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Power output, cadence, and torque are similar between the forward standing and traditional sprint cycling positions

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Original Investigation

Title:

Power output, cadence, and torque are similar between the forward standing and traditional sprint cycling positions.

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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

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 cycle sprinting.[1-7] 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·kg^{-1};[4] 989-1443 W[1,4] and female: 10.8-16.2 W·kg^{-1};[8] 716-1088 W[8]) over durations of approximately 9 to 17 s in males[1,4] and 10 to 30 s in females.[8] However, studies have also shown that peak power output is not the only important factor to success.[2] 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, aerodynamic drag (CdA), road characteristics, and environmental variables.[9] 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.[6,7]

In recent studies 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.[6,7] Adopting the forward standing position might result in an increase of up to approximately 1.4 m·s^{-1} (5 km·h^{-1}) when cyclists are able to produce the same power output in each mentioned position.[6] While the forward standing position was more aerodynamic[6,7] 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.[10] Compared with a seated position, in the standing position the center of gravity is shifted further forward[11] which increased the degrees of freedom due to an increase in hip angle.[12] This altered muscle recruitment patterns, and it increased muscle activation in both upper and lower body muscles.[12-15] 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[15-17] and sprinting.[18,19] 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).[19] Likewise, Reiser and colleagues[18] 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·kg^{-1} vs. 17.9 and 10.4 W·kg^{-1}, respectively). By adopting the forward standing position, the center 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 hypothesized 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.[20] During road cycling races and training, crank arm length can be considered as a constant and it has therefore no effect on sprint performance.[21-26] Two studies have shown a higher peak and mean cadence in the standing position when compared with the seated position during 8[18] (i.e. 4.7 and 5.0%, respectively) and 30 s[19] 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.[11,15] Both Chen and colleagues[15] and Caldwell and colleagues[11] 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[11] 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.

Methods

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; maximal oxygen uptake ($\dot{V}O_2$max), 54.5 ± 5.2 mL·kg^{-1}·min^{-1}; power output at $\dot{V}O_2$max (PPO), 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.[27] Prior to data collection, the subjects provided written informed consent in accordance with the Edith Cowan University Human Research Ethics Committee. All participants were asked to avoid strenuous exercise and refrained from the consumption of caffeine 24 hours prior to testing.

Study design

The participants visited the laboratory on four separate occasions. During the first visit they completed an incremental cycling test followed by a familiarization session. The participants were instructed to practice the three different sprint positions (Figure 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[3]. The three experimental trials were conducted in a randomized 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).[28] The metabolic cart was calibrated as per manufacture's guidelines before each test. Maximal oxygen consumption ($\dot{V}O_2max$) was defined as the highest $\dot{V}O_2$ value recorded over a 30 s average. Maximal heart rate (HRmax) was determined as the highest heart rate during the test. Power output at $\dot{V}O_2max$ (PPO) was calculated using equation 1:[29]

$$PPO = PO_{final} + \frac{t}{T*PO} \quad \text{(Equation 1)}$$

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 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). PPO was used to quantify intensity of the familiarization and experimental sessions (described below).

Familiarization session

Fifteen minutes after completing the incremental cycling test, participants were familiarized with the incremental high-intensity protocol, as described by Menaspà and colleagues[3] (outlined below).

Experimental sessions

During each of the three experimental sessions, participants completed a 10 min warm-up at 50% of PPO, followed by 3 min of rest (30% of PPO). Participants then performed a maximal 14 s sprint (PRE) in one of three sprint positions (i.e. seated, standing, and forward standing; Figure 1). The 14 s sprint was used to replicate the sprint duration observed in professional male road cycling sprints.[1,5] 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 familiarization: 0 until 5th min: 50% of PPO; 6th until 9th min: 65% of PPO; 10th min: 80% of PPO; and during experimental sessions: 0 until 5th min: 55% of PPO; 6th until 9th min: 70% of PPO; 10th min: 90% of PPO) to simulate the demands observed in the final 10 min of road races ending in a sprint.[5]

All experimental sessions were performed on an SRM ergometer with the seat height and saddle 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).[30] Crank arm length was the same for each experimental session (i.e. 172.5 mm), since crank arm length can affect power output.[21-26]

