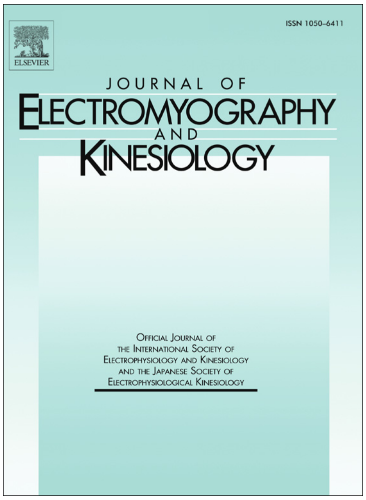

Prolonged cycling alters stride time variability and kinematics of a post-cycle transition run in triathletes

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INTRODUCTION

Triathlon is a multi-discipline sport that comprises swimming, cycling and running consecutively, with a transition between each of these activities. The cycle to run transition is of particular importance in triathlon because running performance is highly correlated with overall triathlon finishing position [Frohlich et al., 2008]. Accordingly, running-specific kinematics and muscle activation patterns which are unaffected by previous cycling activity are likely to improve transition run and triathlon performance [Chapman et al., 2008].

From a biomechanical perspective, the cycle to run transition is challenging because triathletes must successfully negotiate a change in the dominant type of loading, the type of muscle contraction, and a change in lower limb range of motion (ROM); cycling is a non-weight bearing activity, principally requires concentric muscle contractions and relatively smaller ROM, whereas running is load-bearing, requires the leg muscles to perform substantial eccentric work, and requires larger ROM [Heiden and Burnett, 2003]. From a research perspective, studies have investigated the effects of cycling on the kinematics of transition running in order to precisely identify the affected features [Chapman et al., 2008; Gottschall and Palmer, 2000; Vercruyssen et al., 2002]. Several studies have investigated the effects of cycling on the running stride with varied results. Some have reported shorter running strides after cycling [Gottschall and Palmer, 2000; Hausswirth and Lehenaff, 2001], while others have seen no changes [Hue et al., 1998]. However, given the inherent differences in ROM involved in cycling and running, it is perhaps surprising that few studies have investigated the effect of cycling on lower-limb ROM in a transition run. The effect of cycling on muscle activation during a subsequent transition run has also been disputed [Bonacci et al., 2011; Chapman et al., 2008]. One study reported that after just 20 minutes of cycling some triathletes exhibited altered tibialis anterior (TA) muscle activation in a transition run [Chapman et al., 2008], though this effect was observed in only 5 out of 14 triathletes, and reasons to differentiate responders from non-responders are not known.

One potential reason why studies have failed to observe consistent results concerns the duration of the cycling protocol. Previous studies have generally employed cycling protocols of 1hour or less [Chapman et al., 2008; Gottschall and Palmer, 2000] which is consistent with Olympic distance triathlons which include 40km of cycling. However, longer distance triathlons are increasingly popular with cycling distances of 90 to 180km, resulting in a cycling time of 3 to 7 hours. In addition, experienced recreational triathletes are adapted to cycling because they cycle for approximately 5.8 hours per week or 48% of the total training time [Andersen et al., 2013], which would likely comprise acute bouts which are longer than 1 hour. We posit that an acute bout of prolonged cycling will stimulate measurable neuromuscular and kinematic responses in a subsequent transition run in experienced triathletes. However, no studies have investigated the effect of prolonged cycling on muscle activation and kinematics in a transition run.

Activities that stimulate a fatigue response tend to lead to pronounced changes in movement and increased movement variability [Barbieri et al., 2013]. Measures of movement variability are considered to provide a general assessment of the integrity of the motor system. Movement variability has been evaluated in running and walking using stride time variability (STV), where increased variability is associated with problems in locomotor control [Hausdorff, 2009; Jordan and Newell, 2008; Padulo et al., 2012]. Indeed, the perception of impaired locomotor control in the lower limbs in the first kilometre of the transition run is one reported effect of the cycle to run transition [Heiden and Burnett, 2003]. However, no previous studies have established the effect of prolonged cycling on STV in a transition run.

The aim of this study was to investigate the effect of 3 hours of cycling on STV, stride length, lower limb ROM, and TA muscle activation in a post-cycle transition run in triathletes. We hypothesised that triathletes who completed a 3 hour cycling protocol would show significantly greater STV and TA muscle activation, and would employ shorter strides with reduced lower limb ROM at the beginning of a post-cycle transition run compared to a control run.

METHODS

Participants

Participants were eight trained triathletes with a minimum of four years triathlon experience, currently training at least three days per week, free of injury, and accustomed to treadmill running. Participants mean (± SD) age (yrs.), height (cm) and weight (kg) were 41.9 (± 6.0), 177 (± 8.5), 76.2 (± 4.5) respectively. Although a mean age of 41.9 years is higher than the typical age of participants in other sport science research, there are two features of Ironman triathlon which indicate that our sample is representative of the majority of recreational trained triathletes competing in Ironman triathlon. Firstly, an analysis of Ironman participation revealed that the 40-44 age category provides the greatest individual contribution to male Ironman finishers [Stiefel et al., 2013]. Secondly, peak Ironman triathlon performance occurs at 33-34 years which is up to 10 years later compared to the average age of peak performance in other sports such as sprinting [Rust et al., 2012; Schulz and Curnow, 1988]. The study was approved by the university ethics committee. All participants gave written informed consent and were fully informed of the purposes and procedures for this study.

