THE EFFECT OF PRIOR CYCLING ON LEG STIFFNESS DURING RUNNING IN HIGH PERFORMANCE TRIATHLETES

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The purpose of this study was to investigate the influence cycling has on lower limb stiffness during the run leg in triathletes. Seven well trained triathletes completed a triathlon-run (TR; run preceded by a 40 km cycle) and a control-run (CR; run at the same pace as TR, but without a prior cycle). Vertical, hip, knee and ankle stiffness measured during double leg jumping (2.2 Hz) were compared both before and after the cycle leg and between TR and CR conditions. Maximum hip and knee moments and knee joint stiffness were significantly greater immediately following cycling. However, maximum hip moments and hip joint stiffness were lower in CR than TR. This study provided an insight into how joint stiffness is altered following cycling and may help explain the perceived loss of coordination reported frequently by triathletes at the start of the run leg.

KEY WORDS: joint stiffness, triathlon, running, cycling.

INTRODUCTION: The ability to transition from swimming to cycling and then to running has been recognized as important skills in triathlon (Hue, Le Gallais, Boussana, Chollet, & Prefaut, 1999). Of particular importance is the transition from the cycle to the run as run leg performance is highly correlated with success in Olympic distance triathlon (Vleck, Burgi, & Bentley, 2006). However, triathletes typically report a perceived loss of running coordination as they transfer from the nonweight bearing activity of cycling to the weight-bearing activity of running (Heiden & Burnett, 2003). In laboratory studies, decreased running economy and changes in stride frequency (SF), stride length (SL) and running posture have been observed when running is preceded by cycling (Hausswirth, Bigard, & Guezennec, 1997; Gottschall & Palmer, 2002; Bonacci, et al., 2010). However, the effect of cycling on SF and SL during running remains equivocal, due to reports of SF being increased, decreased, or remaining the same following cycling (Hue, et al., 1999; Millet, Millet, & Candau, 2001; Gottschall & Palmer, 2002).
Limited literature exists on the influence cycling has on the ability of the musculotendinous system to store and utilise elastic energy generated during footstrike. This is surprising as significant interactions have been found between leg stiffness and running economy, stride frequency (SF), stride length (SL), ground contact time and vertical displacement of the centre of mass (COM) (Farley & Gonzalez, 1996; Morin, Samozino, Zameziati, & Belli, 2007; Rabita, Slawinski, Girard, Bignet, & Hausswirth, 2011). Positive relationships have been also found between several of these variables and increased running performance (Kuitunen, Komi, & Kyröläinen, 2002). Surprisingly, the influence of cycling on lower limb stiffness have not been reported in the scientific literature. Accordingly, the purpose of this study was to investigate the influence cycling has on lower limb stiffness during the run leg in triathletes.

METHODS: Seven well trained triathletes including five males (26 ±2.7 y, 75.5 ±1.4 kg, 1.82 ±0.05 m) and two females (26 ±1 y, 59.2 ±5.4 kg, 1.73. ±0.03 m) participated in the study. Athletes completed two testing sessions at similar times of day over consecutive weeks. The triathlon-run (TR) consisted of a 40 km cycle followed by a 3 km run at a pace equal to the participant's best 10 km run performance during a triathlon race. Control-run (CR) consisted of a non-fatigued 3 km run at an identical pace as during TR. Athletes were requested to have completed a similar training load during the five days leading up to both testing sessions. Athletes were free to consume fluids and carbohydrate gels during the cycle leg as per normal racing conditions and the order of testing (i.e. TR then CR, or CR then TR) was

