©Journal of Sports Science and Medicine (2006) **5**, 25-32
http://www.jssm.org

Research article

THE EFFECTS OF BICYCLE FRAME GEOMETRY ON MUSCLE ACTIVATION AND POWER DURING A WINGATE ANAEROBIC TEST

Mark D. Ricard [1]✉, Patrick Hills-Meyer [2], Michael G. Miller [2] and Timothy J. Michael [2]

[1] Exercise Science Research Laboratories, Department of Kinesiology, University of Texas at Arlington, Arlington, TX, USA
[2] Biomechanics Laboratory 1060 SRC, HPER Department, Western Michigan University, Kalamazoo, MI, USA

Received: 13 October 2005 / Accepted: 30 November 2005 / Published (online): 01 March 2006

ABSTRACT

The purpose of this study was to compare the effects of bicycle seat tube angles (STA) of (72° and 82°) on power production and EMG of the vastus laeralis (VL), vastus medialis (VM), semimembranous (SM), biceps femoris (BF) during a Wingate test (WAT). Twelve experienced cyclists performed a WAT at each STA. Repeated measures ANOVA was used to identify differences in muscular activation by STA. EMG variables were normalized to isometric maximum voluntary contraction (MVC). Paired t-tests were used to test the effects of STA on: peak power, average power, minimum power and percent power drop. Results indicated BF activation was significantly lower at STA 82° (482.9 ± 166.6 %MVC·s) compared to STA 72° (712.6 ± 265.6 %MVC·s). There were no differences in the power variables between STAs. The primary finding was that increasing the STA from 72° to 82° enabled triathletes' to maintain power production, while significantly reducing the muscular activation of the biceps femoris muscle.

KEY WORDS: Cycling, anaerobic power, triathlon, efficiency, EMG.

INTRODUCTION

Triathlon is a physically challenging sport involving three disciplines: swimming, cycling, and running. Each sub-discipline of triathlon is unique in the movement patterns involved. Swimming uses both upper and lower body for motion through the water, cycling relies almost entirely on the lower body for propulsion across the land in a seated position, where as running relies mostly on the lower body in the upright position.

Difficulties in the transition between events will sometimes adversely affect the overall performance of triathlon. There is general agreement among triathletes that the transition from cycling to running impinges upon running performance (Bentley et al., 2002; Tew, 2005). One strategy triathletes have adapted to help with performance decrements has been to alter the frame geometry of the bicycle. The most common alteration in the bicycle frame geometry is changing the seat tube angle (STA) (see Figure 1). The STA is defined as the position of the seat relative to the crank axis, the pedal shaft and the center axis of rotation for the front gears, of the bicycle (Vandewalle et al., 1991). The typical range in STA for a road bike is between 70° to 76°. This position places the rider in a posture more similar to sitting in a chair with the hips behind

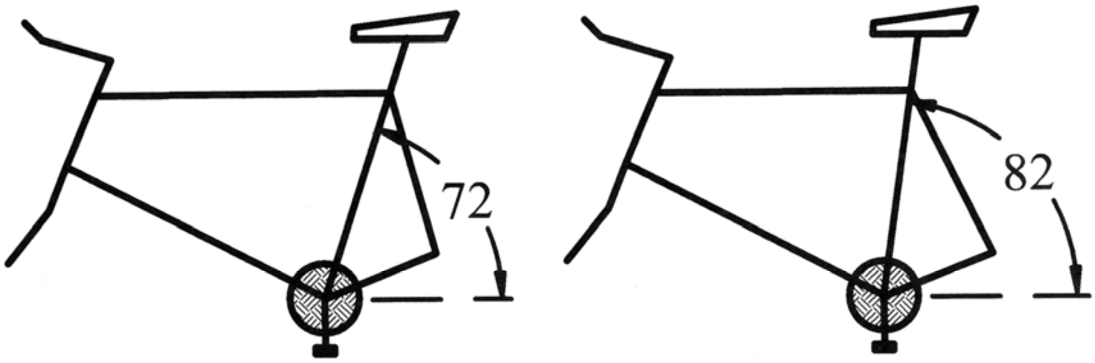


Figure 1. Seat Tube Angle (STA) of 72°, this STA mimics “shallow” frame geometry and STA of 82°, which mimics “steep” frame geometry.

the feet and crank axis. A triathlon bike usually has a steeper geometry with a STA greater than 76°. The steeper STA places the rider in a posture more similar to running with the hips over the feet and crank axis (Burke, 1994).

