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

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Original Investigation

Title:

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

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Abstract

Purpose: To assess the influence of a seated, standing, and forward standing cycling sprint position on aerodynamic drag CdA and the reproducibility of a field test of CdA calculated in these different positions. ***Methods:*** Eleven recreational male road cyclists rode 250 m in two directions at around 25, 32, and 40 $km \cdot h^{-1}$ and in each of the three 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 use regression analysis. ***Results:*** A main effect of position showed that the average CdA of the two 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. While no significant difference was observed in CdA between the two test days, a poor between day reliability was observed. ***Conclusion:*** A novel forward standing cycling sprint position resulted in a 23 and 26% reduction in CdA compared with a seated and standing position. This decrease in CdA could potentially result in an important increase in cycling sprint velocity of 3.9-4.9 $km \cdot h^{-1}$, although these results should be interpreted with caution since poor reliability of CdA was observed between days.

Keywords CdA, aerodynamics, cyclist, sprinting, between day reliability.

Introduction

The outcome of road cycling races is often decided by a sprint. Indeed, over half of the mass start stages during the three grand tours (i.e. Giro d'Italia, Tour de France, and Vuelta a España) as well as several of the recent World Championships, were decided in either a head-to-head, small group, or mass sprint finish. To date, road cycling sprints have not been extensively examined.[1-5] 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[1,4]) over durations of approximately 9 to 17 s.[1,4] However, studies have also shown that peak power output is not the only important factor to success.[2] 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, aerodynamic drag (CdA), road characteristics, and environmental variables.[6] 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 $km \cdot h^{-1}$.[7] Additionally, the external power required to overcome aerodynamic resistance is a third polynomial of the velocity,[8] making it necessary to increase power output by 2% to increase a cycling velocity by 1% only, when riding at 65 $km \cdot h^{-1}$.[6] Reducing CdA is therefore extremely important to road cycling performance, and even more in sprint performance since 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 are meaningful to overall sprint performances.

CdA can be determined using a wind tunnel or mathematical modelling.[6] However, wind tunnel testing is relatively expensive and facilities 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.[8-12] 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 and colleagues[6] reported CdA values based on cycling position of three track sprinters. Sprinting while seated resulted in a CdA of 0.245 m^2, while a standing position resulted in a CdA of 0.304 m^2. In a different study, Martin and colleagues[1] modelled the difference in CdA between one seated (0.288 m^2) and one standing sprint (0.360 m^2). However, comparing different positions was not the focus of these studies.[1,6] From data published on aerodynamics in cycling, it is known that lowering the torso[8-11] and head[9,12] 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.

Methods

Participants

Eleven recreational male road cyclists (age, 37.1 ± 6.1 y; height, 178.7 ± 6.6 cm; 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 and colleagues.[13] The participants completed a familiarization session and two identical aerodynamic field tests[14] separated by at least two days and a maximum of seven days. Prior to data collection, the subjects provided written informed consent in accordance with the Edith Cowan University Human Research Ethics Committee and the principals 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.

Experimental design

The familiarization 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 three different positions (i.e. seated, standing, and forward standing; Figure 1). During the familiarization session, participants were assessed by a single investigator using video footage (described below) to determine whether they were capable to maintain each position. When a participant was not able to ride in each position he was excluded from the study. In total two participants were excluded from the study. One of the participants was not able to hold the standing and forward standing positions longer than 5 s. The video analysis did not reveal a noticeable difference between the standing and the forward standing position in the other participant.

During the two aerodynamic field tests participants performed the protocol described by Martin and colleagues[14] in three different positions three minutes after a 10-minute warm-up. Specifically, both aerodynamic testing sessions were identical and involved participants to ride 250 m in two directions at 24 to 26, 31 to 33, and 39 to 41 $km \cdot h^{-1}$ and in each of the three positions, resulting in a total of 18 efforts per participant. All efforts were conducted in a randomized and counter-balanced order. Participants were asked to reach constant velocity before entering the 250 m test section and to maintain constant velocity and 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 handle bars during the seated and standing position, and the front fork during the forward standing position. A recovery period of 4 min was given between each effort.