randomised between athletes. All athletes completed the same individual warm-up before each testing session.
The bike leg completed prior to the TR involved the athletes completing a flat 40 km virtual cycle course using their own bike mounted on a magnetically braked cycle ergometer (Velotron Pro cycle ergometer; RacerMate Inc., Seattle, USA). During the cycle leg athletes were encouraged to complete the course at an effort replicative of their racing strategy and were free to self-select pedal cadence and resistance. Heart rate (Forerunner 305; Garmin Inc., Chicago, USA), rating of perceived exertion (Borg scale 6-20) and time per 10 km data was recorded at every 10 km mark during the cycle and participants were able to view course progress and speed in real-time using the ergometer software. At the end of the cycle, athletes were allowed 60 s to change from their cleated cycling shoes into their running shoes, which allowed standardisation between athletes and replicated the demands of cycle-run transitioning in elite triathlon racing (Bonacci, et al., 2010). The 3 km run consisted of three 1 km laps on paved bitumen path. Running speed was controlled using the Pace Alerts function of the global positioning system (GPS) enabled heart rate monitor.
Prior to the cycle, immediately after the cycle 1, 2 and 3 km during both run conditions, lower limb joint stiffness data were collected using standard protocols (Hobara, et al., 2010). This required participants to perform 15 double leg rebounds (frequency 2.2 Hz) on a force platform sampling at 1000 Hz (Bertec Corporation, Columbus, USA). Three-dimensional (3D) kinematic data were captured (500 Hz) using seven infrared cameras (Qualysis AB, Gothenburg, Sweden) to track the coordinates of retro-reflective markers placed over standard lower body landmarks. Ground Reaction Force (GRF) and kinematic data were then modelled in 3D using standard software (Visual3D, C-Motion, Inc., USA) to construct a 6 segment rigid body model of the pelvis and lower limbs. A 2nd order low-pass digital filter (13 Hz) was used to smooth the data prior to it being processed to compute inverse dynamics data for each lower limb segment. Vertical stiffness was calculated as the ratio of the peak vertical GRF to the maximum vertical displacement of the centre of mass (McMahon & Cheng, 1990). Joint stiffness was calculated as the ratio of the change in joint moment to the change in joint angular displacement (Stefanyshyn & Nigg, 1998).
Repeated measure ANOVA was used to compare between condition pre- and post-bike, TR or CR, and distance (1 km, 2 km, and 3 km). Post-hoc analyses were undertaken using paired t-Test with Bonferroni corrections. Comparision between TR and CR values were were determined using independent samples t-Tests. A significance level of $p<0.05$ was used for all analyses. Results are presented as means ±one SD of the mean.

RESULTS: Athletes successfully adhered to the protocol design as demonstrated by no significant differences in hopping frequency during stiffness testing, or TR or CR run times. In addition, there was no significant change in any of the baseline variables between testing sessions. Repeated measures ANOVA testing indicated that there was no change in any of the measured variables during the run tests and so values at 1, 2 and 3 km were averaged. Kinetic and joint stiffness variables measured between TR and CR are shown in Table 1.
ANOVA testing showed that hip ($p=0.039$) and knee ($p=0.038$) joint moments increased together with knee joint stiffness ($p=0.046$) immediately following the bike leg. In addition, decreases in maximum hip joint moment ($p=0.033$) and hip joint stiffness were observed ($p=0.031$) between the CR and TR conditions. No other variables changed significantly between conditions

DISCUSSION: Baseline values recorded for maximum joint moments and the various stiffness measures were comparable to those reported previously for endurance athletes undertaking similar protocols (Hobara, et al., 2008; Hobara, et al., 2010). The increase in knee joint stiffness present immediately post-bike was surprising, as researchers have indicated that musculoarticular stiffness typically decreases following fatiguing cycling (Ditroilo, et al., 2011). However, the protocols used by these researchers involved multiple sprints and so direct comparison with the steady state cycling protocol used in this research in difficult. In addition, although fatigued, the triathletes in this study were not exhausted at the end of the cycle and so rather than reducing joint stiffness, the cycle appears to have increased knees joint stiffness. Interestingly, research involving incremental cycling to fatigue protocols has shown that with higher workloads and increasing fatigue there is greater knee joint contribution to the total net joint moments during the pedal stroke (Bini & Diefenthaeler, 2010). Therefore, to maintain power output throughout the cycle the triathletes may have adopted similar changes in cycling technique, particularly during the latter stages (Bini & Diefenthaeler, 2010). This increased reliance on the knee and hip to maintain power output also may have resulted in a change in motor coordination patterns that subsequently influenced the immediate post-bike knee joint stiffness (Chapman, Vicenzino, Blanch, Dowlan, & Hodges, 2008).