Several studies have examined the effects of STA on subsequent performance and physiologic variables during cycling and or running. Heil and colleagues (1995) examined cardiorespiratory (CR) responses to STA variations, and found that steeper STA’s (76°, 83°, 90°) produced smaller CR responses compared to a shallow STA (69°) during steady-state cycling. In a latter study, Heil et al. (1997) observed that cyclists optimized their VO_2 costs in submaximal cycling with a frame geometry that closely matched their own bicycle, suggesting a possible training specific effect. Price and Donne (1997) found that increasing the STA produced lower mean VO_2 and significantly higher power efficiency. Based upon these findings, it appears that increasing the seat tube angle improves the efficiency of cycling.

Road cyclists claim that STA’s between 72° and 76° are most effective for optimal performance in racing (Hunter et al., 2003). Anecdotal testimony of triathletes, however, suggests that a steeper STA (greater than 76°) provides a smoother bike to run transition, allowing for greater comfort, efficiency, and power production when running or biking (Hunter et al., 2003). Gnehm et al. (1997) observed that increasing the STA extends the hips, allowing a more forward and crouched upper body position, resulting in a decrease in drag at higher speeds. Garside and Doran (2000) found that cyclists were able to complete the first 5 km of a 10 km run following a 40 km ride significantly faster using a STA of 81° when compared to an STA of 73°. There were no differences in physiological responses to riding with the different frame configurations, suggesting that the steeper STA improved efficiency. Stride length during the first 5 km was greater after riding with the 82° STA than when riding with the 73° STA. The authors speculated that the 82° STA might have enabled the riders to utilize a muscle activation pattern that optimized the transition from cycling to running.

The cycling literature is replete with reports of electromyographic analyses (Brown et al., 1996; Creer et al., 2004; Heiden and Burnett, 2003; Hunter et al., 2002; MacIntosh et al., 2000), yet there is a paucity of the effects of variations of seat tube angle on muscle activation (Savelberg et al., 2003). The EMG amplitude has been shown to increase with increasing workload and pedal cadence (Ericson et al., 1985) and increased power output (MacIntosh et al., 2000). Hunter et al. (2002) compared EMG normalization techniques for cycling. Their results suggested that isometric contractions were well suited for normalizing dynamic contractions in cycling. Savelberg et al. (2003) inspected how body configuration affects muscle recruitment. Finally, Vanderwalle (1991) examined EMG during all out exercise on an ergometer. Heiden and Burnett (2003) recently studied the effects of prior cycling upon muscle activation in the running leg of the triathlon. They found significantly lower biceps femoris EMG and greater vastus lateralis EMG in the cycle/run condition, when compared to a run/run condition.

Increasing the seat tube angle and utilizing aerobars increases the inclination of the trunk and therefore improves cycling aerodynamics (Hausswirth et al., 2001; Heil, 2002). In addition to reducing wind drag, the seat forward position may also improve power production by altering muscle force-velocity and force-length relationships during cycling (Browning et al., 1992; Reiser et al., 2002; Savelberg et al., 2003). Peak power, during cycling, has been shown to be highly correlated with the time required to complete the cycling performance (Bentley et al., 1998; Tan and Aziz, 2005). Tan and Aziz (2005) recently reported that absolute power accurately predicts cycling performance on a flat course and relative power is a better predictor of uphill cycling performance. Power production is related to triathlon and cycling (Coyle et al., 1991; Tanaka et al., 1993) performance. Despite this, little is known about the effects of seat tube angle upon muscle activation and power production. Furthermore, since previous investigations (Heil et al., 1995; 1997) utilizing steady state cycling reported no change in stride length or stride frequency we chose to utilize the Wingate anaerobic test (Bar-Or, 1987) to investigate the affects of seat tube angle upon muscular activation. We hypothesized that unlike steady state cycling, the level of neural drive required to complete a Wingate test would elucidate the effects of seat tube angle upon muscular activation. Therefore, the purpose of this study was to determine if differences in STA would affect power output and muscle activation of the vastus lateralis (VL), vastus medialis (VM), semimembranous (SM), and biceps femoris (BF) muscles during a Wingate anaerobic test (WAT).

