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Original article (short paper)

Electromyographic analysis of riding posture during the bicycling start moment

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Abstract — Professional cyclists often adopt a competition-start standing posture, which has been shown to improve performance. The biomechanical basis of this is unclear, and might be due to a greater mechanical advantage or increased key muscle activity. Previous observations in steady state cycling showed greater activation of the *tibialis anterior, erector spinae*, and *biceps brachii* when adopting a standing vs. seated-riding posture. Little is known regarding the effect of riding posture on activation during a standing start. Eleven cyclists performed standing starts in seated and standing-postures using stationary-cycle and on the track. Electromyography of the *gastrocnemius medialis*, tibialis anterior, *erector spinae*, and *biceps brachii* was recorded during first and subsequent pedal strokes. Results showed that the *gastrocnemius medialis* did not modify activity. The tibialis anterior, erector spinae, and *biceps brachii* activity was increased during the standing posture compared to seated, only during the first pedal stroke. These increased activation intensities were accompanied by a corresponding 10% increase in bike speed during the first 5 meters following a standing start in the standing posture compared to the seated one. Adopting a standing posture during a standing start improves performance through greater initial acceleration.

Keywords: sEMG, cycling, performance

Introduction

Many factors are known to affect cycling performance: (i) the geometry of the bike, such as crank length[1] and saddle position[2,3]; (ii) various aerodynamic variables such as proper aero position and (iii) pedaling frequency, which determines maximal power output during cycling[3,4]. Alterations in posture, such as changing from a seated to a standing posture, also result in changes in performance[5,6]. When cycling with a standing posture, a greater production of power output is developed for the same speed, presumably to manage the increased number of degrees of freedom of the lower limbs due to the loss of contact of the buttocks with the saddle[7]. Yet, cycling with a standing posture allows a significant but temporary mechanical power "over-boost", which riders can exploit for special situations (e.g., start, attack and sprint at the finish). Such a posture change has therefore a great influence on pedal kinetics[3].

Cyclists predominantly adopt a prolonged standing posture during an all-out standing start (from zero speed as opposed to a flying start) to increase power output compared to a seated posture[3,8,9]. However, the use of a standing posture requires the maintenance of a larger metabolic power and to counterbalance the higher aerodynamic drag due to an increased drag area associated with the overall postural change[9,10]. Therefore, a standing posture seems to be advantageous and metabolically sustainable only for short duration, high-acceleration, and high-torque periods, such as an all-out standing start. For these periods, skilled cyclists prefer to adopt a standing posture.

The specific motor control of the lower extremities during standing *vs.* seated cycling postures has been previously described using surface electromyography (sEMG)[11-14]. The findings of these investigations have suggested that a standing posture is associated with greater force applied to the pedals and that this increased for application is likely due to the pedals supporting the mass of the cyclist. Conversely, in a seated posture, the cyclist's mass is mostly supported by the saddle[15]. The findings of this study are supported by individual power profiles and demonstrate that instantaneous power is strongly correlated to pedal normal force[16]. However, the same study has also shown that the overall maximum power is highly correlated to the cyclist's muscle mass. Although previous research has demonstrated that a standing posture is associated with greater pedal force and overall powers applied to the pedals, few differences have been observed in lower extremity joint kinetics between standing and seated cycling postures[3]. It has been suggested that when cycling with a standing posture, forces produced by the upper extremity enhance overall power production[17]. Limited research has investigated the contributions of the upper extremity musculature to cycling performance, and changes in muscle activation of the upper extremity have not been previously investigated in standing *vs.* seated cycling postures.

An understanding of the changing contributions of upper and lower extremity musculature to the observed differences in standing start performance using a standing compared to seated cycling posture, would enhance individually optimized training programs. In addition to improving performance, individualized training programs may also reduce the incidence and prevalence of training-related injuries in cyclists. Therefore, the purpose of this study was to quantify changes in muscle activation of ankle, trunk, and elbow musculature in standing compared to seated cycling postures during a maximal standing start. It was hypothesized that the standing posture would be associated with significantly greater muscle activation intensities compared to seated postures.