Participants completed the familiarization session and two aerodynamic field tests on a road bicycle, with the seat height and saddle 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 four strain gauges per crank arm.[15] 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 cyclists was in the middle of the video footage and exported to Adobe Illustrator (Adobe Systems, San Jose, USA) afterwards. In this software, the front wheel was standardized 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 2). A negative number for the horizontal distance meant the shoulder was positioned in front of the frontal hub. This data was 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 two times during every effort using a wireless weather station (Davis Instruments Corporation, Hayward, USA). 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 asses riding direction. Wind velocity parallel with the road was calculated using equation 1:[14]

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

in which V_a is wind velocity relative to the participant's riding direction in m·s^{-1}; V_W is absolute wind velocity in m·s^{-1}; D_W is wind direction in °; and D_B is riding direction in °. Finally, measurements of temperature, relative humidity, and barometric pressure were recorded four times during the session with the weather station (Davis Instruments Corporation, Hayward, USA). The average of these four measurement was used to calculate air density using equation 2:[16]

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

in which ρ is air density; P_b is barometric pressure in Pa; 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 upon calculations of Martin and colleagues[17] one CdA value per position was calculated from six trials (i.e. two directions at 24 to 26, 31 to 33, and 39 to 41 km·h^{-1}). Briefly, a regression analysis was performed using the mathematical model in equation 3:

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

in which P is average power output in Watts; E is efficiency of the drive system (assumed to be 97.7%[14]); PE is potential energy; KE is kinetic energy; CdA is aerodynamic drag; ρ is air density; V_g is the ground velocity of the participants in m·s^{-1}; μ is a global coefficient of friction (i.e. 0.006 for rough road[17]); and F_N is the normal force exerted by the bicycle tires on the rolling surface (essentially weight of the bicycle and participant).

Statistical analysis

The vertical and horizontal distances found in the screenshots were analyzed using a two-way ANOVA to identify differences between the standing and forward standing position 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.

CdA was compared between positions (i.e. seated, standing, and forward standing); and between days using a two-way analysis of variance (ANOVA). Furthermore, partial eta squared 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 (IMB SPSS Inc. Statistics, Chicago, USA).

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

Results

Results of the video analysis showed a mean ± standard deviation 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 ($t(32) = -0.939$; $p = 0.355$; two-tailed) were found between days (Table 1).

A significant main effect was observed for position on CdA ($F(2,20) = 9.234$; $p = 0.007$; Partial $\eta 2 = 0.480$) (Figure 3). No main effect of day and interaction effect between position and day on CdA was observed ($F(1,10) = 3.939$; $p = 0.075$; Partial $\eta 2 = 0.283$). 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 ($p = 1.00$). 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 ($p = 0.649$ and $p = 0.073$, respectively). CdA was lower for the forward standing position when compared with the seated position on day 2 (0.034), but not on day 1 ($p = 0.051$). Furthermore, no differences in CdA were observed between the seated and standing positions on both days ($p = 1.00$ and $p = 1.00$, respectively).

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 ($r = 0.600$).

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. While no significant difference was observed in CdA between the two test days, a poor between day reliability was observed.

While several studies have examined CdA in road cycling,[8-12] very few have focused on sprinting.[1,6] 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[1,4]); 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 (ρ = 1.175), an 23-26% improvement in CdA would result in an increase of cycling velocity of approximately 3.9-4.9 km·h^{-1}.[17] 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 frontal area (A_p, in m^2) and the drag coefficient (Cd, dimensionless). From data published on aerodynamics in cycling other than sprinting, it is known that lowering the torso[8-11] and head[9,12] significantly reduced CdA[8-10,12] or A_p.[11] 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.[21]