Table 1: Differences in kinetic and joint stiffness variables between test conditions.

Variable	Pre-bike	Immediately Post-bike	Average during TR†	Average during CR†
Ground contact time (ms)	195 ±64	219 ±27	227 ±31	225 ±30
Peak GRF (N/BW)	41.1 ±14.9	45.3 ±5.6	43.1 ±8.3	43.7 ±5.5
Vertical Stiffness (kN/m/BW)	0.37 ±0.09	0.36 ±0.06	0.33 ±0.05	0.33 ±0.04
Max Hip Moment (Nm)	1.6 ±0.4	2.3 ±0.4*	2.1 ±0.6	1.7 ±0.4‡
Max Knee Moment (Nm)	3.8 ±1.0	5.3 ±1.3*	4.9 ±1.2	4.3 ±1.1
Max Ankle Moment (Nm)	3.2 ±0.6	3.2 ±0.6	3.1 ±0.5	3.2 ±0.5
Hip Joint Stiffness (Nm/rad/BW)	15.6 ±3.0	22.8 ±11.3	23.7 ±13.9	17.3 ±6.6‡
Knee Joint Stiffness (Nm/rad/BW)	29.0 ±5.0	49.9 ±20.4*	40.0 ±19.5	31.5 ±11.0
Ankle Joint Stiffness (Nm/rad/BW)	15.7 ±8.0	15.3 ±7.4	14.0 ±8.0	13.0 ±4.0

† TR=triathlon or post-bike run, while CR=control run or run without a prior bike ride.
* Indicates significant differences between Pre-Bike and Immediately Post Bike values.
‡ Indicates significant differences between average values recorded during the TR and CR.

Results also indicated that joint stiffness characteristics differed between TR and CR conditions. It is possible that the greater hip stiffness following cycling may be a result of sustained the flexed posture adopted during cycling resulting in a pre-shortening of the hip flexors. Similarly, the immediate effects of the cycle leg may resulted in small changes in running coordination patterns that then continued throughout the TR (Chapman, et al., 2008). Millet et al (2000) proposed that the changes in running economy observed following cycling are a result of changes in stiffness regulation, with elite triathletes demonstrating greater regulatory abilities than less capable competitors. However, while these changes in joint stiffness may alter running mechanics and a sense of loss of coordination, it is not yet know whether they are sufficient to result in a detriment to performance.
The TR values for all of the joint stiffness measures were greater than those reported previously for other endurance athletes undertaking similar protocols (Hobara, et al., 2008; Hobara, et al., 2010). There is no conclusive evidence of the level of lower extremity stiffness required to maximise running performance. Similarly, the interaction between stiffness and injury rates in running remains unclear although literature suggests that too little, or too high stiffness will increase the risk of injury (Butler, Crowell, & Davis, 2003). However, the relatively high TR joint stiffness results suggest that excessive post-bike running may increase joint stiffness, which may in turn expose triathletes to increased risk of lower limb bony injuries.

CONCLUSION: This study demonstrated that a fatiguing cycle has an immediate influence on lower limb joint stiffness and joint kinetics. These changes subsequently influenced joint stiffness during post-bike running. However, it is not yet know whether these changes in lower limb joint stiffness are determental to running performance, or likely to result in an increase in injury prevalence. This study may also help explain the perceived loss of coordination reported frequently by triathletes at the start of the run leg.

REFERENCES:

Bini, R. R., & Diefenthaeler, F. (2010). Kinetics and kinematics analysis of incremental cycling to exhaustion. *Sports Biomechanics, 9*(4), 223-235.

Bonacci, J., Green, D., Saunders, P. U., Blanch, P., Franettovich, M., Chapman, A. R., & Vicenzino, B. (2010). Change in running kinematics after cycling are related to alterations in running economy in triathletes. *Journal of Science and Medicine in Sport, 13*(4), 460-464.