Methods

Participants

Eleven male amateur cyclists participated in this study (age: 31 ± 3 years [range 27 ÷ 36], mass: 69.0 ± 4.1 kg, height: 1.76 ± 0.04 meters, BMI: 22.1 ± 1.5 kg/m^2; data reported as mean ± SD; with no history of major lower extremities injuries). All participants were highly skilled cyclists with more than six years of sport-specific training, had a cycling-specific training volume of more than 400 km *per* week and were ranked regionally or nationally within their category. This study was conducted in accordance with the Declaration of Helsinki. The experimental protocol was approved by the University e-Campus research ethics board, and each participant gave signed informed consent prior to participation in this study.

Laboratory measures and procedures

The participants were asked to pedal on a commercial and commonly available cycle ergometer (Schwinn, Johnny G Pro Spin Bike; crank length: 17 cm; resistance mob: halfway), wearing their competition cycling shoes and pedals with toe clips. Seat height was adjusted for each participant according to his preferred seated cycling posture on a road bike, such that his knee was nearly fully extended and the sole of the foot was perpendicular to the shank when the crank was at the bottom-dead-center. Crank position was considered to be at 0° when the crank was aligned with the positive Y-axis and the clockwise (anterior) rotation (facing rider's right side) was considered positive (Figure 1B). The handlebars were positioned according to each individual participant's preferred seated cycling posture on a road bike.

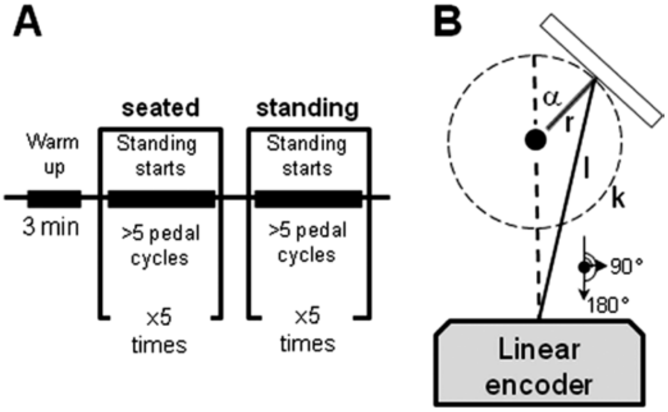

Figure 1. (A) Schematic description of the experimental procedure. (B) Schematic description of the measurement of the crank angle using a linear encoder attached to the pedal (see text for details). k = distance of the linear encoder from crank center; l = distance pedal-linear encoder (measured by the linear encoder); α = crank angle; r = crank length.

Participants completed the whole experimental procedure during one single visit. Experimental procedure laboratory temperature was comfortable (i.e., ~ 20°C) and participants were allowed to drink water *ad libitum* to keep their hydration *status* adequate. Participants were first required to perform a 3-min warm up consisting of low-resistance pedaling (Figure 1A). All participants started pedaling with their right (dominant) limb. The dominant limb was defined as the limb the athlete would use to kick a ball, and was the only limb evaluated for each participant. Participants performed five maximal effort trials with hands positioned on the bottom of the handlebar and a 70° starting crank angle for a minimum of five consecutive pedaling cycles (maximum of ten consecutive pedaling cycles; average trial duration 5 s[18]. Between trials, participants were asked to stop completely and rest for 4 min (Figure 1A). A minimum of 25 pedaling strokes was collected from each participant. Participants completed this protocol for each experimental condition (seated and standing cycling postures). The sequence of riding posture conditions (seated *vs.* standing) was randomized across participants. To standardize the exercise in the seated compared to standing posture, participants were required to accelerate as quickly as possible from a standing start (zero speed) and then to pedal at same (seated) warm up cadence.