Throughout the sprints an SRM power meter software (Schoberer Rad Messtechnik, Jülich, Germany) measured torque at 200 Hz and calculated cadence once per pedal revolution. This data was than converted to power output by a PowerControl IV head unit software (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.[30] 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 2):

$$Torque = \frac{f - \text{Z}ero\ offset}{Slope} \qquad \text{(Equation 2)}$$

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 synchronize 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 2). 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 50 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 center. 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 3). 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 (CR100) by answering the question: '*How much did you give?*'[31] Directly after each session, participants were asked to rate the intensity of the sessions using the 6-20 rate of perceived exertion scale (RPE).[32] The participants were familiarized with these scales during the familiarization session.

Statistical analysis

Based on previous reported power output data[19] 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 analyzed using multiple two-way analysis of variances (ANOVA) to identify differences between the standing and forward standing position at the $START_{Video}$ and END_{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 $START_{Torque}$ and END_{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. Partial eta squared effect sizes (partial η^2) 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.[33] All statistical analyzes were completed using SPSS (IMB SPSS Inc. Statistics, Chicago, USA).

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 $\text{START}_{\text{Video}}$ and $\text{END}_{\text{Video}}$ 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 $\text{START}_{\text{Video}}$ vs. $\text{END}_{\text{Video}}$ ($p = 0.025$). Pairwise comparisons showed that the torso was further up at $\text{START}_{\text{Video}}$ when compared with $\text{END}_{\text{Video}}$ during a standing sprint. No other differences in both vertical and horizontal direction were found between $\text{START}_{\text{Video}}$ and $\text{END}_{\text{Video}}$, and PRE and POST.

Significant main effects were observed in peak ($F(2,20) = 11.338$; $p = 0.001$; Partial $\eta^2 = 0.53$) and mean power output ($F(2,20) = 6.007$; $p = 0.009$; Partial $\eta^2 = 0.375$) between sprint position (Figure 4). 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 ($F(2,20) = 2.287$; $p = 0.127$; Partial $\eta^2 = 0.186$, $F(2,20) = 0.525$; $p = 0.600$; Partial $\eta^2 = 0.050$, and $F(2,20) = 0.317$; $p = 0.732$; Partial $\eta^2 = 0.031$, respectively). Higher peak and mean power output, and higher peak and mean cadences were observed during PRE when compared with POST ($F(1,10) = 71.227$; $p < 0.001$; Partial $\eta^2 = 0.877$, $F(1,10) = 25.250$; $p = 0.001$; Partial $\eta^2 = 0.716$, $F(1,10) = 104.982$; $p < 0.001$; Partial $\eta^2 = 0.913$, and $F(1,10) = 33.936$; $p < 0.001$; Partial $\eta^2 = 0.772$, respectively).

At $\text{START}_{\text{Torque}}$ 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 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 $\text{END}_{\text{Torque}}$ 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 $\text{START}_{\text{Torque}}$ and $\text{END}_{\text{Torque}}$ ($p \leq 0.05$). 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 $\text{START}_{\text{Torque}}$ and $\text{END}_{\text{Torque}}$ ($p \leq 0.05$). 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 $START_{Torque}$ and 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 $START_{Torque}$ and END_{Torque} ($p \leq 0.05$).

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

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). 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 ($\rho = 1.175$);[6] a CdA of 0.363, 0.372, and 0.295[6] 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.[34] This could be a decisive improvement in velocity given that road cycling races can be decided by very small margins.

It was hypothesized 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[18,19] 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[35]) 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 analyzed 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 familiarization session. Yet it is still plausible that this familiarization was not sufficient to learn how to sprint and produce maximal power output in this position,[36-38] 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 center of gravity and new motor skill and may be an avenue of future research. Changing bicycle setup to optimize 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.[18,19] Bertucci and colleagues[19] 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[18] 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.[12-15] For example, Li and colleagues[12] showed an increase in electromyography (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[13] 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 analyze 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.[15] 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[12-15] or the further forward center of gravity providing leverage over the crank arm in the standing position.[39] 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). 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.[12,13] 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[18] (i.e. 4.7 and 5.0%, respectively) and Bertucci and colleagues[19] (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 optimize 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[3] 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[27] while Menaspà and colleagues[3] tested professional cyclists in level 5. In the study of Etxebarria and colleagues[40], 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.[40] What the effect on sprint performance is of the full length of a cycling race (up to ~7 hours) is unclear.

