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Physiological and Biomechanical Differences Between Seated and Standing Uphill Cycling

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ABSTRACT

International Journal of Exercise Science 13(2): 996-1011, 2020. Despite differences in economy, cyclists climb in seated and standing positions. Prompted by gaps in research, we compared VO_2 and heart rate (HR) (Study 1), muscle activation (Study 2) and breathing and pedaling entrainment (Study 3). METHODS: Subjects rode their bicycles on a treadmill in seated and standing positions. In Study 1, VO_2 and HR of four male cyclists (21.3 ± 1.7 yrs; 69.1 ± 6 ml/kg/min) were collected, alternating positions every 5 minutes for 20 minutes (8 mph, 8% grade). In Study 2, muscle activations of eight male cyclists (24 ± 5 yrs, 67.6 ± 5.5 ml/kg/min) were collected on Rectus Femoris (RF), Biceps Femoris, Vastus Medialis (VM) and Gastrocnemius alternating positions every minute (8 mph, 8% grade). In Study 3, flow rate and entrainment of nine male cyclists (28 ± 7 yrs, 62.7 ± 7.7 ml/kg/min) were collected in 2-minute stages at 6, 8 and 10 mph, (8% grade) alternating positions every minute. RESULTS: VO_2 and HR increased standing (3.17± 0.43 L/min, 175 ± 4 bpm) compared to seated (3.06 ± 0.37 L/min, 166 ± 5 bpm) ($p < 0.05$). Normalized EMG for RF and VM increased standing (47 ± 5%, 57 ± 15%) compared to seated (34 ± 3%, 36 ± 8%) ($p < 0.05$). Peak Inspiratory and Expiratory Flow increased standing (3.44±0.07 and 2.45±0.05 L/sec) compared to seated (3.09 ±0.06 and 2.21±0.04 L/sec) ($p < 0.05$). CONCLUSION: Uphill cycling while standing results in decreased cycling economy due to physiological and biomechanical variations compared to riding seated.

KEY WORDS: Cycling economy, muscle activation, breathing, pedaling entrainment

INTRODUCTION

Cycling is a sport which involves dynamic movements across several riding positions in a variety of disciplines. Technological advances over the last 30 years have given rise to several new bicycle designs including the mountain bike and the aerodynamic time trial bike (18). Although there are general guidelines for bicycle fitting to optimize cycling performance, a wide variation in positioning can still be seen amongst cyclists (6, 20, 21). One aspect of cycling that all disciplines seem to have in common, however, is the ability for cyclists to alternate between several positions while riding their bicycle. A cyclist's reasoning to alternate between riding positions is highly complex, oftentimes involving their personal riding preference in which biomechanical and physiological processes are not easily measured. What is clear, however, is that while cycling in multiple positions, different muscles are recruited to propel the bicycle forward (8), and there are physiological differences between riding positions as well.

The concept of cycling economy (CE) has been the subject of multiple research studies over the past several decades. CE is a defined as oxygen consumption (VO_2) at a given sub-maximal exercise intensity (3). Several studies have addressed the differences in CE in various cycling positions, most notably during uphill cycling conditions. Ryschon and Stray-Gunderson (24) demonstrated that a seated cycling position required less energy expenditure at a given speed and grade as opposed to cycling in a standing position. Similarly, it was observed that during uphill cycling cyclists experienced higher VO_2 and heart rate (HR) while riding in a standing position (3, 26). This evidence suggests that a seated position is more economical during a sustained climb.

In an effort to expand on the concept of CE, Arkesteijn, Jobson, Hopker, & Passfield (4) investigated the metabolic differences between seated and standing uphill cycling in conjunction with muscle activation patterns. Cyclists alternated between seated and standing riding positions across grades of 4% and 8%, and at intensities of 50% and 70% of maximal aerobic power. It was observed that at sub-anaerobic threshold intensities, an increase in VO_2 decreased CE while riding in a standing position; however, the differences were negligible at higher intensities. An inverse relationship was found with regard to muscle activation in which activation amplitudes for the lower leg muscles were significantly greater while riding standing as compared to seated at higher intensities.

Several other studies have also suggested that certain muscles are more active while riding in a standing position compared to a seated position (8, 10, 11, 15, 17, 25, 27). What remains unknown is whether the increased muscle activation of the lower body muscles is related to the decrease in CE, and whether muscle activation patterns differ between the two riding positions in conjunction with the 360-degree pedal cycle. Ryan and Gregor (23) evaluated the changes in muscle activation of lower body muscles across crank angles during level-ground cycling on an ergometer. However, little research exists on differences in muscle activation timing during seated and standing uphill cycling. Previous research has focused on peak muscle activation amplitude differences between the two riding positions, yet it has not been determined at what point activation takes place during the revolution of each pedal stroke. More studies are needed to elucidate why it is that cyclists climb in different riding positions, and why a cyclist would choose to ride in a standing position despite the decrease in CE.

It has been previously documented that during sub-anaerobic threshold exercise there is a concurrent increase in minute ventilation and VO_2 (2). In order to form a more complete understanding in regards to CE, it would be beneficial to study the differences in breathing patterns between riding positions and whether ventilation is increased while riding in a standing position. Flow rate (FR) is the volume of fluid that passes through a system per unit time. In regards to breathing, FR is a volume measurement over time for each inhalation and exhalation. Entrainment (ENT) is the relationship between internal and external rhythms (1; 9; 22). In regards to cycling, ENT is the interaction between the way in which a cyclist breathes and the pedaling motion of riding a bicycle. Although there has been limited research on the topic, it has been previously documented that the inhalation phase of breathing starts concurrently to the onset of left or right leg movement (13). It would be beneficial to study the differences in FR in seated and standing cycling positions, specifically, further research is needed to document the various ways in which cyclists breathe in conjunction to the pedal cycle and body position on the bicycle while climbing. ENT of breathing and pedaling differences between seated and standing uphill cycling could help to better understand the relationship between the physiology and biomechanics of uphill cycling. Few studies have looked at ENT of breathing and pedaling in cycling and none have analyzed differences between seated and standing climbing positions.