The crankshaft pedal was connected to a customized linear encoder (sEMG system with encoder included, MuscleLab™ 4020e, Bosco System, Ergotest Technology, Langensund, Norway), which recorded the vertical displacement of the pedal to synchronize with sEMG signals (Fig. 1B) as previously described[19-22]. The linear encoder had a spatial resolution of 0.1 mm (range 3.5 m, max speed 24 m/s) and a sampling frequency of 100 Hz. The vertical displacement of the pedal was then converted into the angular position of the pedal according to the following equation (Figure 1B): $\alpha = \cos^{-1} (k^2 + r^2 - l^2) / (2\ k\ r)$

where α = crank angle; k = distance of the linear encoder from crank center; l = distance pedal-linear encoder; r = crank length. The angular resolution was determined to be 0.03°. Surface EMG of the *gastrocnemius medialis* (GAS), *tibialis anterior* (TA), *erector spinae* (at L3 level; ES), and *biceps brachii* (BB) were recorded at 1500 Hz using pre-amplified bipolar silver–silver chloride (Ag/AgCl) sEMG electrodes. Previous studies have shown that the selected muscles play a major contribution to the production of power during sprint cycling exercises[6,11,18]. The disc electrodes had a diameter of 1 cm and inter-electrode distance of 2 cm. The input impedance was 2GΩ, common mode rejection rate 100 dB, band-pass filter 6–1,500 Hz, and gain ×600. The electrodes were positioned longitudinally with respect to the orientation of muscle fibers and located according to the recommendations of SENIAM[23]. To reduce electrical impedance, the participant's skin was shaved and cleansed using an alcohol pad prior to electrode placement. To prevent movement artifacts due to movement of electrode cables, the cables were secured using elastic bands (Vetrap™). The raw EMG signal was band-pass filtered (8–1,200 Hz) and converted to root mean square (RMS) with a 20-ms smoothing window as previously reported in the literature. Maximal voluntary isometric contractions (MVIC) for each muscle of interest were systematically determined by averaging the integrated sEMG (iEMG) signal during a 3-s period of sustained maximal force output after the initial peak in the force curve during a maximal contraction of each muscle as previously described[24,25]. Normalized iEMG values were calculated as the quotients of the recorded iEMG values from dynamic trials divided by the iEMG values recorded during the MVIC trials and were represented as percentages of MVIC[26].

To ensure correct riding posture and to investigate cycling kinematics, sagittal plane kinematic data were recorded (210 Hz, 480×360 resolution, Exilim EX-FH20, Casio, Tokyo, Japan). The high-speed digital camera was placed perpendicular to the sagittal plane of the participant's right side at a distance of 5 meters with the camera height at the vertical height of each participant's estimated center of mass[27,28]. Markers were positioned on main body joints (Figure 2A).

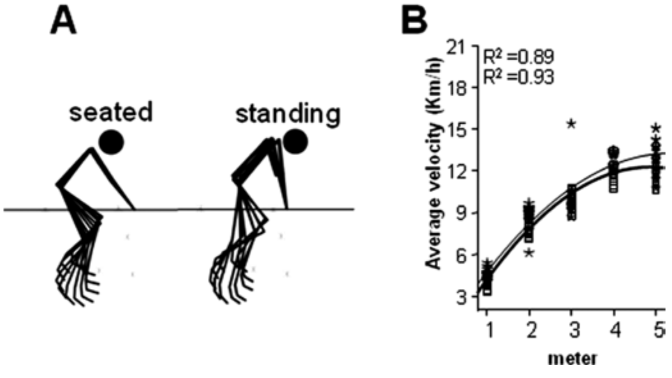

Figure 2. (A) Stick figure of body angles during a standing start in seated and standing positions. (B) Effect of riding position on average speed following a standing start at different distances from the start.

To investigate changes in muscle activation patterns associated with seated compared to standing cycling posture, sEMG, and kinematic data were recorded in a laboratory setting. However, to verify the effect of the two riding postures on instantaneous cycling speed in a real cycling environment, participants were also required to perform a similar experimental protocol on a race bicycle on a sport-specific oval track. This protocol has been used previously to assess cycling performance[19].