In the present study, no significant difference in CdA between the seated and standing position was found. The slightly lower but non-significant group mean difference in CdA between the seated and standing position in this study (~2.5%), is lower than the differences found in other studies: 25%[1] and 24%.[6] Explanations for such discrepancies between studies could be due to differences in the characteristics of the cyclists. In the current 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 the current study were all amateur male road cyclists. In the study of Martin and colleagues[6] three world-class track sprint cyclists were tested (1 male sprint specialist: 1.83 m, 96 kg; 1 male kilometer time trial specialist: 1.82 m, 87 kg; and 1 female 500 m specialist: 1.65 m, 68 kg). Differences between studies might also have arisen from the test location and environmental conditions (outdoor vs. indoors[6]), and sample sizes in the current study (11 vs. 1[1] and 3,[6] respectively). However, in this study all trials for all three positions were performed in a randomized and counter-balanced 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. While 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.[22,23] 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 compared to a seated sprint. To date, it is unknown if cyclists can produce a similar or different power output in the forward standing position compared to other more traditional positions and may be the subject of future studies. Indeed, while 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.[24] 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·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 coefficient of variation (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).[15] These small measurement errors might have resulted in the variability found in this study. Further, 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 utilizing this model to calculate CdA have used the mathematic model and field test in velodromes.[6] Regardless, no differences in environmental conditions between the two days were observed in this study. Furthermore, the mathematical model and field test have previously been validated.[6] 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. While both cycling velocity variability and the analysis of the screenshots from the videos did not show a difference between the two 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. In order 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 one week of training and one familiarization session. In the current study two participants were not able to maintain the requested positions and were excluded from this study after the familiarization session. It is plausible that this familiarization was not sufficient,[25-27] 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 which might have led to these exclusions are anthropometric characteristics, poor balance and coordination, or poor cycling handling skills. However, 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 and may benefit from the forward standing position. Further research is needed to identify the effect of additional familiarization or training sessions, differences in anthropometric characteristics, balance and coordination, and cycling handling skills on the reliability of this field test to identify CdA in different positions.

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 3.9-4.9km·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).

Conclusion

A novel forward standing cycling sprint position resulted in a 23 and 26% reduction in CdA compared with a seated and standing position. This decrease in CdA could result in an increase of approximately 3.9-4.9 km·h^{-1} in cycling sprint velocity. However, these results should be interpreted with caution since 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 one week of training and a single familiarization session is required to ensure reliability of CdA in these sprint positions.

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Figure and tables

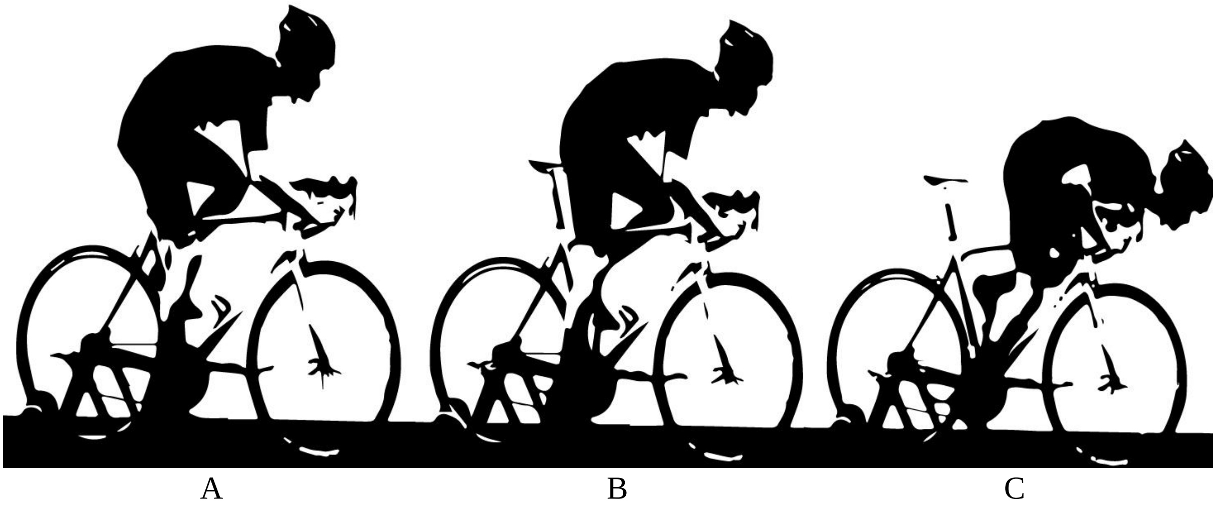

Figure 1 The three sprinting positions: A) seated, B) standing, and C) forward standing.