To this end, here we present results of three studies. First, in two prospective studies, we compared VO_2 and HR during seated and standing uphill cycling at sub-anaerobic threshold intensity (Study 1), and the differences in muscle activation in seated and standing uphill cycling (Study 2). Then, in a randomized design we compared ENT of breathing and pedaling between seated and standing uphill cycling (Study 3). We hypothesized that there would be a decrease in CE, as well as greater muscle activation amplitudes, changes in muscle activation timing, increased FR, and changes in breathing in synchronization with pedal cycle characteristics while climbing in a standing position.

METHODS

All studies were approved by the local university's Institutional Review Board, written informed consent was obtained, and protocols were conducted in accordance with the Declaration of Helsinki. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (19). Upon arrival at the laboratory, height was recorded using a stadiometer to the nearest 1 cm and weight was recorded using a digital weight scale to the nearest 0.1 kg. Following preliminary testing, and prior to data collection, all subjects were given a familiarization period in which they were required to bring their own bicycles and ride on a large treadmill (3x2 meters) (Vacumed, Ventura, CA). Subjects had the ability to self-select the speed and grade in which they rode while freely alternating between seated and standing riding positions.

In each study, an upper body harness secured subjects from overhead in case of inadvertent instability and loss of control. All data were collected at least 24 hours following the familiarization period. Subjects were instructed to limit exercise to light or moderate intensity on the day before the trial. Subjects were given a 10-minute warm up at a self-selected speed and grade prior to data collection. Following warm-up, subjects were instructed to mount their bicycles while holding the rail at the front of the large treadmill and waited for the test administrator to give instructions on how to begin the trial.

Participants: Study 1 – VO_2 and HR

Four male collegiate team cyclists (21.3 ± 1.7 yrs, 68.0 ± 4.6 kg, 69.1 ± 6 ml/kg/min) participated in the study. All subjects self-reported as being healthy and at similar points in their yearly training cycle at the time of data collection. All preliminary tests and exercise trials were conducted at the Monfort Family Human Performance Lab at Colorado Mesa University in Grand Junction, CO.

Protocol

Exercise Trial: Following warm up, subjects donned a chest HR strap which was interfaced with a cycle computer (Edge 800, Garmin Ltd., Olathe, KS) at a 1-sec recording interval. A two-way, non-re-breathable oro-nasal mask (7450 Series Silicone V2, Hans Rudulph Inc, Shawnee, KS) was placed over the subjects mouth and nose. Once comfortable, the treadmill speed was increased to 8 mph and to an 8% grade. A 20-minute continuous trial began in which cycling position (seated vs. standing) was alternated in 5-minute stages. Starting position was selected using randomization. Specific gears were chosen such that subjects pedaled at 66 rpm while seated and 60 rpm while standing. When appropriate, subjects were instructed to shift gears to maintain the required riding cadence which was continuously monitored via the cycle computer. All expired gases were collected continuously via a metabolic cart (TrueOne 2400, Parvo Medics, Sandy, UT) at a 15-second average sampling rate. At the end of each 5-minute stage, rating of perceived exertion (RPE) was recorded for each subject via the 6-20 Borg Scale (7). Following completion of the trial, subjects performed a 10- minute cool down at a self-selected speed and grade.

Participants: Study 2 – Muscle Activation

Eight elite (USA Cycling Category 1 or 2) male cyclists (24 ± 5 yrs, 65.5 ± 5.5 kg, 67.6 ± 5.5 ml/kg/min) participated in the study. All subjects self-reported as being healthy and at similar points in their yearly training cycle at the time of data collection. All preliminary tests and exercise trials were conducted at the Monfort Family Human Performance Lab at Colorado Mesa University in Grand Junction, CO.

Protocol

Preparation of the Subject: Following warm up, wireless electromyography (EMG) sensors (Telemyo DTS, Noraxon, Scottsdale, AZ) and Ag/AgCl electrodes were carefully placed on the Rectus Femoris (RF), Biceps Femoris (BF), Vastus Medialis (VM), and Medial Gastrocnemius (GM) muscles, respectively. In order to ensure accurate sensor placement, specific detail was taken to center electrodes precisely over the midpoint of the length of each muscle. Lightweight elastic stretch tape was placed over the sensors to limit the potential of movement and signal artifact. Retroreflective motion capture markers were placed on the greater trochanter, axis of the knee, and axis of the ankle of the right leg as well as on several key landmarks of the bicycle including the head tube, down tube, and in between the chain-stays for the purpose of bicycle position monitoring. An additional marker was molded to the end of the pedal axle to obtain position data of the pedal cycle in synchronization with EMG throughout the trial. Following the placement of electrodes and markers, the subjects mounted their bicycles on the large treadmill and waited for further instruction.