METHODS

Subjects

Twelve experienced (having at least 1 year of racing experience or competing in 1 triathlon) triathletes (10 men and 2 women) participated in this study. The subjects mean age, height, and body mass were 37.9 ± 8.9 years, 1.79 ± 0.09 m, and 80.76 ± 11.98 kg, respectively. All subjects were given informed consent, Par-Q questionnaires, and inclusion/ exclusion questionnaires during an introductory meeting. After receiving an explanation of the experimental protocol and signing consent forms and completing the questionnaires, each subject performed a 30-second Wingate anaerobic test to allow them to become accustomed to the Monark ergometer and the WAT.

Instrumentation

Power output during a 30 s Wingate test was measured using a Monark stationary ergometer (Stockholm, Sweden, Model 895E Peak) with 10% of the subjects' mass in the weight basket. The weight basket was instrumented with an electromagnetic sensor, which produced a 5 V square wave when the weight basket was dropped. Knee joint angle during each Wingate test was obtained using an electrogoniometer, which was attached to the lateral side of the subjects' knee.

EMG signals were differentially amplified with a gain of 1000 and a bandwidth of 16-1000 Hz at –3dB using a Noraxon Myosystem 2000 (Scottsdale, AZ). The Noraxon amplifiers have an input noise below 1mV RMS and an effective common mode rejection ratio of 135dB. Bipolar surface electrodes, Ag/AgCl, 1 cm circular detection area and a fixed interelectrode distance of 2 cm, (Noraxon #272), were used to record EMG signals.

EMG, Monark weight basket signal, and the knee electrogoniometer signals were sampled at 1000 Hz using a Dell computer equipped with a Keithley-Metrabyte (Taunton, MA) DPCA-3107, 16-bit analog-to-digital converter. A specially written Visual Basic program was used for data collection and analysis.

Experimental protocol

The order of seat tube angle testing was counterbalanced so that half of the subjects began with 72° and half of the subjects began testing at 82°. Trials were performed at least two days apart. Subjects self-selected their seat height prior to the start of each testing session. The subjects then warmed-up by cycling at a self selected resistance and cadence for 5-10 minutes. Following the warm up, the electrode placement sites were prepped by shaving the skin to remove hair. After shaving, the skin was abraded and cleaned with an isopropyl alcohol pad inside a gauze pad to reduce skin impedance. The electrodes were attached to the right leg over the belly of the vastus medialis (VM), vastus lateralis (VL), semimembranous (SM) and biceps femoris (BF) muscles, aligned parallel to the direction of the muscle fibers and securely placed on with under-wrap and elastic stretch tape. The position of each electrode was marked with a small dot and transferred along with other marks (angiomas and/or scars) on the subject's skin to transparency sheets to ensure consistent electrode placement between testing sessions. A ground electrode was placed over the tibial tuberocity. After electrode placement, an electrogoniometer was securely taped to the lateral side of right knee, with the pivot of the electrogoniometer aligned over the axis of the knee rotation.

Following application of EMG electrodes and the electrogoniometer, each subject performed three isometric MVC knee extensions and knee flexions at a 45° knee angle. EMG signals were sampled during the MVC trials for 1 s at 1000 Hz. After completing the MVC trials, the subjects returned to the bike and performed a second warm-up for 5-10 minutes. The WAT was then initiated by giving the subjects a verbal count down prior to dropping the weight basket. The subjects were instructed to attain maximal pedal velocity by the end of the count down, at that point, the weights were dropped and the subject performed the WAT. The subjects were verbally encouraged to pedal as fast as possible