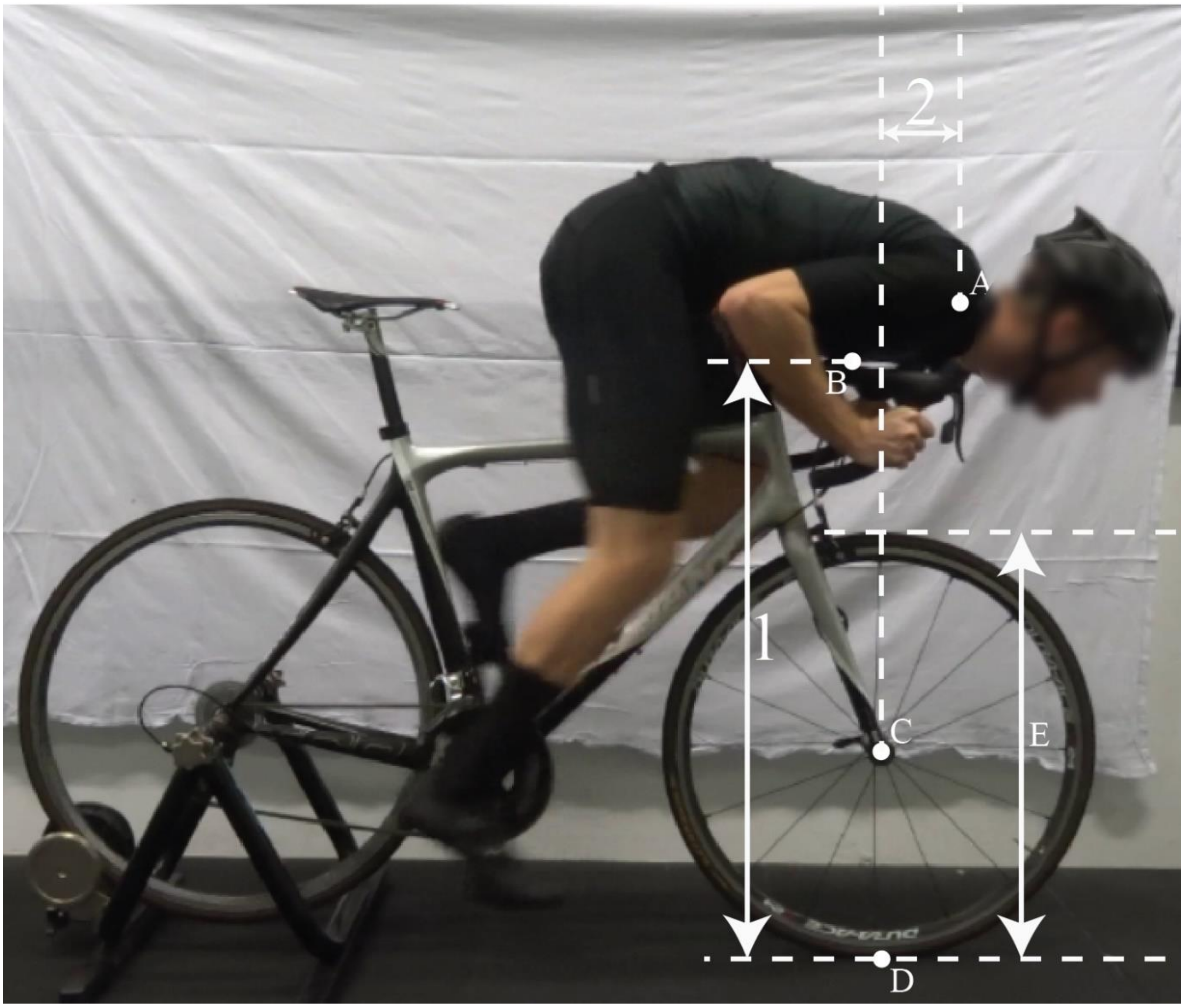

Figure 2 Video analysis overview. 1 – Vertical, 2 – Horizontal, A – Shoulder point, B – Chest point, C – Front wheel hub, D – Bottom of the front wheel, E – Calibration distance (i.e. 200 pt).