Preparation of Equipment: All EMG data were collected at a sampling rate of 1000 Hz. The appropriate sensors were calibrated to the device before they were placed on the subject. A 3D motion capture system (Vicon, Oxford, England) was used to record all position data at a sampling rate of 100 Hz. Calibration of the motion capture cameras occurred before each trial using manufacturer guidelines and specific detail was taken in to ensure that camera placement was the same for each subject throughout the duration of the study. All EMG data were recorded and interfaced through the Vicon software via an analog input.

Exercise Trial: During warm-up, each of the EMG sensors was checked for signal strength and normative muscle activation patterns. During the last two minutes of the warm-up, treadmill grade was increased to 8% such that the subjects would be comfortable riding at that particular grade once the trial began. Treadmill speed was then decreased and the subjects coasted to a stop. This allowed for EMG signals to be zeroed before the start of the trial. In a randomized cycling position starting order, a single continuous trial began which alternated 1-minute stages of either seated or standing cycling, respectively. A total of two seated stages and two standing stages were conducted. Specific gears were chosen such that subjects pedaled at 66 rpm while seated and 60 rpm while standing. When appropriate, subjects were instructed to shift gears to maintain the required riding cadence which was continuously monitored via a cycle computer (Edge 800, Garmin Ltd., Olathe, KS). EMG and position data were collected during the last 30 seconds of each stage. During the last 10 seconds of each stage, subjects were instructed which position they would be riding in next and reminded of the appropriate cadence for that position. At the end of the trial, subjects completed a 10-minute cool down at a self-selected speed and grade.

EMG and Pedal Cycle Synchronization: The data from the first seated and standing bouts from each trial were exported to Microsoft Excel (Microsoft Corporation, Redmond, WA) for data smoothing. Raw EMG data were rectified for each condition. The process for cleaning and smoothing the data involved several steps. All EMG data were smoothed using the root mean square (RMS) at a window of 100 m/s. Muscle activations of 10 consecutive pedal cycles were analyzed for each condition. All cycles, containing EMG and motion capture data from each of the four muscles were pasted into columns in an Excel spreadsheet. Maximum muscle activation was determined for each cycle. Data from the individual cycles were then combined to produce average activations across all muscles in both positions. All EMG data were normalized to the maximal muscle activation values observed while in riding in the seated position for statistical analysis.

Participants: Study 3 – Breathing and Pedaling Entrainment

Nine healthy and active male cyclists (28.4 ± 7.4 yrs, 69.9 ± 10.7 kg, 62.7± 7.7 ml/kg/min) participated in the study. All preliminary tests and subsequent exercise trials were conducted in the Exercise Physiology Laboratory at California Baptist University. Subjects were recruited from cycling clubs in Southern California and self-reported as being healthy at the time of the trial.

Protocol

Preliminary Testing: Subjects completed a preliminary VO_2 max test on a cycle ergometer (VeloTron, Racermate, Seattle, WA) to assess fitness levels and to ensure that they would be able to complete the trial at a sub-anaerobic threshold intensity. This test used a ramped design, starting at 130 watts and increasing at a rate of 30 watts per minute until volitional fatigue or until cadence dropped below 60 rpm. VO2 max was achieved when subjects reached at least 3 of the following 4 criteria: a VO2 plateau (≤150 ml/min rise), RPE ≥18, respiratory exchange ratio (RER) > 1.10, and HR within 10 beats of age predicted max (220-age) (12).

Exercise Trial: Following warm-up, a two-way, non-re-breathable mouthpiece (Hans Rudulph Inc., Shawnee, KS) was placed in the subjects' mouths and a nose clip was donned. FR data including Peak Inspiratory Flow (PIF) and Peak Expiratory Flow (PEF) were recorded at a breath by breath interval and interfaced with a metabolic cart (Vmax, CareFusion, Yorba Linda, CA). Pedal cycle timing was recorded with an accelerometer (MetaMotionR, Mbient Lab, San Francisco, CA) which was placed on the subjects left ankle and set to a recording rate of 100 Hz. The trial design consisted of 2- minute stages of cycling at prescribed speeds of 6, 8, and 10 mph for a total length of 6 minutes, in which subjects were instructed to alternate between seated and standing positions every minute. Starting positions were randomized for the purpose of eliminating the possibility of training adaptation. Cadence was monitored via a cycle computer (Edge 810, Garmin Ltd., Olathe, KS) and subjects were instructed to shift gears to maintain a standard climbing cadence of 70 rpm as speed increased. Immediately following the completion of the trial subjects had the option of completing a cool-down at a self-selected speed and grade. Subjects were then debriefed and asked whether they preferred riding in a seated or standing position while climbing. At each speed, two minutes of data were recorded (one-minute standing and one-minute seated, respectively.) The last 20 seconds of each cycling position were subsequently analyzed.

Statistical Analysis

All data were analyzed using a commercially available software package (Statistica, TIBCO, Palo Alto, CA, USA) and expressed as mean ± standard error of the mean, unless otherwise noted. Statistical significance level was set at $p < 0.05$. Post hoc analyses for effect size and power were calculated using a statistical power analysis software (G*Power, Kiel, Germany).

<u>Study 1</u>

Paired t-tests were used to compare mean VO_2 and HR from seated and standing positions during each 5-mintue stage. Cohen's d tests were conducted to determine effect size and calculate power.

<u>Study 2</u>

EMG data were collected for the last 30 seconds of each stage from which data from 10 pedal cycles were extracted and used for seated vs. standing comparisons. Raw EMG data were rectified, smoothed (RMS, 100 ms window), and normalized across crank angle (0 to 360 degrees). Each muscle amplitude was normalized to the maximum observed during seated cycling. Paired t-tests were used to compare seated and standing EMG data. Cohen's d tests were conducted to determine effect size and calculate power.