Procedures

Participants visited the laboratory on three occasions each separated by at least 72 hours. Visits 1 and 2 consisted of randomly assigned maximal aerobic tests for running and cycling on a treadmill (h/p Cosmos Mercury, Sports & Medical GMBH, Nussdorf-Traunstein, Germany) and cycle ergometer (Lode Excalibur, Groningen, Netherlands). During visit 3 a run-cycle-run test designed to encourage fatigue in participants and simulate the constraints of a long distance triathlon was performed. After a warm-up, the protocol consisted of a 30 minute pre-cycle run at 70% of maximal aerobic speed (Vpeak), 3 hours of cycling at 55% of maximal aerobic power (Wpeak), and a 10 minute post-cycle run at 70% Vpeak.

Maximal incremental cycle test

All participants completed an incremental cycle test to volitional exhaustion to determine VO_2 peak during cycling and power output at VO_2 peak (Wpeak). Prior to starting, height and body mass were recorded. Participants started cycling at 95W for 3 minutes followed by incremental steps of 35W every 3 min until volitional exhaustion. Wpeak was determined by the formula: $Wpeak = Wout + [(t/180)\cdot 35]$, where Wout is the power output (Watts) during the last completed stage, and t is the time (s) in the final stage [Wallis et al., 2005]. Expired gases were collected using the Douglas bag method for the last minute at each workload [Connick and Li, 2014]. The Douglas bag yielding the highest VO_2 data was deemed as having the VO_2 peak values. Wpeak was used to calculate the 55%Wpeak workload, which was later employed in the run-cycle-run test.

Maximal incremental run test

All participants completed an incremental run test to volitional exhaustion to determine VO_2 peak during running and velocity at VO_2 peak (Vpeak). Prior to starting, height and body mass were recorded. Participants completed a 10-minute warm up at self-selected pace prior to the test to ensure they were accustomed to the treadmill (h/p/cosmos, Sports & Medical GMBH, Germany). Participants started at a running velocity of 10km/h for 3 minutes. This was followed by incremental steps of 1 km/h every 3 minutes until volitional exhaustion. Vpeak was determined by the formula Vpeak = Vout + (t/180), where Vout is the running velocity during the last completed stage, and t is the time (s) in the final stage. Expired gases were collected using the Douglas bag method for the last minute at each workload. The Douglas bag yielding the highest VO_2 data was deemed as having the VO_2 peak values. Vpeak was used to calculate the 70% Vpeak workload, which was later employed in the run-cycle-run test.

Run-Cycle-Run Test

Three-dimensional data were captured using a calibrated Vicon MX motion analysis system (Oxford Metrics Ltd., Oxford, England) with 13 cameras operating at a sampling rate of 250Hz, and collected as previously described [Schache et al., 2000]. Retro-reflective markers were attached with double-sided adhesive tape by the same tester to limit inter-tester variability over the greater trochanter, the lateral femoral condyle, the lateral malleolus, the base of the calcaneus, the head of the fifth metatarsal, and the hallux of the right lower limb and foot, and bilaterally on both ASIS and PSIS. Four additional reflective markers were placed superior to the heel counter of the right running shoe, tibial tuberosity and halfway along the lateral and frontal aspects of the thigh. The foot was defined as the vector from the head of the fifth metatarsal to the heel. The shank was defined as the vector from the lateral malleolus and the lateral epicondyle, and the thigh was defined as the vector from the lateral epicondyle to the greater trochanter. The pelvis was defined as the vector from the mid-ASIS to the mid PSIS. Joint angles were defined as shown in Figure 1. Stride length was the distance travelled from right foot contact to ipsilateral foot contact. Foot contacts were calculated based on a previous algorithm [O'Connor et al., 2007] which used heel and toe markers to identify features of the velocity of the foot which correspond to heel strike and toe off. The algorithm produced reliable stride pattern data (ICC (95% CI) = 0.93 (0.76-0.98) [Connick and Li, 2014].

Single differential electrodes (DE-2.3, Delsys Inc., Boston, MA) were placed on the skin longitudinally over the belly of TA of the right leg, parallel with the muscle fibres [Ferris et al., 2001] to record muscle activation patterns. Electrodes were polycarbonate and rectangular in shape (41mm x 20mm x 5mm) and the contact sensors were 10mm x 1mm in size with 10mm spacing and constructed of 99.9% Ag. Input impedance was >1015Ω //0.2pF and Common Mode Rejection Ratio -92 dB. The skin at the site of each electrode site was shaved, abraded and cleaned. Muscle activity data capture was synchronised with the kinematic data and recorded using a Delsys Myomonitor III EMG system (Delsys Inc., Boston, MA) at a sampling rate of 1000Hz.