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.

Perspective

Sprinting in the forward standing sprint position has previously shown its aerodynamic benefits when compared with more regular seated and standing sprint positions.[6,7] 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.

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Figures and tables

Table 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*†¥	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*†$	48.4 ± 12.1†$	54.8 ± 13.8*	0.850	33.6 ± 6.7*†$	46.0 ± 6.7$	46.7 ± 9.9¥	0.650
T at 45° (Nm)	51.9 ± 14.5*†$	37.2 ± 10.1†$	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*†$	120.6 ± 15.5	120.2 ± 18.5	0.761	63.0 ± 8.8†¥	74.6 ± 14.2¥$	73.7 ± 11.9¥$	0.415
T at 180° (Nm)	31.6 ± 8.1*†$	49.9 ± 13.7†$	56.5 ± 15.9*	0.876	32.0 ± 6.2*†$	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.

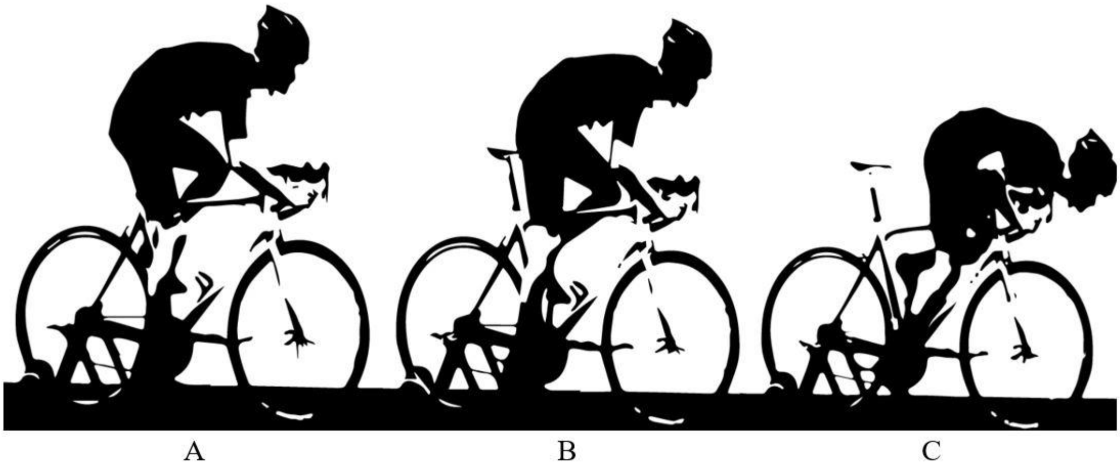

Figure 1 The three sprinting positions: A) seated, B) standing, and C) forward standing (reproduced from Merkes et al.,[6] with permission).