Track measures and procedures

To verify the effects of riding posture on instantaneous speed during a standing start, participants repeated the testing protocol using a race bicycle (FP1, Pinarello, Italy; crank length 17 cm). The participant's hand position was similar to the stationary cycling task (bottom of the handle bar) and the gear selected was consistent with the stationary cycling task[19]. The same bicycle was used to test all participants. The participants wore standard cycling shoes and pedals with toe clips. The seat height was adjusted for each participant according to his preferred cycling posture on a road bike, such that his knee was fully extended and the sole of the foot was perpendicular to the shank when the crank was at bottom-dead-center. The handlebars were positioned according to each participant's preferred posture on a road bike. After a 3-min pedaling warm up, participants were asked to pedal as fast as possible starting in each experimental posture (seated and standing) again with a 70° starting crank angle[18]. Participants were given 4 min rest between trials. The first 5 meters of each standing start trial were recorded with a high-speed digital camera (210 Hz, 480×360 resolution, Exilim EX-FH20, Casio, Tokyo, Japan). The camera was placed on a tripod, perpendicular to the sagittal plane of the participant's right side at a distance of 5 meters from the 5-meter run with the camera placed at the vertical height of each participant's estimated center of mass. To calculate the instantaneous speed of the bicycle the center of the anterior wheel was tracked using Dartfish 5.0 Pro (Dartfish, Fribourg, Switzerland).

Statistical analysis

The RMS signal of each muscle for each experimental condition was averaged over 36 × 10° intervals constituting the entire crank cycle. Previous research has suggested that 10° intervals are most efficacious in the analysis of muscle activation patterns during cycling[29]. For each trial, custom software was used to calculate the average sEMG amplitude across each 10° pedal angle interval (MatLab 2013, MathWorks, Inc., Natick, MA, USA). Average data were then analyzed using a univariate analysis of variance (ANOVA) to identify significant differences in sEMG activity due to riding posture (seated *vs.* standing) and crank angle (36 intervals). All data were provided as mean ± standard deviation. The Shapiro-Wilk test was used to ensure normal distribution of the data.

A two-way repeated measures ANOVA was used to assess the influence of riding posture (seated *vs.* standing) and crank angle (36 intervals) on the average instantaneous speed during the first 5 m of the standing start performance with repeated measures for cycling posture and crank angle factors. In the presence of a significant main effect of posture or posture by crank angle interaction, *post-hoc* t-tests were used to determine the source of the significant findings. Statistical analyses were performed using Excel 2003 and SPSS 15 software. The statistical significance level was set at $P < 0.05$.

Results

Quantitative sEMG elicited during the first and subsequent pedal strokes (i.e., as steady state was achieved), in the seated and standing cycling postures are presented in Figure 3. Peak sEMG amplitudes are showed in normalized data, a finding that is consistent with previously published data[11,30,31].

The univariate ANOVA with pedaling intervals (i.e., 10° pedal intervals) and riding posture as factors revealed no significant changes in iEMG among the different conditions. The time of occurrence and the intensity of the peak activity were not significantly different between the two riding postures (Figure 3, $P > 0.05$) in contrast with the finding by Hug, Turpin, Couturier, Dorel[5]. Similar to the first stroke, there were no significant changes in iEMG during the subsequent pedal strokes. The univariate ANOVA with pedaling order (i.e., first pedal stroke *vs.* subsequent pedal strokes) and riding posture as factors revealed significant differences for both pedaling order ($P < 0.05$) and riding posture ($P < 0.01$) as well as a significant pedaling posture interaction ($P < 0.05$). The standing compared to seated cycling posture was associated with significantly greater iEMG amplitude (Figure 3).