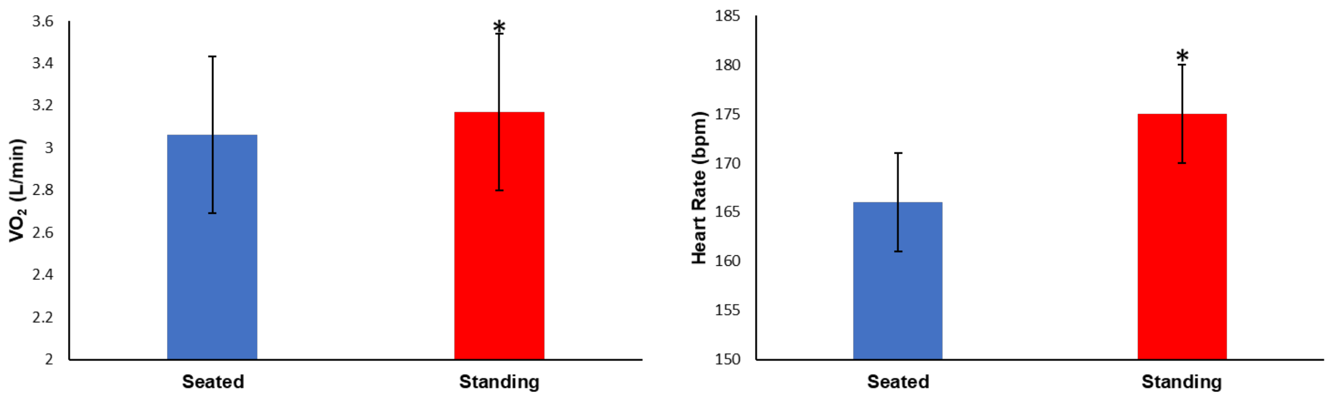
Study 3

FR data including PIF and PEF were analyzed using a two way (condition x speed) repeated measures ANOVA and a Tukey post hoc test was used when there was a significant interaction. An F-test was conducted to determine effect size and calculate power. The ratios of breathing to pedaling frequency were determined for both positions and at every speed and were used to evaluate the coordination of breathing with cycling movement patterns.

RESULTS

Study 1

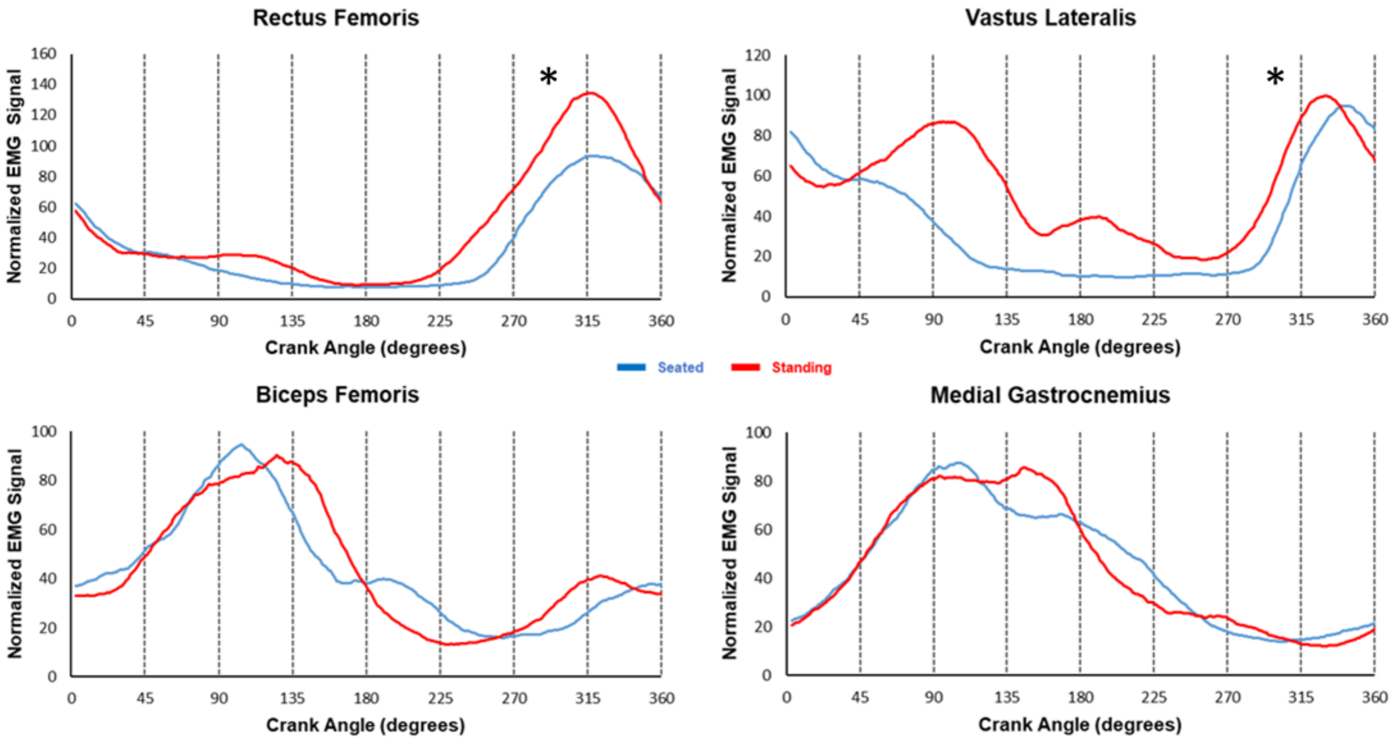
VO_2 and Heart Rate: Mean VO_2 and HR were significantly elevated while climbing in a standing position (3.17± 0.43 L/min) ($p = 0.11$, $d = 0.27$), (175 ± 4 bpm) ($p = 0.91$, $d = 2.03$) as compared to a seated position (3.06 ± 0.37 L/min), (166 ± 5 bpm) ($p < 0.05$) (Figures 1A-1B).