To ensure participants were accustomed to the treadmill, participants ran for 8 minutes at 70% of Vpeak. After the warm-up, participants completed a pre-cycle run of 22 minutes at 70% Vpeak. Muscle activation and 3D-kinematics data were recorded for 30 seconds between 1-1.5 minutes (PRE-1) before participants drank an initial 600ml bolus of water. After 13 minutes of running, muscle activation and 3D-kinematics data were recorded again for 30 seconds (PRE-2). After the control run, participants rapidly changed into their cycling shoes and pedalled for 3 hours at 55% Wpeak using a self-selected cadence throughout. Finally, participants rapidly changed back into running shoes and completed the post-cycle run at 70% of Vpeak for 10 minutes. Muscle activation and kinematics were recorded for 30 seconds between 1-1.5 minutes (POST-1) and 9-9.5 minutes (POST-2). Water was provided ad libitum during the protocol.

Post-processing

Muscle activity data were band-pass filtered with cut-off frequencies of 20Hz and 450Hz, full-wave rectified, and further low-pass filtered using a fourth-order Butterworth low-pass filter with a 10Hz cut off frequency to create a linear envelope [Ferris et al., 2001]. The data were divided into gait cycles using foot contacts to determine a mean linear envelope. In order to measure TA muscle activation, the mean amplitude value (MAV) was calculated for each trial by integrating the linear envelope over the gait cycle [Bressel et al., 2001]. The MAVs for PRE-2, POST-1 and POST-2 were normalised to the first data collection (PRE-1 MAV).

Kinematic data were low-pass filtered using a fourth-order Butterworth filter with a cut off frequency of 12Hz [Lamb et al., 2011; Nigg et al., 2012]. Ensemble-average joint angles were obtained by dividing data into individual gait cycles (0-100%) using foot contacts. STV was calculated as the coefficient of variation (CV) of stride time at each time point.

Statistical Analyses

Normal distribution of data was confirmed using the Shapiro-Wilk test. Repeated measures ANOVA were employed to test for effects on TA muscle activation, STV, stride length, and ankle, knee and hip ROM. Post-hoc t-tests, with appropriate Dunn-Sidak corrections, were employed to determine significant differences between time points [Gallagher et al., 2011; Sokal and Rohlf, 2000]. Effect sizes were measured using Cohen's d which standardises the difference between the means by the common within-population standard deviation[Cohen, 1992]. Effect sizes were interpreted as follows: 0.80 was a large effect size, 0.50 was a medium effect size, and 0.20 was a small effect size[Cohen, 1988]. Statistical analyses were performed using SPSS V.20 (IBM Corporation, Somers, NY) with significance alpha levels set to p=0.05.

Results

Results of the maximal incremental run and cycle tests are presented in Table 1. ANOVA results showed a significant time effect on stride variability [F(3,21)=3.604, p=.03, $\eta_\rho^2 = .34$], stride length [F(3,21)=3.127, p=.047, $\eta_\rho^2 = .31$], ankle ROM [F(3,21)=4.019, p=.021, $\eta_\rho^2 =$ .37] and hip ROM [F(3,21)=3.633, p=.03, $\eta_\rho^2 = .34$].

There were no significant differences between PRE-1 and PRE-2 for any variable. STV significantly increased from 0.89% (±0.33) to 1.29% (±0.41) (d = 0.95), a change of 45%, between PRE-2 and POST-1 (Figure 2A) (p<0.05). Stride length significantly decreased from 2.22m (±0.25) to 2.18m (±0.26) (d = 0.15) between PRE-2 and POST-1 (p<0.05), a change of 1.8% (Figure 3A). By the end of the transition run (POST-2), STV had decreased (d = 0.90) and stride length increased (d = 0.09) compared to POST-1 toward pre-cycling levels but these changes were not significant. Ankle (d = 0.40) (Figure 3B) and hip ROM (d = 0.41) (Figure 3D) significantly increased from POST-1 to POST-2 (p<0.05).

The effect of prolonged cycling on knee ROM [F(3,21)=1.287, p=.305, $\eta_p^2 = .16$] (Figure 3C) and TA muscle activation [F(3,18)=3.728, p=.079, $\eta_p^2 = .39$] (Figure 2B) was not significant.

Discussion

The aim of this study was to establish the effect of 3 hours of cycling on STV, stride length, lower limb ROM and TA muscle activation in a post-cycle transition run. The main results were that, compared to a control run, the triathletes exhibited significantly greater STV and ran with shorter strides at the beginning of the transition run. However, we detected no significant effect of cycling on lower limb ROM and TA activation at the beginning of the transition run. After 10 minutes of transition running triathletes exhibited significantly increased ankle and hip ROM compared to the beginning of the transition run indicating the immediate effect of cycling was transient. Generally, these results agree with previous studies which have shown that short duration cycling alters movement patterns but has little effect on muscle recruitment in transition running [Bonacci et al., 2010].