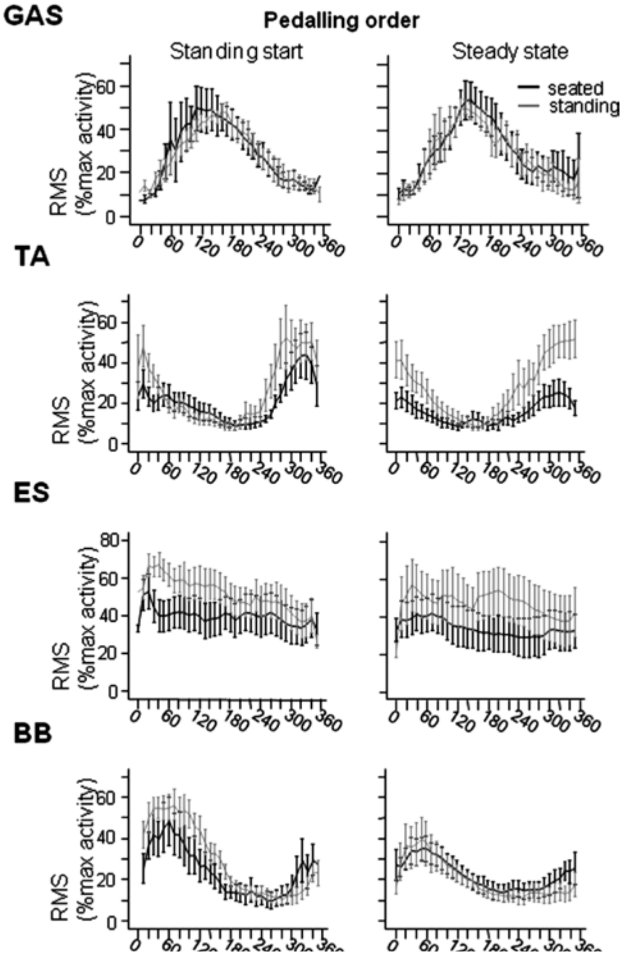

Figure 3. Average sEMG RMSs (% max activity) of the *gastrocnemius medialis* (GAS), *tibialis anterior* (TA), *erector spinae* (ES), and *biceps brachii* (BB) while pedaling the cycle in seated and standing positions are shown for standing start (left panels) and for following cycling ("Steady state", right panels). Values are shown as mean ± SEM.

The analysis of the peak activity of TA muscle revealed no change in peak activity between the two riding postures ($P < 0.05$). Similarly there was no difference between the first pedal stroke compared to subsequent pedal strokes. However, the intensity of the iEMG signal was significantly greater during the first pedal stroke ($P < 0.01$) and during the standing posture compared to the seated one ($P < 0.001$). Unsurprisingly, univariate ANOVA showed significant effect for riding posture on sEMG, but not for pedaling cycle phase, without interaction effect.

Riding posture did not significantly affect BB sEMG. However, univariate ANOVA with riding posture and pedaling order as factors showed that pedaling order (e.g., first *vs.* subsequent pedal strokes) had a significant effect on iEMG data. iEMG was higher during the first pedal stroke. Therefore, as a preliminary key message, we may suggest specific TA strengthening to improve all-out standing start performance.

The basic kinematic analysis of the riding posture during the pedaling cycle phase showed that with standing posture there was little vertical displacement of the hip (Figure 2A). Analysis of the instantaneous speed during on-track standing starts showed that with standing posture the mean acceleration during the first 5 meters was 10% greater than with seated posture (Figure 2B). A *t*-test showed significant differences in the acceleration ($P < 0.05$) between the two postures. The acceleration was 1.32 ± 0.22 and 1.59 ± 0.24 m/s^2 (mean ± SD) for the seated and standing posture, respectively.

Discussion

The purpose of this study was to investigate the effects of seated *vs.* standing posture on muscle activation intensity in muscles of the lower extremities, trunk, and upper extremities in two cycling conditions including a standing start (zero speed) and steady state cycling. The major findings of this study demonstrate that during a standing start (zero speed), muscle activation intensities of the TA and ES are significantly greater in the standing *vs.* seated posture. Additionally, during steady state cycling, greater muscle activation intensities were observed in the TA and BB in the standing compared to seated cycling posture. These data demonstrate that cycling posture significantly alters muscle activation of the lower extremities, trunk, and upper extremities.

In competitive cycling and cycling-inclusive sports such as triathlon, it is not uncommon for races to be decided by small differences in time. Therefore, optimizing performance during training and competition are of the utmost importance to maximize athlete performance. To our knowledge, this is the first study to provide data pertaining to changes in muscle activation intensity associated with a standing compared to seated posture during a standing start and steady state cycling.