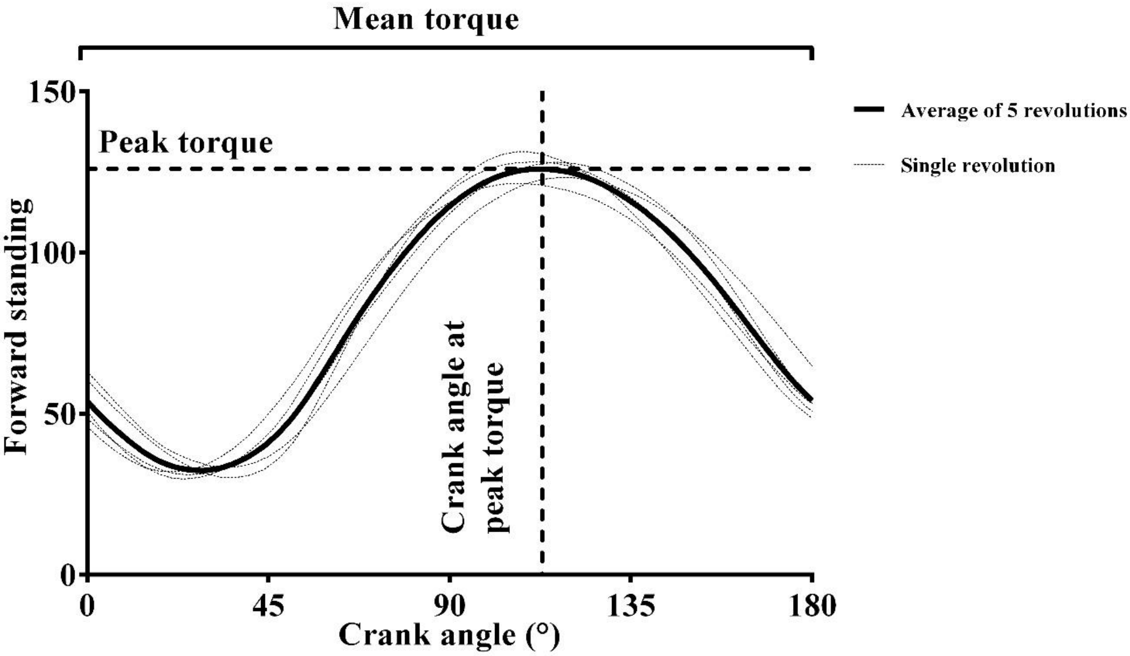

Figure 2 Peak and mean torque, and crank angle at peak torque calculations.