Butler, R. J., Crowell, H. P., & Davis, I. M. (2003). Lower extremity stiffness: implications for performance and injury. *Clinical Biomechanics, 18*(6), 511-517.

Chapman, A. R., Vicenzino, B., Blanch, P., Dowlan, S., & Hodges, P. W. (2008). Does cycling effect motor coordination of the leg during running in elite triathletes? *Journal of Science and Medicine in Sport, 11*(4), 371-380.

Ditroilo, M., Watsford, M., Fernandez-Pena, E., D'Amen, G., Lucertini, F., & De Vito, G. (2011). Effects of fatigue on muscle stiffness and intermittent sprinting during cycling. *Medicine and Science in Sports and Exercise, 43*(5), 837-845.

Farley, C. T., & Gonzalez, O. (1996). Leg stiffness and stride frequency in human running. *Journal of Biomechanics, 29*(2), 181-186.

Gottschall, J. S., & Palmer, B. M. (2002). The acute effects of prior cycling cadence on running performance and kinematics. *Medicine and Science in Sports and Exercise, 34*(9), 1518-1522.

Hausswirth, C., Bigard, A. X., & Guezennec, C. Y. (1997). Relationships between running mechanics and energy cost of running at the end of a triathlon and a marathon. *International Journal of Sports Medicine, 18*(5), 330-339.

Heiden, T., & Burnett, A. (2003). The effect of cycling on muscle activation in the running leg of an Olympic distance triathlon. *Sports Biomechanics, 2*(1), 35-49.

Hobara, H., Kimura, K., Omuro, K., Gomi, K., Muraoka, T., Iso, S., & Kanosue, K. (2008). Determinants of difference in leg stiffness between endurance- and power-trained athletes. *Journal of Biomechanics, 41*(3), 506-514.

Hobara, H., Kimura, K., Omuro, K., Gomi, K., Muraoka, T., Sakamoto, M., & Kanosue, K. (2010). Differences in lower extremity stiffness between endurance-trained athletes and untrained subjects. *Journal of Science and Medicine in Sport, 13*(1), 106-111.

Hue, O., Le Gallais, D., Boussana, A., Chollet, D., & Prefaut, C. (1999). Ventilatory responses during experimental cycle-run transition in triathletes. *Medicine and Science in Sports and Exercise, 31*(10), 1422-1428.

Kuitunen, S., Komi, P. V., & Kyröläinen, H. (2002). Knee and ankle joint stiffness in sprint running. *Medicine and Science in Sports and Exercise, 34*(1), 166-173.

McMahon, T. A., & Cheng, G. C. (1990). The mechanics of running: How does stiffness couple with speed? *Journal of Biomechanics, 23*, 65-78.

Millet, G. P., Millet, G. Y., & 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*(2), 147-153.

Millet, G. P., Millet, G. Y., Hofmann, M. D., & Candau, R. B. (2000). Alterations in running economy and mechanics after maximal cycling in triathletes: influence of performance level. *International Journal of Sports Medicine, 21*, 127-132.

Morin, J. B., Samozino, P., Zameziati, K., & Belli, A. (2007). Effects of altered stride frequency and contact time on leg-spring behavior in human running. *Journal of Biomechanics, 40*(15), 3341-3348.

Rabita, G., Slawinski, J., Girard, O., Bignet, F., & Hausswirth, C. (2011). Spring-mass behavior during exhaustive run at constant velocity in elite triathletes. *Medicine and Science in Sports and Exercise, 43*(4), 685-692.

Stefanyshyn, D. J., & Nigg, B. M. (1998). Dynamic angular stiffness of the ankle joint during running and sprinting. *Journal of Applied Biomechanics, 14*, 292-299.

Vleck, V. E., Burgi, A., & Bentley, D. J. (2006). The consequences of swim, cycle, and run performance on overall result in elite olympic distance triathlon. [Research Support, Non-U.S. Gov't]. *International Journal of Sports Medicine, 27*(1), 43-48.