Figures 1A-1B: Means and standard error of VO_2 and Heart Rate for seated vs standing uphill cycling.* significantly different ($p < 0.05$) between cycling positions. $n = 4$.

Study 2

Muscle Activation: Muscle activation for RF and VM were significantly greater for the standing compared to seated riding position ($p < 0.05$). Mean EMG amplitudes (normalized to peak activation during seated cycling) for RF were 34 ± 4% seated vs. 47 ± 7% standing ($p = 0.97$, $d = 2.11$) while for VM they were 36 ± 6% seated and 55 ± 15% standing ($p = 0.85$, $d = 1.63$) (Figures 2A-2D). Mean activations for BF and GM were not different for seated and standing positions, however, considerable variability of activation was observed across riders when standing, particularly for BF.



Figures 2A-2D: Ensemble muscle activation patterns for seated (blue) and standing (red) riding positions. All data were normalized to maximum muscle activation for the seated condition for each subject prior to ensemble averaging. * significantly different ($p < 0.05$) between cycling positions. $n = 8$.

Study 3

Flow Rate: A significant main effect was detected for FR including PIF and PEF between climbing positions ($F(2, 8) = 54.09$, $p < 0.05$ (Figure 3) ($p = 0.99$, $f = 2.23$) and across speeds ($F(4,16) = 19.36$, $p < 0.05$) (Figure 4). Mean PIF and PEF were 3.09 ± 0.06 and 2.21 ± 0.04 L/sec while riding in a seated position, as opposed to 3.44 ± 0.07 and 2.45 ± 0.05 L/sec while riding in a standing position.

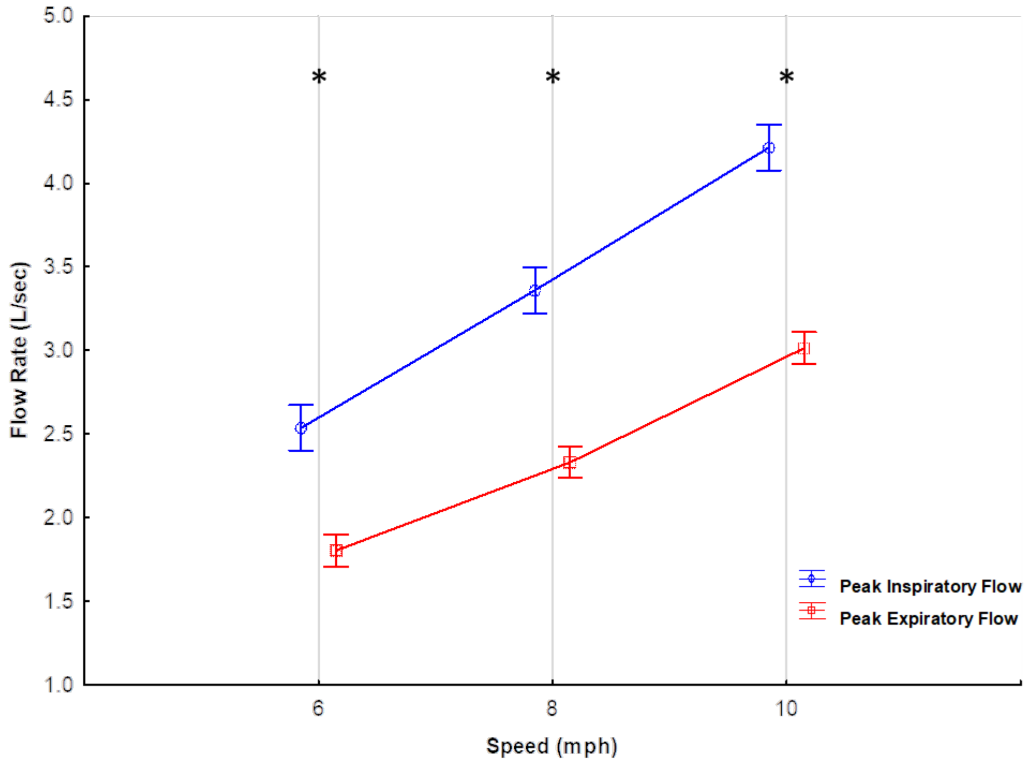


Figure 3: Means and standard error of Peak Inspiratory and Peak Expiratory Flow Rate for seated vs standing uphill cycling. * significantly different ($p < 0.05$) between cycling positions. n = 9

