difference in CdA
240 between the seated and standing position in this study (~2.5%), is lower than the differences
241 found in other studies: 25%¹ and 24%.⁶ Explanations for such discrepancies between studies
242 could be due to differences in the characteristics of the cyclists. In the current study the average
243 height and weight of the participants were 178.7 ± 6.6 cm and 78.9 ± 9.9 kg, respectively.
244 Furthermore, the participants in the current study were all amateur male road cyclists. In the
245 study of Martin and colleagues⁶ three world-class track sprint cyclists were tested (1 male sprint
246 specialist: 1.83 m, 96 kg; 1 male kilometer time trial specialist: 1.82 m, 87 kg; and 1 female
247 500 m specialist: 1.65 m, 68 kg). Differences between studies might also have arisen from the
248 test location and environmental conditions (outdoor vs. indoors⁶), and sample sizes in the
249 current study (11 vs. 1¹ and 3,⁶ respectively). However, in this study all trials for all three
250 positions were performed in a randomized and counter-balanced order on a single day and
251 therefore it is unlikely that environmental conditions were responsible for the low difference
252 observed between the seated and the standing position. While no difference in CdA between
253 the seated and the standing positions was observed, it has been previously shown that cyclists
254 are able to generate greater power output in the standing position compared with the seated
255 position.^{22,23} The combination of a similar CdA and the possibility to generate greater power
256 output during a standing sprint will result in a higher cycling velocity compared to a seated
257 sprint. To date, it is unknown if cyclists can produce a similar or different power output in the
258 forward standing position compared to other more traditional positions and may be the subject
259 of future studies. Indeed, while this position was more aerodynamic it is plausible that changes
260 in body position may influence the movement kinetics compromising or increasing effective
261 pedal forces.

262 The second aim of this study was to assess the reproducibility of a field test to calculate
263 CdA in the seated, standing, and forward standing positions. This study showed poor reliability
264 to measure CdA in these positions. Such variability between days can be due to technological,
265 methodological, or biological variability.²⁴ The technological variability within this study may
266 have arisen from the equipment used (i.e. weather station, scale, stadiometer, power meter,
267 speed sensor, and head unit). According to the manufacturer's guideline the weather station's
268 accuracy was 1 hPa, 3%, 0.5°C, 3°, and 1 m·s⁻¹ for measuring barometric pressure, relative
269 humidity, temperature, wind direction, and wind velocity, respectively. The Verve Cycling
270 InfoCrank power meter showed similar mean deviation (trueness) to a mathematical model of
271 treadmill cycling and coefficient of variation (precision), compared with the golden standard:
272 the SRM power meter (i.e. Trueness = -1.7 ± 1.1 vs. -0.5 ± 2.4%; Precision = 0.6 ± 0.4 vs. 0.8
273 ± 0.4%, respectively).¹⁵ These small measurement errors might have resulted in the variability
274 found in this study. Further, methodological variability in this study could have arisen from the
275 environmental conditions and mathematical modelling. Within this study tests were conducted

276 outdoors whereas previous studies utilizing this model to calculate CdA have used the
277 mathematic model and field test in velodromes.⁶ Regardless, no differences in environmental
278 conditions between the two days were observed in this study. Furthermore, the mathematical
279 model and field test have previously been validated.⁶ In this study the greatest biological
280 variability would likely have been the ability of the participant to either maintain the required
281 position or an even velocity over the entire 250 m test section. While both cycling velocity
282 variability and the analysis of the screenshots from the videos did not show a difference between
283 the two days, it is plausible that minor fluctuations in velocity and position occurred which
284 might have influenced the outcomes of this study. In addition, a single camera next to the 250
285 m test section might not have been sufficient to identify these small fluctuations. Regardless of
286 this, this study was still able to identify differences between the forward standing and both the
287 seated and standing positions, highlighting the large effect that the forward standing position
288 has on CdA. In order to reduce biological variability only well-trained cyclists were recruited
289 in this study. Furthermore, to ensure that the participants were able to maintain the required
290 position over the test section the participants performed one week of training and one
291 familiarization session. In the current study two participants were not able to maintain the
292 requested positions and were excluded from this study after the familiarization session. It is
293 plausible that this familiarization was not sufficient,²⁵⁻²⁷ and more practice is needed before
294 adopting the forward standing position for performance. Future research should examine the
295 influence of training on the consistency of adopting such abnormal sprint positions. Other
296 factors which might have led to these exclusions are anthropometric characteristics, poor
297 balance and coordination, or poor cycling handling skills. However, the anthropometric
298 characteristics of the participants in the current study suggests that cyclists within a wide range
299 in height and weight are able to adopt and may benefit from the forward standing position.
300 Further research is needed to identify the effect of additional familiarization or training sessions,
301 differences in anthropometric characteristics, balance and coordination, and cycling handling
302 skills on the reliability of this field test to identify CdA in different positions.