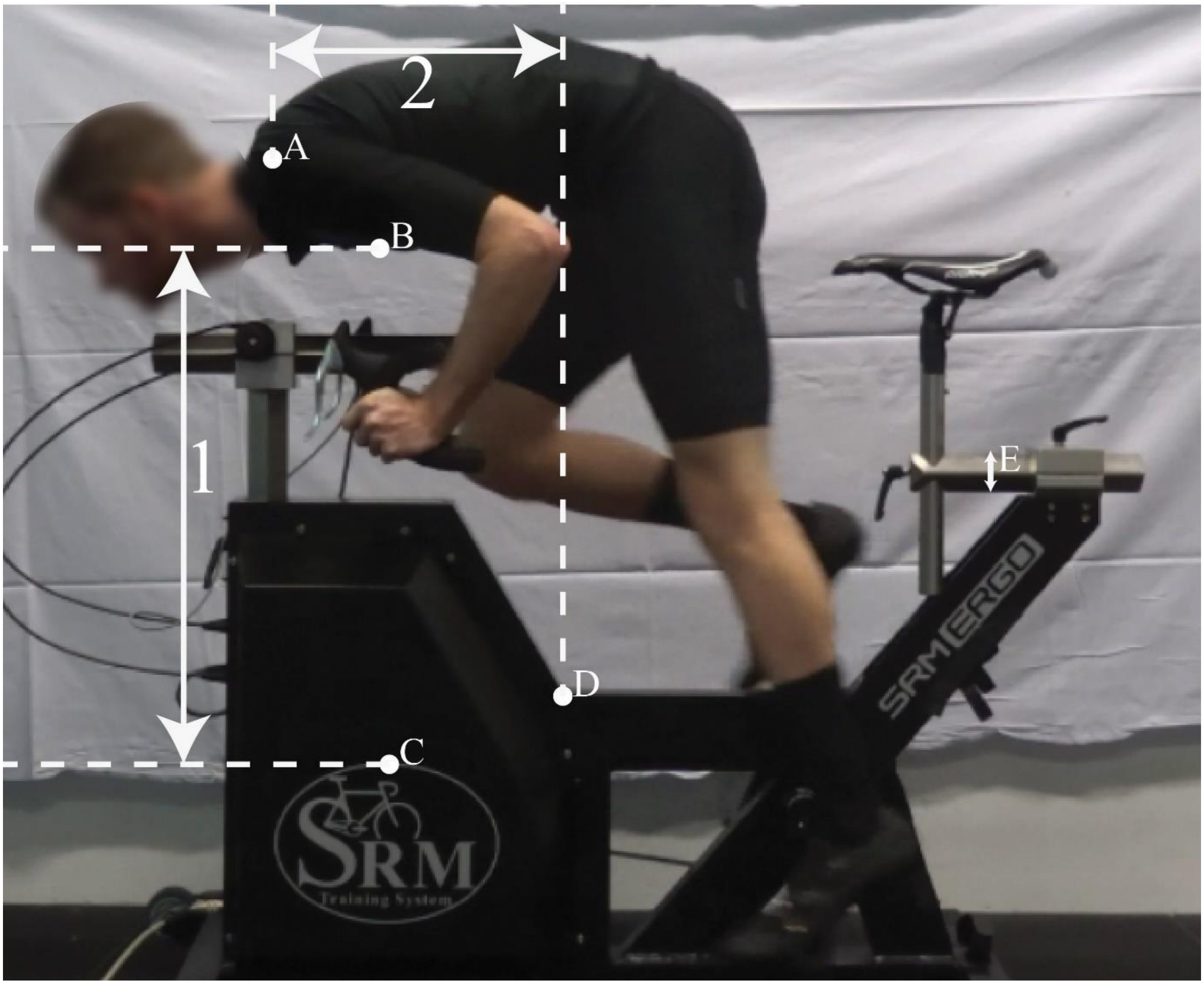

Figure 3 Video analysis overview.
1) Vertical, 2) Horizontal, A) Shoulder, B) Chest, C) Top of SRM logo, D) Corner in the ergometer’s frame, E) Calibration distance (i.e. 20 pt).