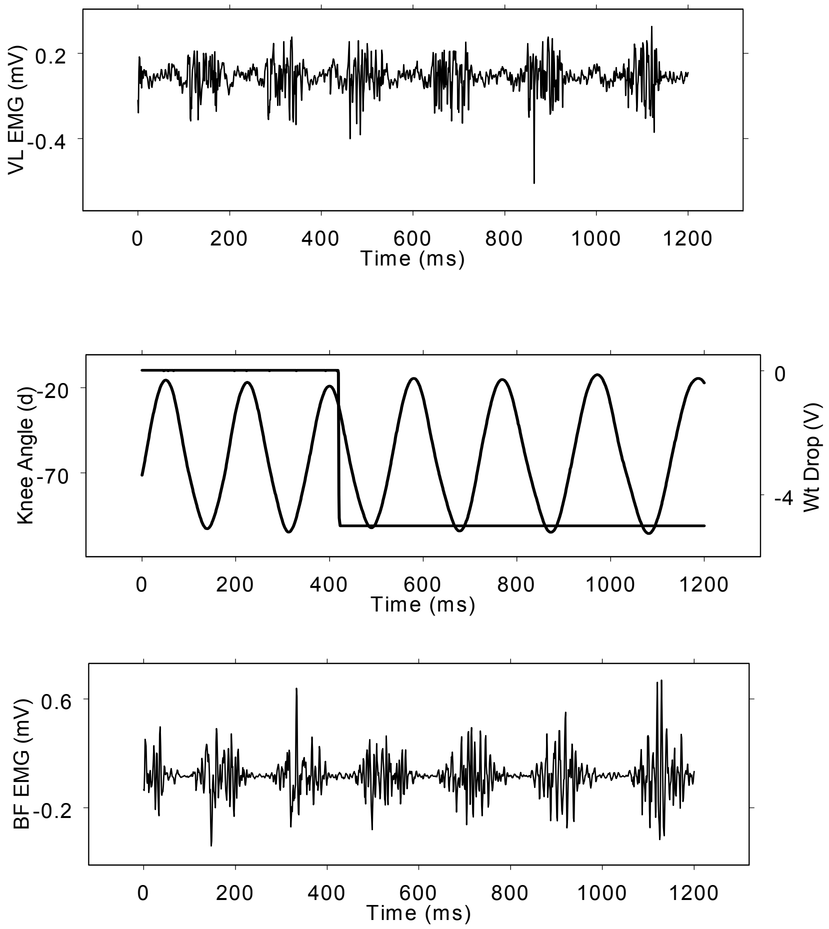


Figure 2. EMG amplitude and electrogoniometer with weight drop shown.

throughout the test. During the test, the subjects were not allowed to get out of the seat or change their hand placement on the handlebars during the test. EMG, knee electrogoniometer and weight drop pulse data were sampled at 1000 Hz for 36 seconds during the Wingate test, 3 seconds prior to the start of the test and 3 seconds following the end of the test.

Data analysis

The MVC trials were analyzed by computing the RMS amplitude of the EMG signal for all four muscles and the highest amplitude was retained for normalization of the EMG during the Wingate trials. The raw EMG data were demeaned, full wave rectified and then filtered using a fourth order recursive Butterworth digital filter set at 4 Hz to produce a linear envelop. The EMG of each muscle was then expressed as a percentage of the EMG value during the MVC.

The Wingate trial data were analyzed by first finding the start of the weight basket drop (Figure 2). Knee extension and flexion phases were identified from the electrogoniometer. Full knee extension was determined to be 180° on the electrogoniometer. Instantaneous power was computed for the entire 30 s Wingate test. The following power variables were computed from the instantaneous power: peak power, average power, minimum power and percent power drop. All power variables were normalized by dividing by the subjects' mass in kg.

Test-retest reliability

To establish between-day reliability for EMG, ten subjects performed a Wingate test using a seat tube angle of 82° on two separate days, with 3-5 days between tests. The electrode locations were marked with a small dot and transferred along with other marks (angiomas and/or scars) on the subject's skin to transparency sheets to ensure consistent electrode placement between days. The EMG data for the reliability analysis were processed using the same methods as the seat tube angle analysis, thus they were normalized to MVC.

Statistical analysis

Reproducibility of EMG variables was analyzed using SPSS (11.5 for Windows) to compute the intraclass correlation coefficients (ICC) using a two factor mixed effects model and type consistency (McGraw and Wong, 1996).

A repeated measure ANOVA with two within subjects factors muscle (VL, VM, BF, SM) and seat tube angle (72°, 82°) was used to identify differences in muscular activation. Paired t-tests were used to test the effects of seat tube angle (72°, 82°) on the mechanical variables: peak power, average power, minimum power and percent power drop. An alpha level of $p \leq 0.05$ was used to determine statistical significance and the *Bonferroni* procedure was used to control for experiment-wise error.

RESULTS

The results of the separate between-day reliability analysis for EMG, in which subjects performed a Wingate test using a seat tube angle of 82° on two separate days, revealed a high level of reproducibility. Between day ICC values for BF, SM, VL and VM were: 0.91, 0.87, 0.92, 0.90, respectively.