303

304 **Practical applications**

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

311

312 **Conclusion**

313 A novel forward standing cycling sprint position resulted in a 23 and 26% reduction in
314 CdA compared with a seated and standing position. This decrease in CdA could result in an
315 increase of approximately 3.9-4.9 km·h⁻¹ in cycling sprint velocity. However, these results
316 should be interpreted with caution since poor reliability of CdA was observed between days.
317 Further research is required to determine factors influencing the poor reliability observed. It is
318 plausible that more than one week of training and a single familiarization session is required to
319 ensure reliability of CdA in these sprint positions.

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394 **Figure and tables**
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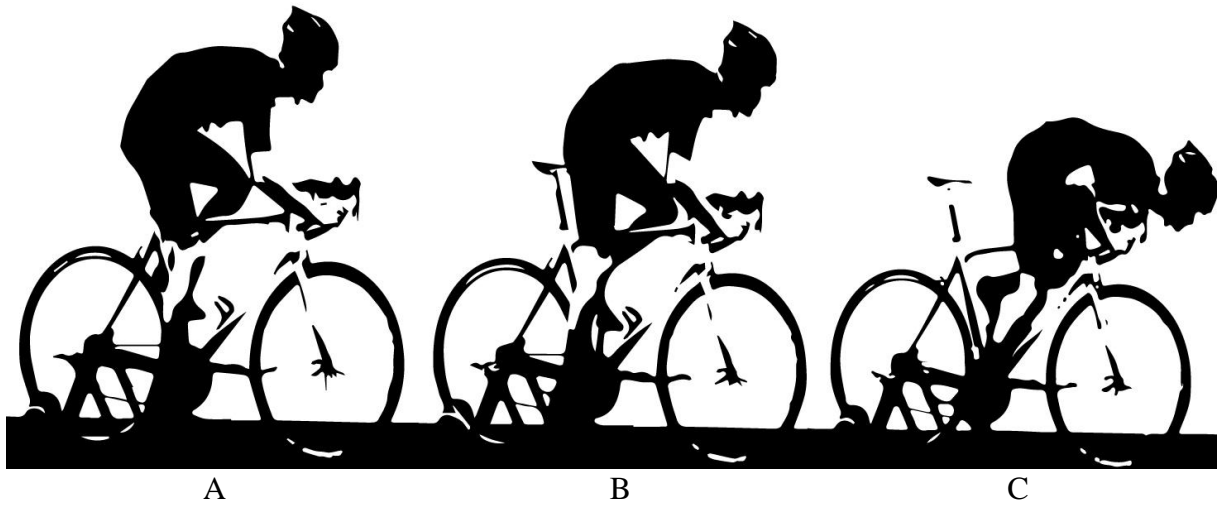
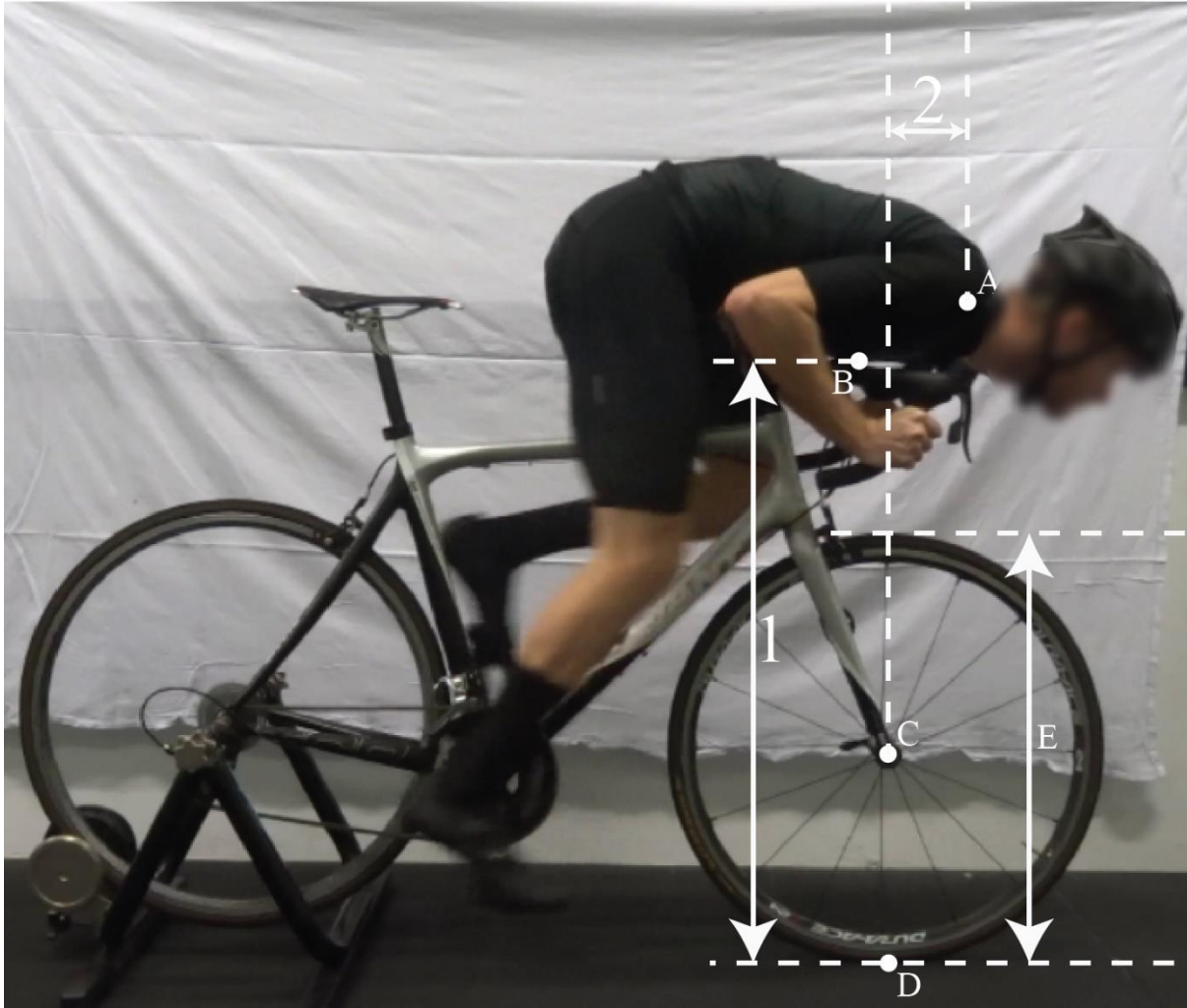