The standing start (zero speed) is commonly used in time trials and cycling-inclusive sports to begin the cycling portion of the competition. Successful sprint cyclists produce greater accelerations from a standing start resulting in greater speeds earlier in the race. This is achieved by generating greater crank torques and powers. The results of the current study indicate that the standing start was associated with significantly greater TA and BB muscle activation intensity compared to steady state cycling. It is theorized that these alterations in muscle activation would result in greater lower extremity power output to be transferred to the crank during the standing start[3,8,9]. Specifically, the increased amplitude of the BB activation would produce greater elbow flexion torques to the cycle handles and aid in reducing unwanted vertical displacement of the center of mass, allowing greater downward force to be applied to the pedals in the standing start condition [11-14]. This increased transfer of lower extremity power would generate greater accelerations for the standing start. Therefore, increased BB activation intensity may result in improved efficiency of lower extremity kinetics by maintaining a stable platform from which the lower extremity can apply torques to the cycle. Similarly, greater TA activation may be present to functionally stiffen the ankle joint through antagonist co-activation in response to greater loading from the lower extremity[32]. By increasing ankle joint stiffness, the joint torques and powers produced by large anti-gravity muscles of the lower extremities are more optimally applied to the cycle pedals. Although TA-GAS co-activation was not empirically calculated in the current study, no differences were observed in GAS activation while TA activation was significantly increased. Further, previous research has supported our hypothesis by suggesting that TA function in cycling is associated with enhanced power transmission to the crank[22,33]. These findings would strongly suggest that an increase in TA co-activation is associated with improved cycling performance. While the postulated mechanics offer plausible explanations for the observed changes in muscle activation of the lower extremities, no quantitative data was included in the present study to support these proposed mechanisms of function including handle forces or joint stiffness data.

Conversely, previous data has been published pertaining to differences in lower extremities muscle activation during steady state cycling in a standing compared to seated posture. Specifically, previous research data has shown that cycling in a standing posture is associated with significantly greater muscle activation intensities of the *vastus lateralis* and *gluteus maximum* compared to a seated posture[11-14]. The observed increases in hip and knee extensor muscle activation may serve to increase hip and knee joint torques and powers to improve cycling performance when cycling with a standing compared to seated postures. Conversely, greater hip and knee extensor muscle activation may be due to the requisite need to increase hip and knee extensor forces to support the greater load associated with a standing posture.

During steady state cycling, no significant differences in GAS and BB muscle activation intensities were observed in the standing compared to seated cycling posture. These findings contrast with previously published data[11,12]. Specifically, it has been shown that cycling with a standing posture is associated with significantly greater lower extremity muscle activation intensities compared to a seated posture[11,12]. Further, it was also noted that uniarticular muscles exhibited larger increases in muscle activation intensity compared to biarticular muscles[12]. It is possible that the methodological differences between each of these studies underlie these conflicting findings.

While the current study presents unique findings pertaining to differences in the intensity of muscle activation when cycling with a standing compared to seated posture, the authors acknowledge several limitations of the current study. First, the sample size was relatively small. Although several statistically significant differences were observed, it is possible that the study was underpowered to detect all significant differences. Second, the low number of muscles recorded during testing. Previous studies investigating cycling performance with changing postures have collected data from a greater number of muscles[11,12]. It is possible that by collecting from a greater number of muscles, this study could have captured other differences in neuromuscular strategy that exist in a standing compared to seated cycling posture. Third, there was a lack of joint and crank kinetic data (i.e., crank torque and power output). The presence of kinetic data would provide greater insight into the biomechanical efficacy of the observed neuromuscular changes associated with a standing *vs.* seated posture. Fourth, lateral sway of the cycles used in field testing were not recorded. It is possible that energy was expended in the frontal plane, which was not accounted for in our analysis of cycling performance.

Conclusions

The findings of this study demonstrate that the enhanced performance during a standing start (zero speed) when adopting a standing cycling posture, is associated with increased muscle activation of the *biceps brachii* and *tibialis anterior* muscles. Although these muscle activations do not drive the pedal stroke, they may indirectly benefit cycling performance by providing a more stable platform and more efficient lever to improve power transfer to the crank. A straight practical indication provided by this study is that the standing posture allows a bike standing start speed 10% increase with respect to the seated posture. Therefore, this finding may potentially be useful for specific training protocols for cyclists to improve the technique for a standing start. Further research is required to more fully understand the biomechanical effects of altering cycling posture during both steady state cycling and a standing start.

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