The cycle to run transition is often characterised by a perception of impaired locomotor control in the lower limbs [Heiden and Burnett, 2003], and previous gait studies have associated poor locomotor control with high stride-to-stride variability [Hausdorff, 2009]. The pre-cycle STV values in the current study were consistent with STV from previous studies in healthy runners [Belli et al., 1995; Nakayama et al., 2010]. However, our results showed that an acute three hour bout of cycling was associated with a 45% increase in STV from the pre-cycle run to the transition run. According to Cohen's d this was a large effect size and the highest effect size observed in the current study representing an increase in the mean of almost one standard deviation. Increased STV is associated with muscle fatigue, which is mediated by a disruption to neuromuscular control, and is a factor associated with increased risk of injury [Barbieri et al., 2013; Heiderscheit et al., 2011; Helbostad et al., 2007]. Therefore, perhaps the most important practical implication of this study is that STV can potentially be used as a non-invasive measure to evaluate the impact of cycling training interventions on the integrity of the locomotor control system in a transition run, and further studies are warranted to investigate the validity of this specific application of STV.

Our data cannot identify causality between transition running STV and cycling. However, previous studies have suggested that in a transition run the neuromuscular system is unable to quickly adapt to the change in neural firing rate from cycling, and instead the firing pattern established during the cycling stage is maintained [Gottschall and Palmer, 2000]. This type of inappropriate and involuntary maintenance of a prior activity is called perseveration and, in the context of cyclical activities, offers a coherent explanation for the increased STV found in this study [Gottschall and Palmer, 2000]. Compared to experienced distance runners, non-runners exhibit significantly greater STV indicating that specialised distance running stabilises the stride (i.e. minimises STV) as a by-product of task-related optimisation [Nakayama et al., 2010]. Consequently, stride time variability is likely to be a trainable feature of transition running and in support of this hypothesis studies suggest that, compared with their novice counterparts, elite triathletes are more resistant to loss of coordination and physiological changes at the beginning of the transition run [Millet et al., 2000; Millet and Vleck, 2000].

The finding that our sample of triathletes took shorter strides at the beginning of the transition run concurs with previous research [Gottschall and Palmer, 2000; Hausswirth and Brisswalter, 2008]. In addition to studies which have indicated that runners select a stride pattern which is close to the most economical [Cavanagh and Williams, 1982], more recent research suggests that runners are capable of adjusting the stride pattern toward more favourable outcomes [Connick and Li, 2014; Hunter and Smith, 2007]. For example, relatively small adjustments toward shorter running strides (<2.9%) are associated with improved running economy in healthy runners [Connick and Li, 2014], and fatigued runners adjust their stride pattern in order to maintain an economical stride [Hunter and Smith, 2007]. Therefore the small effect on stride length observed in the current study (1.8%) indicates that the stride was most likely adjusted in order to maintain a stride pattern which was close to the most economical at the beginning of the transition run.

We investigated the effect of cycling on TA activation because TA is an important muscle in running - TA acts to dorsiflex the foot, helps to regulate force at the leg, and controls ankle joint position [Chapman et al., 2008]. However, while significant findings were observed in stride time variability and stride length, an effect of 3 hours of cycling on TA activation was absent which is consistent with the results of previous studies which investigated the effect of short duration (15 to 20 minutes) cycling on TA activation [Bonacci et al., 2010; Chapman et al., 2008]. Although a significant effect was not observed, there was greater variation in TA activation at the beginning of the transition run compared to the pre-cycling run (Figure 2B), and this provides support to the theory that some triathletes exhibited a greater TA neuromuscular response in a transition run compared with others [Chapman et al., 2008].

Although the use of a treadmill in gait and running research is commonplace, there are some methodological limitations that should be considered when interpreting data derived from running on a treadmill. Firstly there should be a degree of caution when generalising treadmill data to overground running [Bonacci et al., 2011]. However, there are studies suggesting that treadmill running can be generalised to overground running providing the treadmill is well maintained [Riley et al., 2008]. Secondly, the protocol required a controlling running velocity pre and post-cycling because kinematics and muscle recruitment change with running speed [Bonacci et al., 2011]. Consequently, caution should be exercised when generalising the results to race situations where triathletes adopt a variety of speeds

[Hausswirth et al., 2010]. Further investigations are needed to establish if stride time variability increases in overground transition running which simulate race conditions.

In conclusion, the main result of the current study showed that after 3 hours of cycling, triathletes exhibited greater stride time variability and shorter strides at the beginning of a post cycle transition run. These results indicate that locomotor control and kinematics of a transition run are affected by prolonged cycling, and stride time variability might offer a non-invasive method of assessing the immediate impact of prolonged cycling on the locomotor control of running. Future studies are warranted to evaluate the validity of using stride time variability for this purpose, and to establish if altered stride time variability and stride length affect performance in overground transition running.

Conflict of interest

The authors have no conflicts of interest.