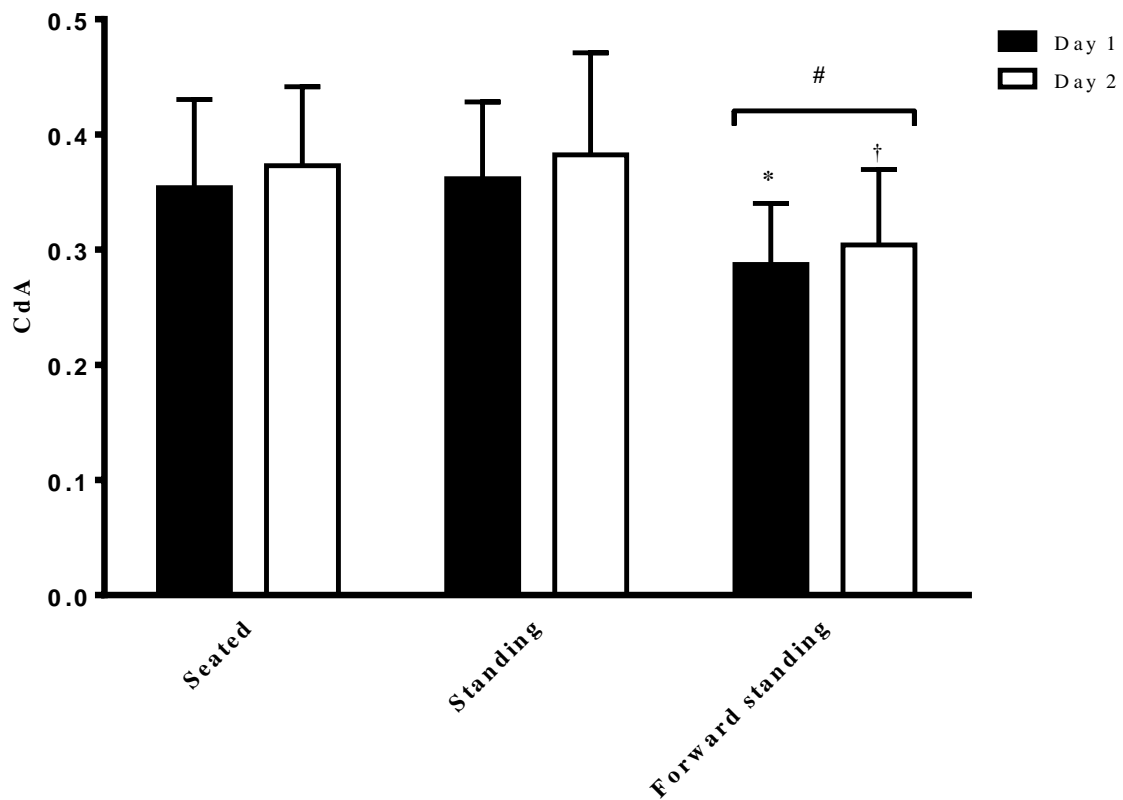
Figure 1 The three sprinting positions: A) seated, B) standing, and C) forward standing.

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Figure 2 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).



404
 405 **Figure 3** CdA per sprinting position for day 1 and 2.
 406 * = $P \leq 0.05$; Forward standing day 1 vs. Standing day 1.
 407 † = $P < 0.05$; Forward standing day 2 vs. Seated day 1.
 408 # = $P < 0.05$; Forward standing vs. Seated and Standing (main effect).
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 410

Table 1 Mean \pm SD of variables used for CdA calculations.

		Seated	Standing	Forward standing
ρ	Day 1	1.176 \pm 0.022	1.176 \pm 0.022	1.176 \pm 0.022
	Day 2	1.174 \pm 0.017	1.174 \pm 0.017	1.174 \pm 0.017
V_a ($m \cdot s^{-1}$)	Day 1	0.21 \pm 0.51	-1.79 \pm 0.44	-0.01 \pm 0.65
	Day 2	-0.23 \pm 0.50	-0.14 \pm 0.50	-0.07 \pm 0.56
V_g variability ($km \cdot h^{-1}$)	Day 1	0.47 \pm 0.06	0.60 \pm 0.08	0.69 \pm 0.17
	Day 2	0.46 \pm 0.10	0.65 \pm 0.14	0.71 \pm 0.20

V_g = the ground velocity variability of the participants; ρ = air density; V_a = wind velocity relative to the participant's riding direction.

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