The means and standard deviations for muscle activation by seat tube angle are shown in Figure 3. A significant muscle by seat angle interaction was found for muscle activation [$F(3,33) = 3.28$, $p = 0.03$, power = 0.70]. Post hoc analysis identified a significant seat tube angle effect for biceps femoris EMG. When riding the road frame bicycle (STA 72°), the biceps femoris muscular activation was 712.6 ± 265.6 %MVC·s and for the triathlon bicycle (STA 82°) the biceps femoris activation was significantly lower, 482.9 ± 166.6 %MVC·s, identified by '*' in Figure 3. Post hoc analysis of muscle effects for STA 72° indicated that VL (757.2 ± 163.4 %MVC·s), VM (853.0 ± 297.1 %MVC·s), and BF (712.6 ± 265.6 %MVC·s) were all significantly different from SM (525.0 ± 200.7 %MVC·s), identified by '[a]' in Figure 3; and VM was significantly different from BF, , identified by '[b]' in Figure 3. For the 82° seat tube angle VL (734.1 ± 163.5 %MVC·s) and VM (762.9 ± 225.0 %MVC·s) were both significantly different from BF (712.6 ± 265.6 %MVC·s) and SM (417.9 ± 201.5 %MVC·s) , identified by '[c]' in Figure 3.

Variations in seat tube angle had no effect upon power production in a Wingate anaerobic test, Table 1. There were no differences in peak power between the two seat tube angles, [$t(11) = -0.84$, $p = .42$]. Average power production was not affected by seat tube angle, [$t(11) = 1.27$, $p = .23$]. Both minimum power, [$t(11) = 0.55$, $p = 0.59$], and percent drop in power, [[$t(11) = -0.96$, $p = 0.36$], were unchanged by alterations in bicycle seat tube angle.

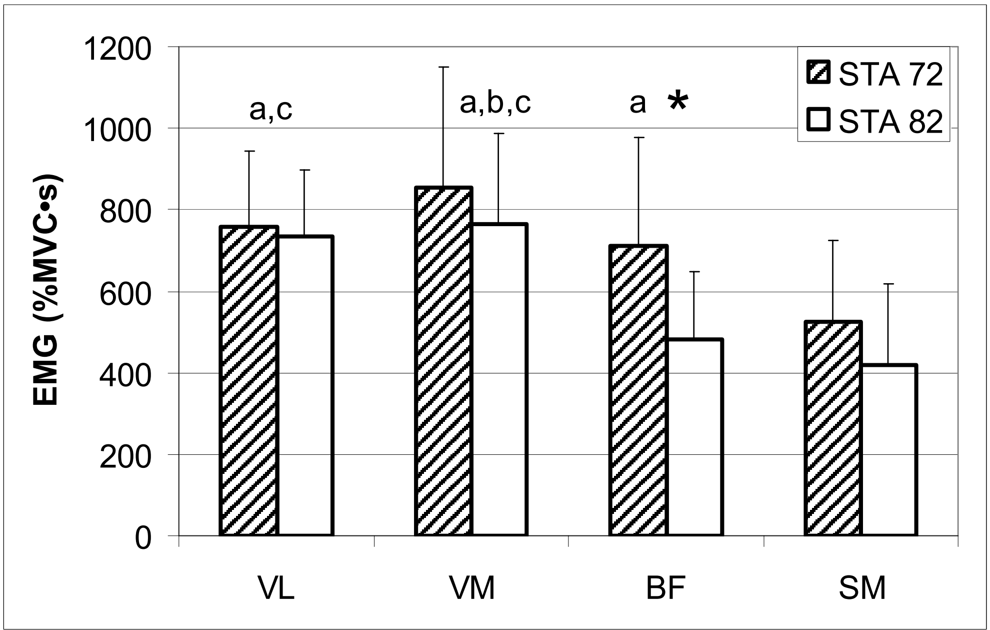


Figure 3. Normalized muscular activation (mean ± SD) for vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF) and semimenbranous (SM) muscles by seat tube angle (STA).
**Indicates significant difference between 72° and 82° seat tube angle (p < 0.05); [a] Indicates muscle is significantly different from SM for 72° seat tube angle (p<0.05); [b] Indicates muscle is significantly different from BF for 72° seat tube angle (p<0.05); [c] Indicates muscle is significantly different from SM and BF for 72° seat tube angle (p<0.05).*

Table 1. Mechanical power by Seat Tube Angle. Data are means (± SD).