References

Andersen CA, Clarsen B, Johansen TV, Engebretsen L. High prevalence of overuse injury among iron-distance triathletes. Br J Sports Med. 2013;47:857-61.

Barbieri FA, Lee YJ, Gobbi LT, Pijnappels M, Van DJH. The effect of muscle fatigue on the last stride before stepping down a curb. Gait & posture. 2013;37:542-6.

Belli A, Lacour JR, Komi PV, Candau R, Denis C. Mechanical step variability during treadmill running. Eur J Appl Physiol Occup Physiol. 1995;70:510-7.

Bonacci J, Blanch P, Chapman AR, Vicenzino B. Altered movement patterns but not muscle recruitment in moderately trained triathletes during running after cycling. J Sports Sci. 2010;28:1477-87.

Bonacci J, Saunders PU, Alexander M, Blanch P, Vicenzino B. Neuromuscular control and running economy is preserved in elite international triathletes after cycling. Sports Biomech. 2011;10:59-71.

Bressel E, Bressel M, Marquez M, Heise GD. The effect of handgrip position on upper extremity neuromuscular responses to arm cranking exercise. J Electromyogr Kinesiol. 2001;11:291-8.

Cavanagh PR, Williams KR. The effect of stride length variation on oxygen uptake during distance running. Medicine and science in sports and exercise. 1982;14:30-5.

Chapman AR, Vicenzino B, Blanch P, Dowlan S, Hodges PW. Does cycling effect motor coordination of the leg during running in elite triathletes? J Sci Med Sport. 2008;11:371-80.

Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2nd ed. Erlbaum, Hillsdale, NJ: Psychology Press; 1988.

Cohen J. Statistical Power Analysis. Current Directions in Psychological Science. 1992;1:98-101.

Connick MJ, Li FX. Changes in timing of muscle contractions and running economy with altered stride pattern during running. Gait & posture. 2014;39:634-7.

Ferris DP, Aagaard P, Simonsen EB, Farley CT, Dyhre-Poulsen P. Soleus H-reflex gain in humans walking and running under simulated reduced gravity. J Physiol. 2001;530:167-80.

Frohlich M, Klein M, Pieter A, Emrich E, Gießing J. Consequences of the three disciplines on the overall result in Olympic-distance triathlon. International Journal of Sports Science and Engineering. 2008;2:204-10.

Gallagher S, Pollard J, Porter WL. Locomotion in restricted space: kinematic and electromyographic analysis of stoopwalking and crawling. Gait & posture. 2011;33:71-6.

Gottschall JS, Palmer BM. Acute effects of cycling on running step length and step frequency. Journal of Strength and Conditioning Research. 2000;14:97-101.

Hausdorff JM. Gait dynamics in Parkinson's disease: common and distinct behavior among stride length, gait variability, and fractal-like scaling. Chaos. 2009;19:026113.

Hausswirth C, Brisswalter J. Strategies for improving performance in long duration events: Olympic distance triathlon. Sports Med. 2008;38:881-91.

Hausswirth C, Le Meur Y, Bieuzen F, Brisswalter J, Bernard T. Pacing strategy during the initial phase of the run in triathlon: influence on overall performance. Eur J Appl Physiol. 2010;108:1115-23.

Hausswirth C, Lehenaff D. Physiological demands of running during long distance runs and triathlons. Sports Med. 2001;31:679-89.

Heiden T, Burnett A. The effect of cycling on muscle activation in the running leg of an Olympic distance triathlon. Sports Biomech. 2003;2:35-49.

Heiderscheit BC, Chumanov ES, Michalski MP, Wille CM, Ryan MB. Effects of step rate manipulation on joint mechanics during running. Medicine and science in sports and exercise. 2011;43:296-302.

Helbostad JL, Leirfall S, Moe-Nilssen R, Sletvold O. Physical fatigue affects gait characteristics in older persons. J Gerontol A Biol Sci Med Sci. 2007;62:1010-5.

Hue O, Le GD, Chollet D, Boussana A, Prefaut C. The influence of prior cycling on biomechanical and cardiorespiratory response profiles during running in triathletes. Eur J Appl Physiol Occup Physiol. 1998;77:98-105.

Hunter I, Smith GA. Preferred and optimal stride frequency, stiffness and economy: changes with fatigue during a 1-h high-intensity run. Eur J Appl Physiol. 2007;100:653-61.

Jordan K, Newell KM. The structure of variability in human walking and running is speed-dependent. Exerc Sport Sci Rev. 2008;36:200-4.

Lamb PF, Mundermann A, Bartlett RM, Robins A. Visualizing changes in lower body coordination with different types of foot orthoses using self-organizing maps (SOM). Gait & posture. 2011;34:485-9.

Millet GP, Millet GY, Hofmann MD, Candau RB. Alterations in running economy and mechanics after maximal cycling in triathletes: influence of performance level. Int J Sports Med. 2000;21:127-32.

Millet GP, Vleck VE. Physiological and biomechanical adaptations to the cycle to run transition in Olympic triathlon: review and practical recommendations for training. Br J Sports Med. 2000;34:384-90.