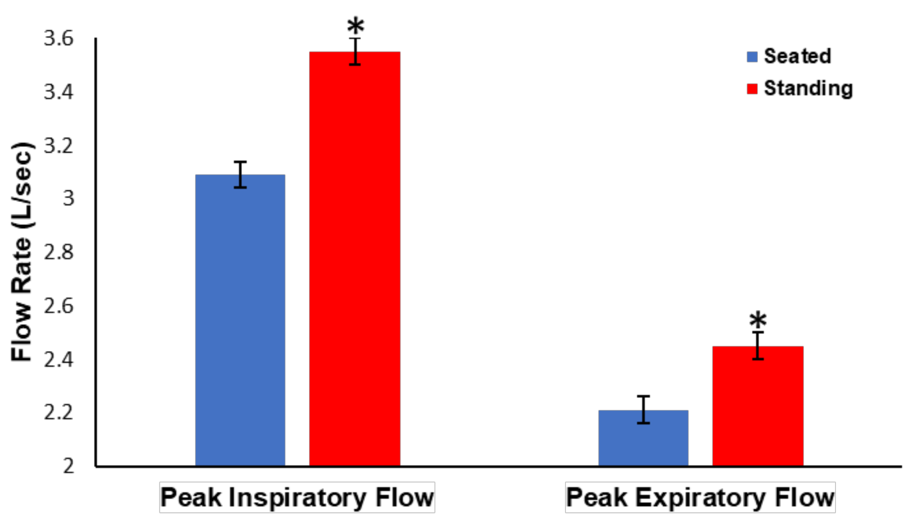


Figure 4: Flow rate including peak inspiratory and peak expiratory flow during 6, 8, and 10 mph cycling. * significantly different ($p < 0.05$) between speeds. n = 9.

Breathing and Pedaling Synchronization: The ratios of breathing to pedaling frequency were on average 4:1 at 6 mph, 3:1 at 8 mph, and 2:1 at 10 mph during both seated and standing positions (Figure 5), however there was considerable variability between subjects. No differences between seated and standing positions were observed.

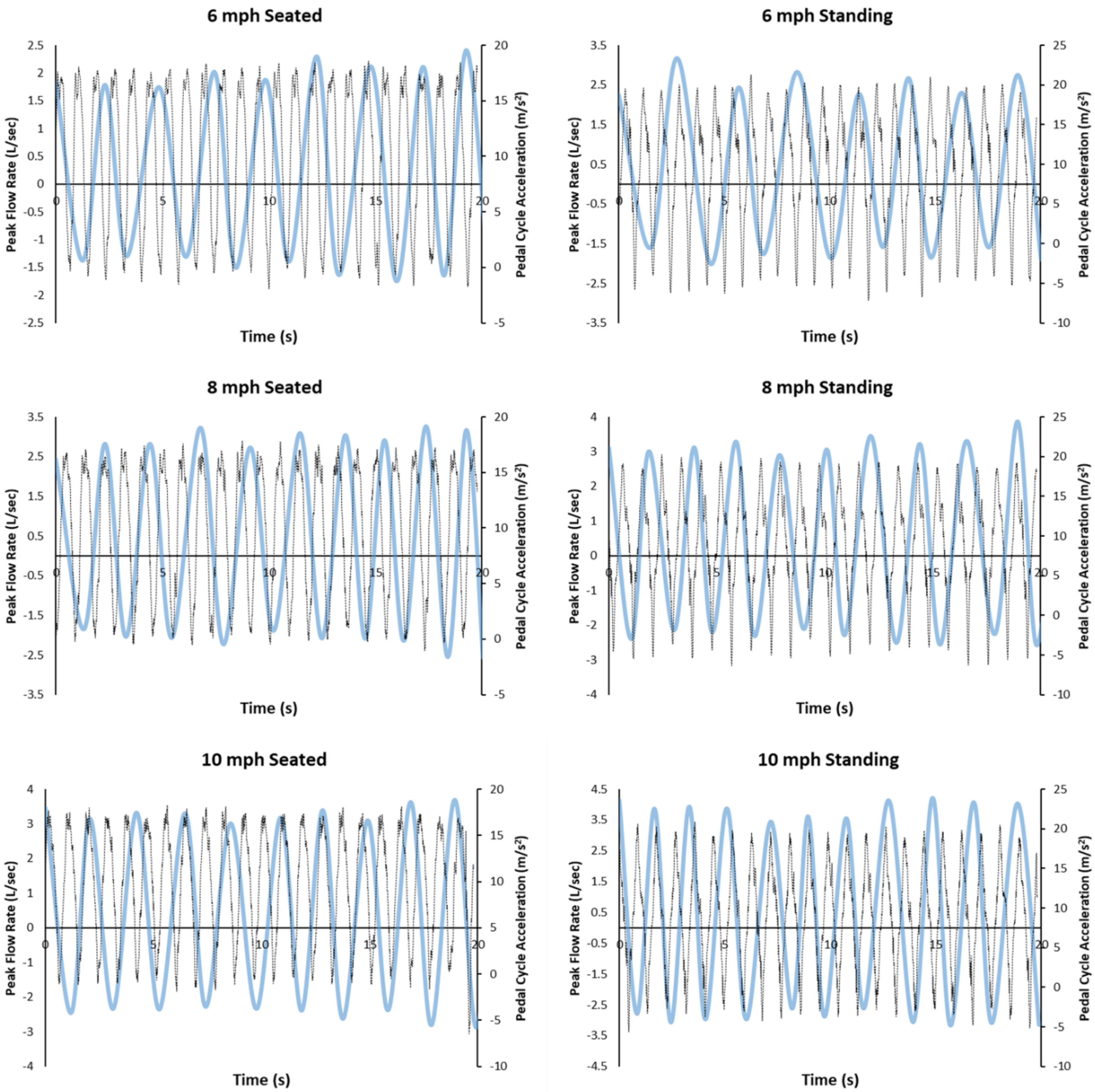


Figure 5: Breathing and Pedaling Synchronization for one subject in seated and standing riding positions and at 6, 8, and 10 mph. The blue line signifies Peak Flow Rate whereas the black line signifies acceleration throughout the pedal cycle. Note the peak positive acceleration as Top Dead Center and the peak negative acceleration as Bottom Dead Center of the pedal cycle.