	Seat Tube Angle	
	72°	82°
Peak Power ($W \cdot kg^{-1}$)	18.8 (1.81)	19.0 (1.9)
Ave. Power ($W \cdot kg^{-1}$)	10.0 (.07)	9.8 (. 8)
Min. Power ($W \cdot kg^{-1}$)	6.1 (.9)	6.0 (.8)
Power Drop ($\%W \cdot kg^{-1}$)	67.1 (7.2)	68.1 (5.5)

DISCUSSION

The primary finding of this investigation was that increasing the seat tube angle from 72° to 82° enabled triathletes' to maintain power production, while significantly reducing the muscular activation of the biceps femoris muscle. Furthermore, since all of the muscles studied had reduced activation when using the 82° seat tube angle, and power was unchanged, these results suggest that the triathlon frame optimizes muscular activation without adversely affecting maximal power production, (Figure 3). Triathletes typically use a seat tube angle greater than 76°, which has been purported to facilitate the bike to run transition, allowing for greater comfort, efficiency, and power production (Garside and Doran, 2000; Hunter et al., 2003; Millet et al., 2001; Price and Donne, 1997). Garside and Doran (2000) compared run performance after cycling 40 km with STA's of 73° and 81°. They observed significant improvements in run performance and greater stride length during the first 5 km of the 10 km run for the 81° STA. Heiden and Burnett (2003) suggested that reducing the bicep femoris activation during cycling would enhance the run portion of the triathlon. Our finding of reduced bicep femoris activation in the 82° STA condition may serve to reduce hamstring tightness following the bike phase of the triathlon, allowing the runner to use a longer stride length.

Increasing the bicycle seat tube angle moves the rider forward relative to the crank axis. As a result of this forward movement of the rider, the hip is more extended during the power phase of pedaling (Brown et al., 1996; Heil et al., 1995). Brown et al. (1996) observed that forward movement of the rider relative to the crank axis enabled the rider to generate greater hip torque with lower levels of bicep femoris activation. Furthermore, Browning et al. (1992) reported that with steeper seat tube angles cycling mechanics was enhanced as the lower limb was positioned more directly over the crank axis. When the cyclists used both an increased seat tube angle and aerobars a more efficient pedal force application pattern occurred, enabling the cyclists to generate a constant workload of 250W with lower net hip, knee and ankle joint torques. In addition to being mechanically more efficient, the combination of steeper STA and aerobars reduces form drag and the net energy requirements to complete the cycling leg of the triathlon (Gnehm et al., 1997; Hausswirth et al., 2001; Heil, 2001; 2002).

Power production in cycling depends upon the force applied to the pedals and the pedal rate. The amplitude of the EMG signal is related to the intensity of cycling (Farina et al., 2004). When cycling at higher power levels the EMG amplitude increases as fast twitch motor units are recruited to increase pedal forces (Farina et al., 2004). In contrast, when power is held constant, a reduction in EMG amplitude represents improved efficiency (MacIntosh et al., 2000). It has been proposed that increasing hip joint angle by increasing seat tube angle, changes the working length of the muscles crossing the hip, which may change force-producing capabilities of these muscles (Hunter et al., 2003; Savelberg et al., 2003). It is possible that the reduction in biceps femoris activation for the 82° seat tube angle is due in part to alterations in the muscles force-velocity relationship. Two joint muscles, like the biceps femoris, are more efficient than mono-articular joint muscles in transferring power from proximal to distal segments (Jacobs et al., 1996; Savelberg et al., 2003; van Ingen Schenau et al., 1992). Thus, power can be generated with lower levels of muscular activation (Heil et al., 1995), which may minimize energy expenditure for a given power output in cycling (Hunter et al., 2003).

CONCLUSIONS

Triathletes often lose valuable time in the early portion of the run phase due to the adverse affects of prior cycling upon running. After cycling, triathletes often appear to run in a squat-like position, as though they were still seated on the bicycle. The results of this study suggested that utilizing a bike with a steeper seat tube angle might reduce the deleterious effects of cycling upon running. The steeper seat tube angle enabled cyclists to maintain power production despite lower levels of muscular activation. In particular, the two joint biceps femoris muscle was significantly lower when riding at the steeper seat tube angle. Reduced fatigue of the biceps femoris muscle may enable the triathletes to run in a more upright position and use a longer stride length during the run phase of the triathlon.

REFERENCES

Bar-Or, O. (1987) The Wingate anaerobic test. An update on methodology, reliability and validity. *Sports Medicine* **4**, 381-394.

Bentley, D.J., Millet, G.P., Vleck, V.E. and McNaughton, L.R. (2002) Specific aspects of contemporary triathlon: implications for physiological analysis and performance. *Sports Medicine* **32**, 345-359.