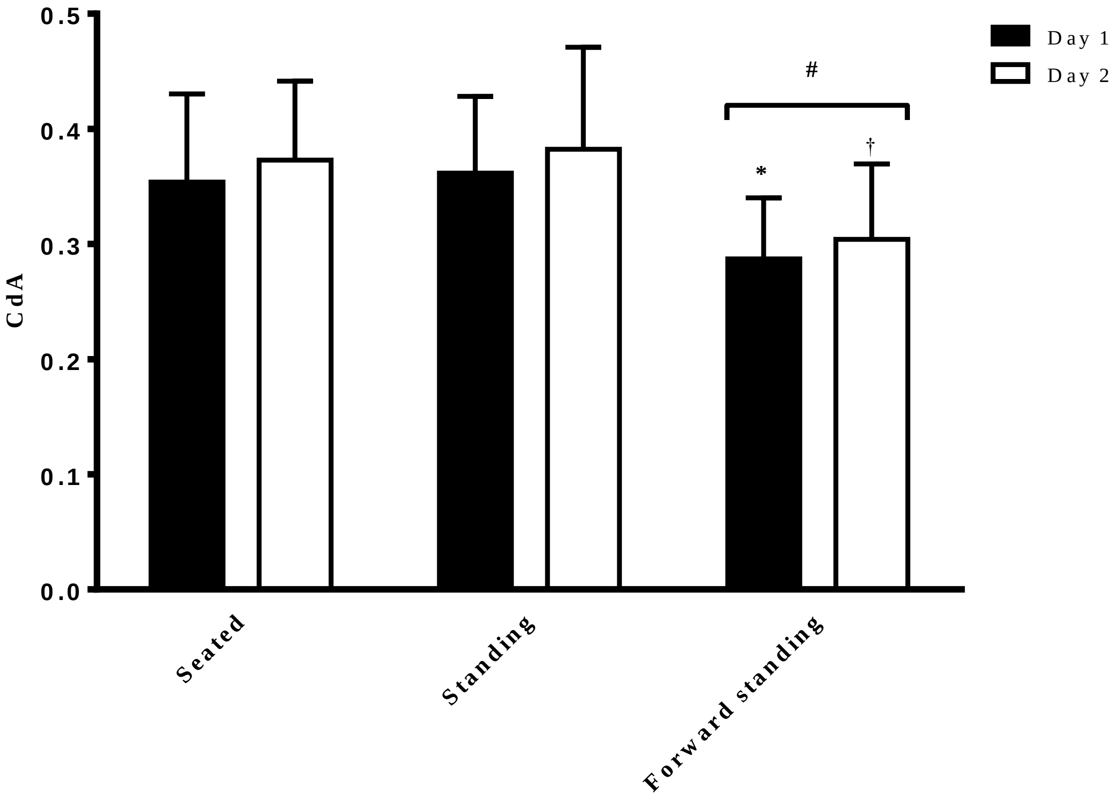

Figure 3 CdA per sprinting position for day 1 and 2.
* = $P \leq 0.05$; Forward standing day 1 vs. Standing day 1.
† = $P < 0.05$; Forward standing day 2 vs. Seated day 1.
# = $P < 0.05$; Forward standing vs. Seated and Standing (main effect).

Table 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	Day 1	0.21 ± 0.51	-1.79 ± 0.44	-0.01 ± 0.65
($\mathrm{m \cdot s^{-1}}$)	Day 2	-0.23 ± 0.50	-0.14 ± 0.50	-0.07 ± 0.56
V_g variability	Day 1	0.47 ± 0.06	0.60 ± 0.08	0.69 ± 0.17
($\mathrm{km \cdot h^{-1}}$)	Day 2	0.46 ± 0.10	0.65 ± 0.14	0.71 ± 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.