Nakayama Y, Kudo K, Ohtsuki T. Variability and fluctuation in running gait cycle of trained runners and non-runners. Gait & posture. 2010;31:331-5.

Nigg BM, Baltich J, Maurer C, Federolf P. Shoe midsole hardness, sex and age effects on lower extremity kinematics during running. J Biomech. 2012;45:1692-7.

O'Connor CM, Thorpe SK, O'Malley MJ, Vaughan CL. Automatic detection of gait events using kinematic data. Gait & posture. 2007;25:469-74.

Padulo J, Di CR, Viggiano D. Pedaling time variability is increased in dropped riding position. Eur J Appl Physiol. 2012;112:3161-5.

Riley PO, Dicharry J, Franz J, Della Croce U, Wilder RP, Kerrigan DC. A kinematics and kinetic comparison of overground and treadmill running. Medicine and science in sports and exercise. 2008;40:1093-100.

Rust CA, Knechtle B, Knechtle P, Rosemann T, Lepers R. Age of peak performance in elite male and female Ironman triathletes competing in Ironman Switzerland, a qualifier for the Ironman world championship, Ironman Hawaii, from 1995 to 2011. Open access journal of sports medicine. 2012;3:175-82.

Schache AG, Blanch PD, Murphy AT. Relation of anterior pelvic tilt during running to clinical and kinematic measures of hip extension. Br J Sports Med. 2000;34:279-83.

Schulz R, Curnow C. Peak performance and age among superathletes: track and field, swimming, baseball, tennis, and golf. Journal of gerontology. 1988;43:P113-20.

Sokal RR, Rohlf FJ. Biometry. Third ed. U.S.A: W. H. Freeman and Company; 2000.

Stiefel M, Rust CA, Rosemann T, Knechtle B. A comparison of participation and performance in age-group finishers competing in and qualifying for Ironman Hawaii. International journal of general medicine. 2013;6:67-77.

Vercruyssen F, Brisswalter J, Hausswirth C, Bernard T, Bernard O, Vallier JM. Influence of cycling cadence on subsequent running performance in triathletes. Medicine and science in sports and exercise. 2002;34:530-6.

Wallis GA, Rowlands DS, Shaw C, Jentjens RL, Jeukendrup AE. Oxidation of combined ingestion of maltodextrins and fructose during exercise. Medicine and science in sports and exercise. 2005;37:426-32.

Table 1. Results of the maximal incremental running and cycling tests. Participants ran at 70% Vpeak and cycled at 55% Wpeak during the run-cycle-run protocol.

Activity	**Variable**	**Mean (± SD)**
Running	VO_2 peak (ml/kg/min)	58.0 (3.6)
	Vpeak (km/h)	16.1 (1.5)
	70% Vpeak (km/h)	11.2 (1.0)
Cycling	VO_2 peak (ml/kg/min)	56.2 (8.4)
	Wpeak (Watts)	332.1 (45.2)
	55% Wpeak (Watts)	182.8 (24.8)

Figure 1. Joint angle definitions. θ_H is hip angle, θ_K is knee angle, θ_A is ankle angle.

Figure 2. Mean (+1 S.D.) stride time variability (A) and TA muscle activation (B) at each time point. PRE-1 and PRE-2 are the first and second time points from the control run. POST-1 and POST-2 are the first and second time points from the transition run. TA muscle activation data were normalised to PRE-1. * indicates a significant difference compared to PRE-2.

Figure 3. Mean (+1 S.D.) stride length (A), Ankle ROM (B), Knee ROM (C), Hip ROM (D) at each time point. PRE-1 and PRE-2 are the first and second time points from the control run. POST-1 and POST-2 are the first and second time points from the transition run. * indicates a significant difference compared to PRE-2. # indicates a significant difference compared to POST-1.