Bentley, D.J., Wilson, G.J., Davie, A.J. and Zhou, S. (1998) Correlations between peak power output, muscular strength and cycle time trial performance in triathletes. *Journal of Sports Medicine Physical Fitness* **38**, 201-207.

Brown, D.A., Kautz, S.A. and Dairaghi, C.A. (1996) Muscle activity patterns altered during pedaling at different body orientations. *Journal of Biomechanics* **29**, 1349-1356.

Browning, R.C., Gregor, R.J. Broker, J.P. (1992) Lower extremity kinetics in elite athletes in aerodynamic cycling positions. *Medicine Science in Sports and Exercise* **24**, S186.

Burke, E.R. (1994) Proper fit of the bicycle. *Clinics in Sports Medicine* **13**, 1-14.

Coyle, E.F., Feltner, M.E., Kautz, S.A., Hamilton, M.T., Montain, S.J., Baylor, A.M., Abraham, L.D. and Petrek, G.W. (1991) Physiological and biomechanical factors associated with elite endurance cycling performance. *Medicine in Science and Sports Exercise* **23**, 93-107.

Creer, A.R., Ricard, M.D., Conlee, R. ., Hoyt, G.L. and Parcell, A. C. (2004) Neural, metabolic, and performance adaptations to four weeks of high intensity sprint-interval training in trained cyclists. *International Journal of Sports Medicine* *25*, 92-98.

Ericson, M.O., Nisell, R., Arborelius, U.P. and Ekholm, J. (1985) Muscular activity during ergometer cycling. *Scandavian Journal of Rehabilitation and Medicine* **17**, 53-61.

Farina, D., Macaluso, A., Ferguson, R.A. and De Vito, G. (2004) Effect of power, pedal rate, and force on average muscle fiber conduction velocity during cycling. *Journal of Applied Physiology* **97**, 2035-2041.

Garside, I. and Doran, D.A. (2000) Effects of bicycle frame ergonomics on triathlon 10-km running performance. *Journal of Sports Science* **18**, 825-833.

Gnehm, P., Reichenbach, S., Altpeter, E., Widmer, H. and Hoppeler, H. (1997) Influence of different racing positions on metabolic cost in elite cyclists. *Medicine in Science and Sports Exercise* **29**, 818-823.

Hausswirth, C., Vallier, J., Lehenaff, D., Brisswalter, J., Smith, D., Millet, G. and Dreano, P. (2001) Effect of two drafting modalities in cycling on running performance. *Medicine in Science and Sports Exercise* **33**, 485-492.

Heiden, T. and Burnett, A. (2003) The effect of cycling on muscle activation in the running leg of an Olympic distance triathlon. *Sports Biomechanics* **2**, 35-49.

Heil, D.P. (2001) Body mass scaling of projected frontal area in competitive cyclists. *European Journal of Applied Physiology* **85**, 358-366.

Heil, D.P. (2002) Body mass scaling of frontal area in competitive cyclists not using aero-handlebars. *European Journal of Applied Physiology* **87**, 520-528.

Heil, D.P., Derrick, T.R. and Whittlesey, S. (1997) The relationship between preferred and optimal positioning during submaximal cycle ergometry. *European Journal of Applied Physiology and Occupational Physiology* **75**, 160-165.

Heil, D.P., Wilcox, A.R. and Quinn, C.M. (1995) Cardiorespiratory responses to seat-tube angle variation during steady-state cycling. *Medicine in Science and Sports Exercise* **27**, 730-735.

Hill, D.W. (2004) The relationship between power and time to fatigue in cycle ergometer exercise. *International Journal of Sports Medicine* **25**, 357-361.

Hunter, A.M., St Clair Gibson, A., Lambert, M. and Noakes, T.D. (2002) Electromyographic (EMG) normalization method for cycle fatigue protocols. *Medicine in Science and Sports Exercise* **34**, 857-861.

Hunter, A.M., St Clair Gibson, A., Lambert, M.I., Nobbs, L. and Noakes, T.D. (2003) Effects of supramaximal exercise on the electromyographic signal. *British Journal of Sports Medicine* **37**, 296-299.

Jacobs, R., Bobbert, M.F. and van Ingen Schenau, G.J. (1996) Mechanical output from individual muscles during explosive leg extensions: The role of biarticular muscles. *Journal of Biomechanics* **29**, 513-523.