DISCUSSION

Study 1

The purpose of this study was to compare VO_2 and HR during sub-anaerobic threshold seated and standing uphill cycling and determine whether there were changes in CE across riding positions. The primary findings of this study were that VO_2 and HR were significantly increased while riding in a standing position at a speed of 8 mph and an 8% grade as compared to seated uphill cycling under the same conditions (Figure 1). The increase in VO_2 corresponds to a decrease in CE and could be attributed to an increase in the upper body contribution to VO_2, facilitating greater oxygen demand to the working muscles (26). Similarly, due to the linear relationship between VO_2 and HR during steady state exercise (2), as the demand for oxygen increases, HR is concurrently elevated. It is possible that the simultaneous side to side riding motion as well as increased use of the torso elicited greater oxygen demands on muscles of the upper body while climbing in a standing position.

These data are in line with those of Arkesteijn et al. (4) who compared CE during seated and standing uphill at 50% and 70% of maximal aerobic power at 4 and 8% grades, and determined that while riding at sub-anerobic threshold intensity, CE decreased while riding in a standing position. Several notable differences exist between the protocol design of Arkesteijn et al. and that of the current study. While Arkesteijn et al. compared CE across multiple intensities and grades, riding bouts were broken into 5-minute stages with three minutes of recovery between stages. The current study employed a design that consisted of a single continuous bout of uphill cycling at a constant speed and grade, alternating between seated and standing riding positions every 5 minutes for a total duration of 20 minutes. Both studies assigned a randomized order for riding position; however, the current study was designed with the intent to simulate real world conditions of continuous riding during a sustained climb. Additionally, Arkesteijn et al. adapted a single bicycle for use with all subjects whereas the current study required for each subject to use their own bicycle which had been professionally fitted for them. It is possible that postural inadequacies due to the constraints of fitting all subjects on a single bicycle may have influenced CE in one, or both positions.

Regardless of the differences in protocols, the results of the current study and those of Arkessteijn et al. (4) are two of the few studies to compare CE during cycling seated and standing uphill while riding on a large treadmill. The rationale for using a treadmill was to simulate an environment as close to possible to real riding conditions in which subjects were not constricted to the fixed riding position of a cycle ergometer. Previous researchers have primarily found significant differences between riding positions while cycling uphill at moderate grades (<10%). Ryschon and Stray-Gunderson (24) determined that cycling uphill in a standing position led to a significant increase in energy expenditure (expressed as VO_2 per unit combined weight) compared to a seated position while riding at 4% grade. Similarly, Tanaka et al. (26) found that uphill treadmill cycling at a speed of 12 mph and a grade of 4% led to an increase in both VO_2 and HR while riding in a standing position. There were no significant differences between positions while riding at 7.6 mph and at a 10% grade, suggesting that perhaps the differences may be blunted during steeper grades. The current study is one of the first to establish clear decreases in CE between seated and standing positions while riding on a treadmill at a grade in excess of 4%. One possibility that may explain the discrepancy in the literature could be attributed to whether or not subjects were above anaerobic threshold while cycling at steeper grades. Further research is needed to investigate the differences in CE at more difficult grades over prolonged periods of time to resolve the contrasting results of studies in the current literature.

Study 2

The purpose of this study was to compare muscle activation differences during sub-anaerobic threshold seated and standing uphill cycling. The primary findings of this study were that muscle activation of RF and VM were significantly increased while riding in a standing position at a speed of 8 mph and an 8% grade as compared to seated uphill cycling under the same conditions. Additionally, there were no significant differences in muscle activations of BF and GM while riding in either position (Figures 2A-2D). While indirectly related, it is possible that the increased muscle activation of the quadriceps while riding in a standing position requires greater oxygen demand, thus leading to increases in VO_2, HR, and a decrease in CE.

These outcomes are consistent with those of previous research including a study conducted by Li and Caldwell (15), in which cyclists exercised on a stationary ergometer at an 8% grade in seated and standing positions. Results indicated that greater EMG magnitudes were seen in RF while riding in a standing position. Additionally, it was observed that there were no differences in muscle activation of BF and GM for either of the two positions. In a recent study on uphill cycling while riding on a treadmill, Arkesteijn et al. (4) found that muscle activation of the upper leg muscles, including RF and VM were increased while riding in a standing position, however when compared across various climbing intensities, only muscle activation in VM was greater when riding at higher intensity. No differences in GM were observed across climbing positions or intensities.

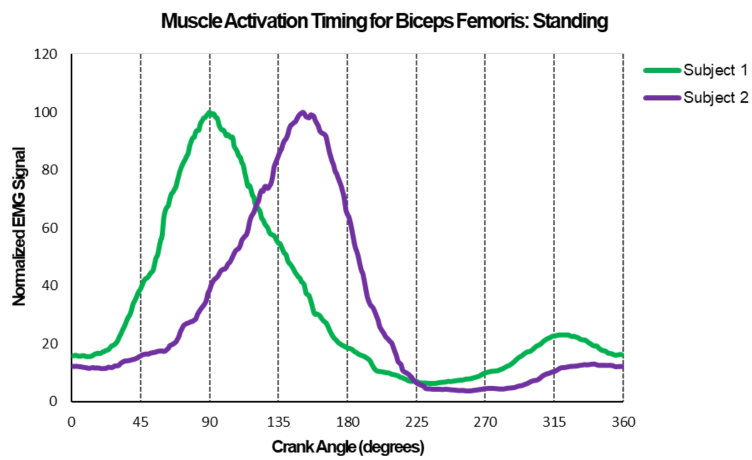


Figure 6: Muscle activation timing for Biceps Femoris during the standing condition. Data were normalized to percentages of maximal activation. Note the differences in activation timing between two subjects.