Figure 1 - Joint Angle Definitions

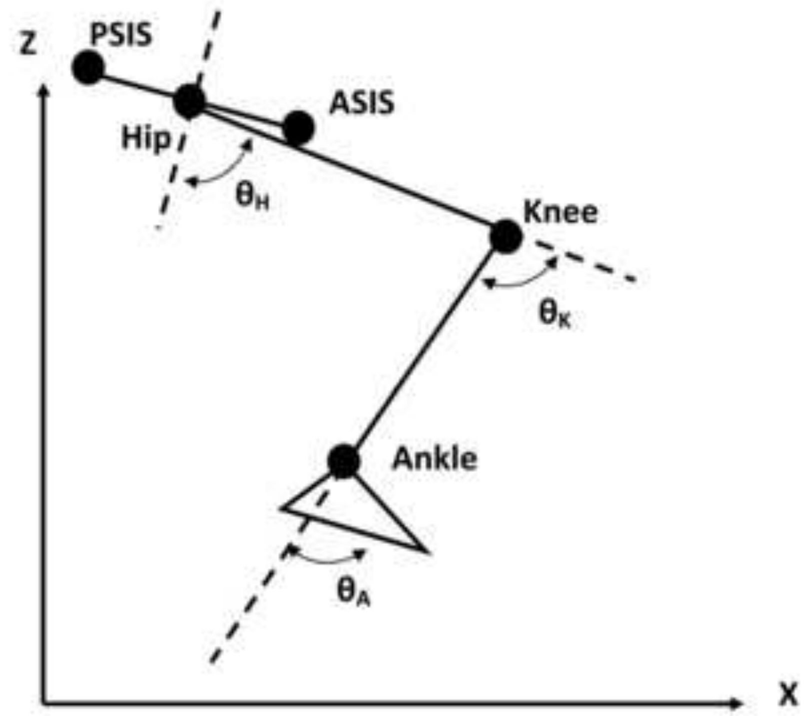


Figure 2

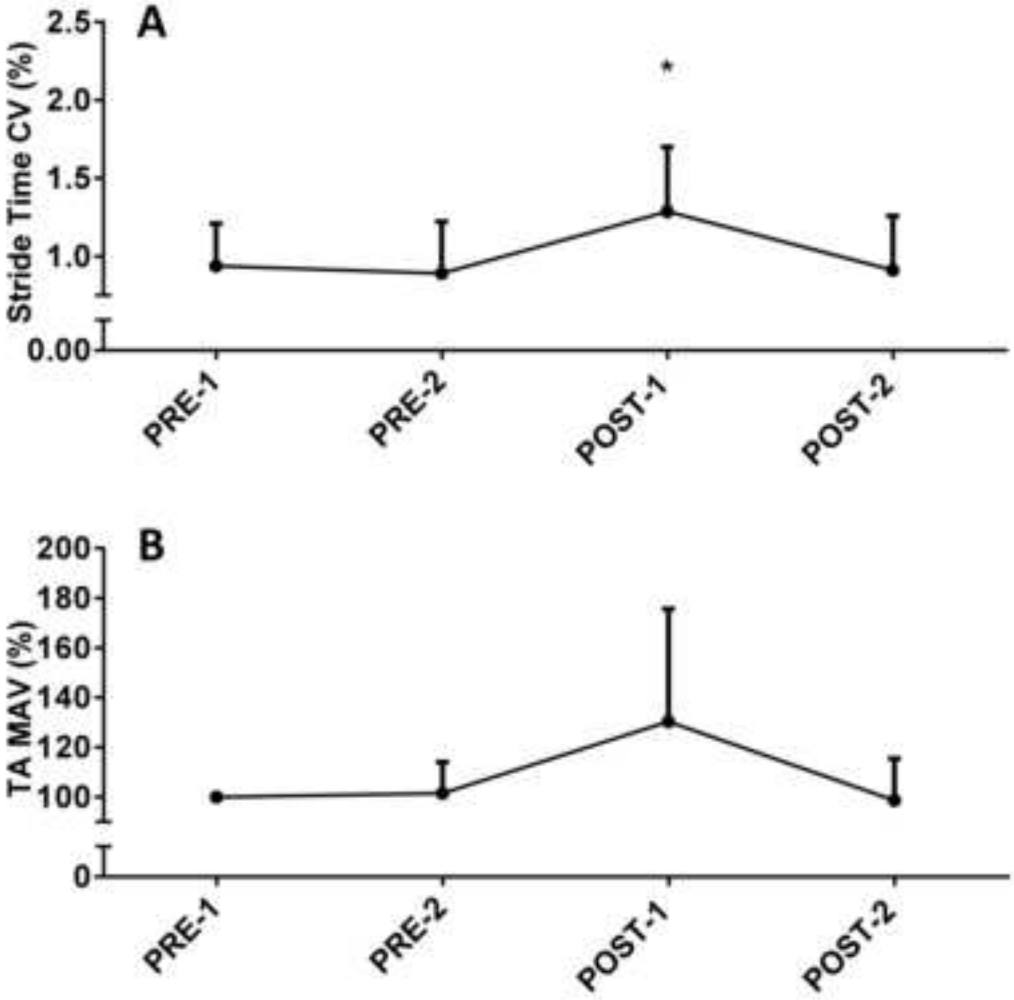
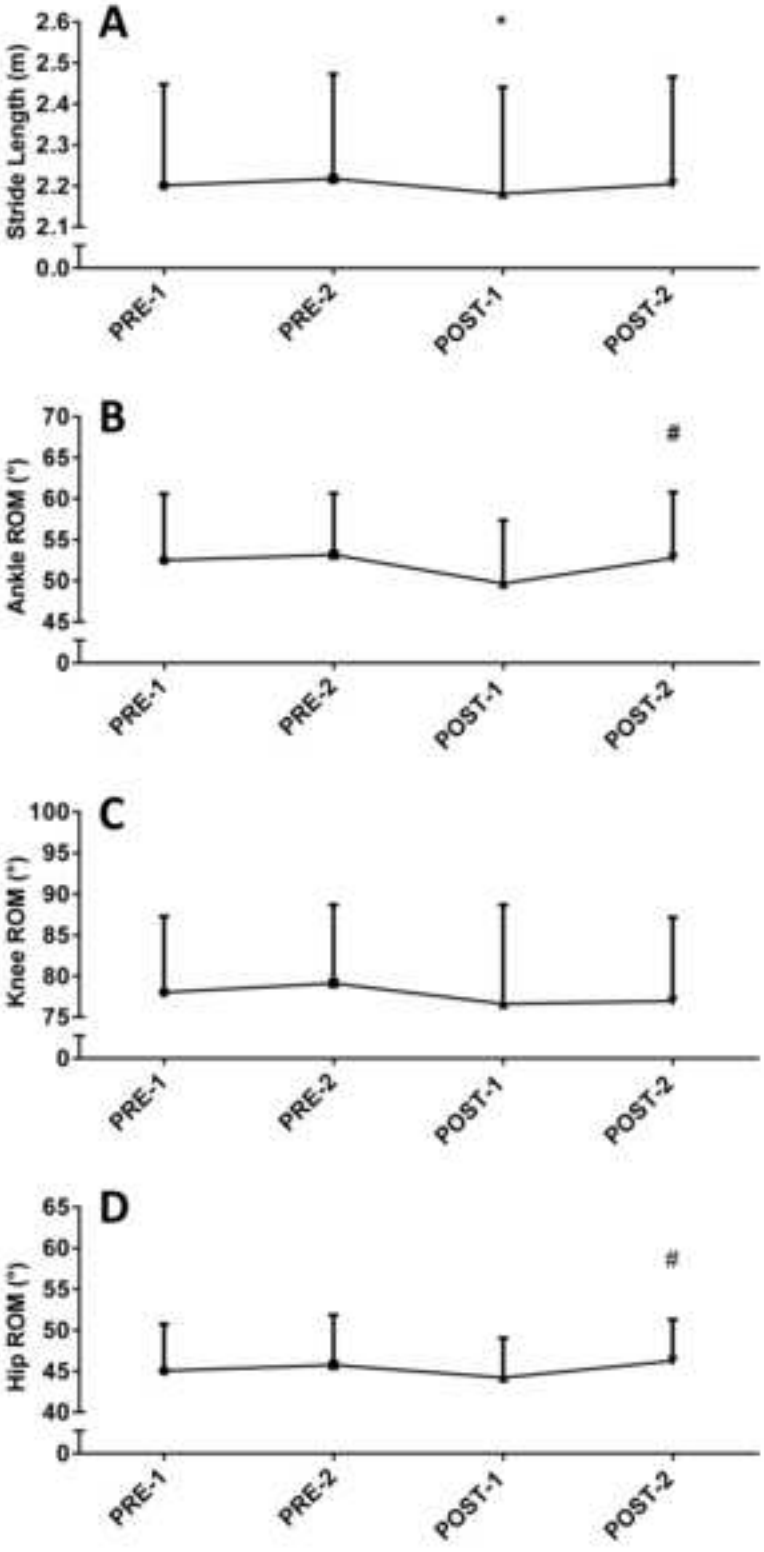