MacIntosh, B.R., Neptune, R.R. and Horton, J.F. (2000) Cadence, power, and muscle activation in cycle ergometry. *Medicine in Science and Sports Exercise* **32**, 1281-1287.

McGraw, K.O. and Wong, S.P. (1996) Forming inferences about some intraclass correlation coefficients. *Psychological Methods* **1**, 30-46.

Millet, G.P., Millet, G.Y. and Candau, R.B. (2001) Duration and seriousness of running mechanics alterations after maximal cycling in triathletes. Influence of the performance level. *Journal of Sports Medicine and Physical Fitness* **41**, 147-153.

Price, D. and Donne, B. (1997) Effect of variation in seat tube angle at different seat heights on submaximal cycling performance in man. *Journal of Sports Science* **15**, 395-402.

Reiser, R.F., 2nd, Peterson, M.L. and Broker, J.P. (2002) Influence of hip orientation on Wingate power output and cycling technique. *Journal of Strength and Conditioning Research* **16**, 556-560.

Savelberg, H., Van de Port, I. and Willems, P. (2003) Body configuration in cycling affects muscle recruitment and movement pattern. *Journal of Applied Biomechanics* **19**, 310-324.

Tan, F.H. and Aziz, A.R. (2005) Cycling time trials and their performance correlates with peak power output in moderately trained cyclists. *Journal of Sports Science and Medicine* **4**, 278-284.

Tanaka, H., Bassett, D.R.Jr., Swensen, T.C. and Sampedro, R.M. (1993) Aerobic and anaerobic power characteristics of competitive cyclists in the United States Cycling Federation. *International Journal of Sports Medicine* **14**, 334-338.

Tew, G.A. (2005) The effect of cycling cadence on subsequent 10 km running performance in well-trained triathletes. *Journal of Sports Science and Medicine* **4**, 342-353.

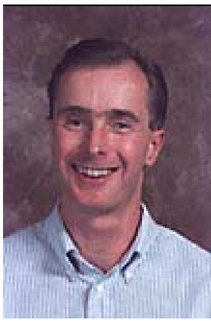
van Ingen Schenau, G.J., Boots, P.J., de Groot, G., Snackers, R.J. and van Woensel, W.W. (1992) The constrained control of force and position in multi-joint movements. *Neuroscience* **46**, 197-207.

Vandewalle, H., Maton, B., Le Bozec, S. and Guerenbourg, G. (1991) An elecromyographic study of an all-out exercise on a cycle ergometer. *International Archives of Physiology Biochemistry* **99**, 89-93.

KEY POINTS

- Road cyclists claim that bicycle seat tube angles between 72° and 76° are most effective for optimal performance in racing.
- Triathletes typically use seat tube angles greater than 76°. It is thought that a seat tube angle greater than 76° facilitates a smoother bike to run transition in the triathlon.
- Increasing the seat tube angle from 72° to 82° enabled triathletes' to maintain power production, while significantly reducing the muscular activation of the biceps femoris muscle.
- Reduced hamstring muscular activation in the triathlon frame (82° seat tube angle) may serve to reduce hamstring tightness following the bike phase of the triathlon, allowing the runner to use a longer stride length.

AUTHORS BIOGRAPHY



Mark D. RICARD
Employment
Assoc. Prof., Department of Kinesiology, University of Texas at Arlington, USA.
Degree
PhD
Research interest
EMG force/fatigue relationships, sport biomechanics, mechanics of injury.
E-mail: Ricard@uta.edu

Patrick HILLS-MEYER
Employment
Mercy Sports Medicine & Rehabilitation Center
Degrees
ATC, MA
Research interests
Athletic injury rehabilitation, cycling performance.
E-mail:
phillsmeyeratc@yahoo.com

Michael G. MILLER
Employment
Assoc. Prof., HPER Department, Western Michigan Univ., USA
Degrees
ATC, PhD
Research interest
Aquatic Plyometrics, bicycling performance, electrical modalities
E-mail:
michael.g.miller@wmich.edu

Timothy J. MICHAEL
Employment
Assoc. Prof., HPER Department, Western Michigan Univ., USA
Degree
PhD
Research interest
Sport performance and nutrition, Pediatric exercise science, clinical aspects of exercise, perception of exertion.
E-mail: tim.michael@wmich.edu

✉ **Mark Ricard**
Exercise Science Research Lab, Depart. of Kinesiology, P.O. Box 19259, University of Texas at Arlington, 801 Greek Row Drive, Arlington, TX 76019, USA.