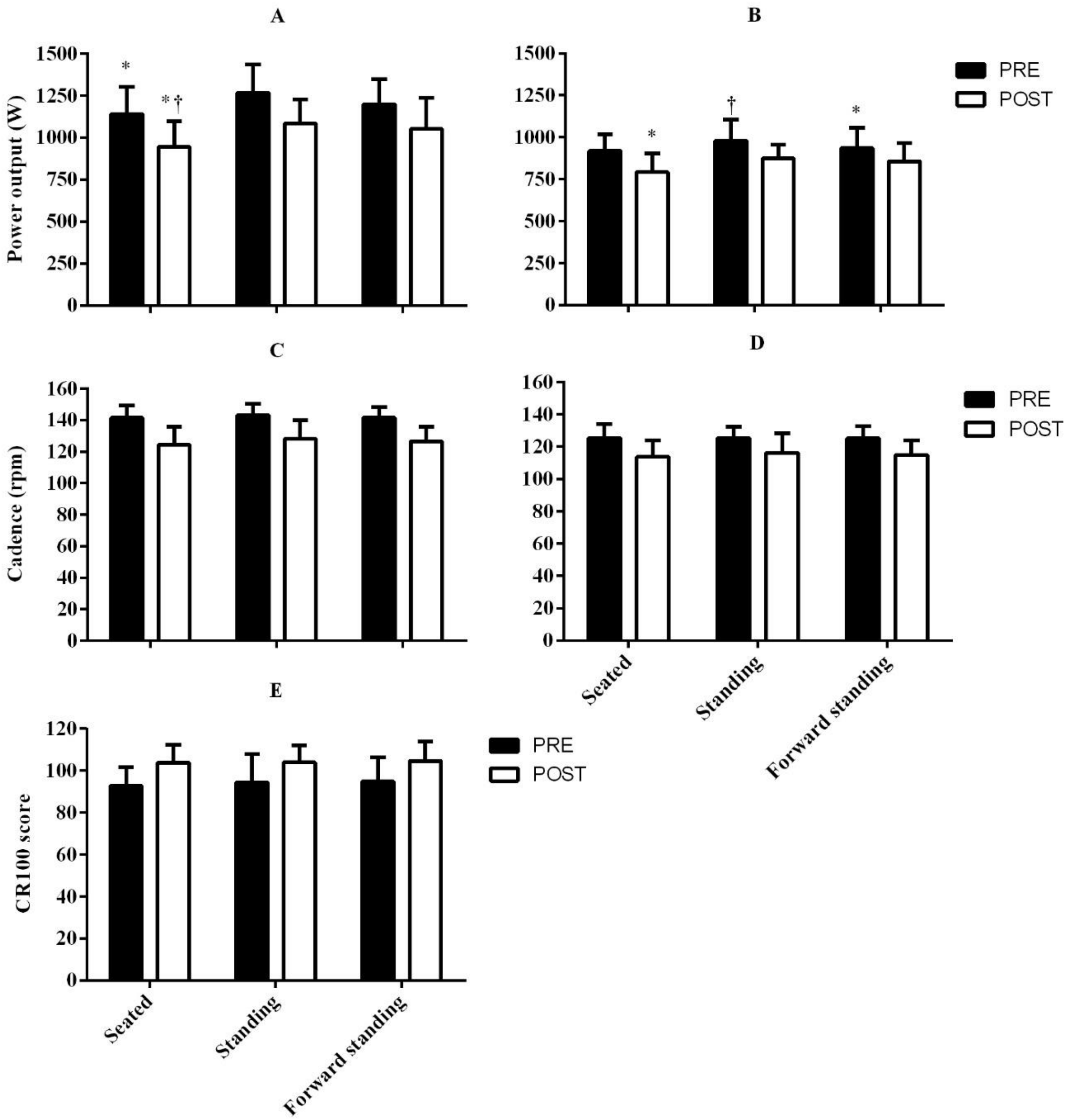

Figure 2 Power output, cadence, and rating of effort differences between sprint positions before and after 10 min lead-up. A) Peak power output (W), B) Mean power output (W), C) Peak cadence (rpm), D) Mean cadence (rpm), E) Rating of effort.
* = $p \leq 0.05$ vs. Standing; † = $p \leq 0.05$ vs. Forward standing.

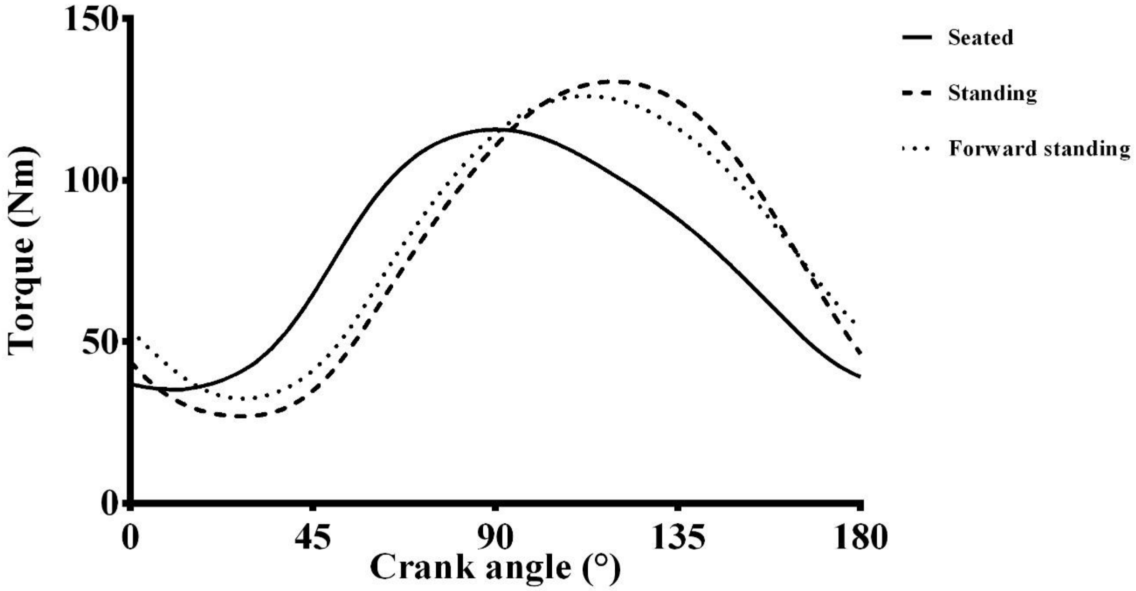

Figure 3 Example of torque distribution for each sprint position.