A
Stride Time CV (%)
2.5
2.0
1.5
1.0
0.00
*
PRE-1
PRE-2
POST-1
POST-2
B
TA MAV (%)
200
180
160
140
120
100
0
PRE-1
PRE-2
POST-1
POST-2

Figure 3


A
Stride Length (m)
2.6
2.5
2.4
2.3
2.2
2.1
0.0
*
PRE-1
PRE-2
POST-1
POST-2
B
Ankle ROM (°)
70
65
60
55
50
45
0
#
PRE-1
PRE-2
POST-1
POST-2
C
Knee ROM (°)
100
95
90
85
80
75
0
PRE-1
PRE-2
POST-1
POST-2
D
Hip ROM (°)
65
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Prolonged cycling alters stride time variability and kinematics of a post-cycle transition run in triathletes

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Abstract

Previous studies have employed relatively short cycling protocols to investigate the effect of cycling on muscle activation and kinematics in running. The aim of this study was to investigate the effect of three hours of cycling on stride time variability (STV), stride length, tibialis anterior (TA) activation, and lower limb range of motion (ROM) in a transition run. Eight triathletes completed a run-cycle-run protocol. Data were collected from a pre-cycle run and a transition run after three hours of cycling. STV, stride length and ROM were assessed using three-dimensional motion analysis, and TA activation was recorded using surface electromyography. Results showed that compared with the pre-cycle run triathletes exhibited increased STV (Cohen's $d=0.95$) and shorter strides ($d=0.15$) in the transition run ($p<0.05$). TA activation and ROM did not change. After ten minutes of transition running, ankle and hip ROM significantly increased ($d=0.40$ and 0.41 respectively) compared to the beginning of the transition run ($p<0.05$) but no other changes were observed. The results suggest that locomotor control and kinematics in a transition run are affected by prolonged cycling and stride time variability is potentially a novel method of evaluating the immediate effect of prolonged cycling on the locomotor control of running.

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