An interesting observation made during the current study was that although average muscle activations for seated and standing conditions were not different for BF and GM, considerable differences in muscle activation patterns between individual cyclists were noted. Additionally, muscle activation timing was quite variable across subjects for BF during the standing condition. Figure 6 shows the differences in muscle activation timing between two subjects while riding in a standing position. Subject 1 elicited maximal muscle activation for BF fairly early in the downstroke of the pedal cycle (90°) whereas Subject 2 had a much later peak muscle activation (150°). This could be due to differences in pedaling mechanics as well as the use of different muscles as primary contributors to activations during various points in time throughout the pedal cycle. It is possible that activation timing of several muscles shift independently of climbing position, and in a subject dependent manner.

It is important to note that the current study did not measure every agonist muscle of the lower body used in uphill cycling, and instead chose to measure representative muscles of the upper and lower legs. It is possible that while some muscles were more active in the standing position, others may have stayed the same or shown decreases in muscle activation. Taken together, the results of the current study and those of previous research show an increase in muscle activation of muscles of the upper legs while standing when cycling uphill at moderate grades.

To our knowledge, the current study was one of the first to combine concurrent recording of EMG and continuous position monitoring throughout the 360° pedal cycle while riding uphill on a treadmill. Due to the fact that treadmill cycling most closely simulates that of riding out on the road, further research is needed using this mode of exercise to investigate the differences in a larger variety of the agonist muscles used in seated and standing uphill cycling, and across various climbing intensities.

Study 3

The purpose of this study was to compare breathing and pedaling entrainment differences between seated and standing uphill cycling. The key finding of this study was that average FR including PIF and PEF was significantly increased while cycling uphill in a standing position (Figure 3) at a constant 8% grade and at speeds of 6, 8, and 10 mph (Figure 4), compared to cycling at the same speeds and grade in a seated position. The increase in FR was likely due to an increase in metabolic cost compared to riding in a seated position. As the arterial pressure of CO_2 rises, central chemoreceptors are activated resulting in increased ventilation to maintain CO_2 concentrations (14). Measurement of ENT of breathing and pedaling showed a wide variation in breathing frequency among subjects, however breathing to pedaling cycle timing was consistent at each speed and for both climbing conditions. Generally, the inspiration phase occurred during the upstroke of the pedal cycle, ending near Top Dead Center (TDC). Conversely, exhalation occurred during the downstroke of the pedal cycle ending near Bottom Dead Center (BDC). This suggests that there is a relationship between the way in which cyclists breathe in conjunction to the pedal cycle.

The data from the current study are similar to the findings to Garlando et al. (13) who determined that the inspiration phase of breathing starts near the onset of leg movement. In contrast, Garlando et al. indicated that the expiration phase occurred mid-way through the pedal cycle; whereas, data from the current study showed a trend of the beginning of exhalation occurring near TDC and continuing through the downstroke. It is important to note that previous research has been conducted on a fixed cycle ergometer and not during uphill cycling conditions, which may have had an influence on the outcome.

Additionally, the lack of a difference in ENT data in seated and standing positions (Figure 5) suggest that the increase in FR is not influenced by ENT of breathing and pedaling but is rather driven by metabolism. It is unknown if FR and ENT of breathing and pedaling are influenced by cadence and if that might alter results. The prescribed cadence of 70 rpm was chosen as a standard climbing cadence for cyclists (16); however, several subjects noted that they tended to ride uphill at higher cadences. A suggested direction for further research on the topic of ENT of breathing and pedaling in uphill cycling would be to allow cyclists to self-select their preferred cycling cadence, and determine if there is a difference in outcome.

One aspect of the study that cannot be overlooked is the influence that personal position preferences might have on overall cycling performance. Of the 66% of cyclists who stated that climbing while seated was their preferred position, all but one mentioned that they preferred riding seated across all intensities while climbing. One subject mentioned that he was more comfortable riding seated at slower speeds and felt that a standing position was more beneficial for high intensity and maximal climbing efforts. The 33% who preferred to climb while standing indicated that they felt as if they were able to get into a better rhythm out of the saddle, however all data analyzed from this study point against that preference. It is possible, however, that a mental preference for or against a certain riding position may have an influence on performance, especially during longer, more sustained riding efforts. Further research needs to be conducted on the psychological influences during seated and standing uphill cycling for extended periods of time to investigate such a possibility.

In summary, the combined results from the current studies include increased VO_2, HR, increased muscle activation of the quadriceps, as well as increased FR while standing. These findings suggest that climbing in a standing position may have a negative effect on CE compared to climbing in a seated position. The implication for elite cyclists looking to conserve effort during a race would be to stay in a seated riding position for as long as possible and only stand for short bouts to alleviate pressure points and possible muscle soreness. Conversely, the implication for the general population, or for those in a clinical setting looking to maximize the effect of a workout, would be to spend a significant amount of time riding in a standing position as increased VO_2, HR, muscle activation, and FR might increase caloric expenditure due to greater metabolic demand.

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