ACCUMULATED FATIGUE AFFECTS RUNNING BIOMECHANICS DEPENDING ON THE PERFORMANCE LEVEL DURING A TRIATHLON COMPETITION

Antonio Cala[1,2] and Enrique Navarro[1]

Sports Biomechanics Laboratory, Polytechnic University of Madrid, Spain[1]
Institute of Sport & Recreation Research, AUT University, New Zealand.[2]

The purposes of the present study were 1) to examine the different responses to the accumulated fatigue between international and national level triathletes in competition, and 2) to compare the profile of the running part presented by the two different performance levels. 32 participants at Madrid 2008 Triathlon World Cup and 32 participants at Spanish National Championships 2008, made up the sample. We found higher values ($p<0.05$) of stride frequency, stride length and flight time in international level triathletes. Also, lower values ($p<0.05$) in contact time and knee angles at toe-off were obtained. International level triathletes showed a consistent tendency in some of the analyzed variables ($p = 1.00$ among the laps) whereas the national level participants presented significant differences ($p<0.05$).

KEY WORDS: Triathlon, Cycle-run transition, competition, performance level.

INTRODUCTION: One of the most difficult parts (strategically and physically) of a triathlon is the transition from cycling to running (Rowlands & Downey, 2000). In fact, the performance of a triathlete may decrease due to a discomfort during the first part of the running provoked by the previous cycling (Quigley & Richards, 1996; Hue *et al*., 1998, 2000).
The cycle-run transition has been widely studied in laboratory-conditions (Quigley & Richards, 1996; Hausswirth *et al*., 1996; Millet *et al*., 2001; Millet & Bentley, 2004; Palazzetti *et al*., 2005) but only one study has been carried out in competition (Cala *et al*., 2009). A Triathlon World Cup event was analyzed and they found no effect of the previous cycling on the subsequent running kinematics in elite triathletes.
However, the influence of the performance level is not clear. Millet *et al*. (2000) analyzed the running off the bike in elite and middle-level triathletes and they found differences in the vertical displacement of the centre of gravity between the two groups. But the study was performed in laboratory conditions and the situation in competition remains unclear.
Therefore, the aims of the present study are: (1) to examine the different responses to the previous cycling between international and national level in competition, and 2) to compare the profile of the running part presented by the two different performance levels.

METHODS: Data Collection: Two different competitions were analyzed: Madrid 2008 Triathlon World Cup and Spanish National Championships 2008. Both events took place in the same circuit at the same time in two consecutive days. The sample size was 64 triathletes: 16 men and 16 women, ranked among the first sixteen competitors at the end of the cycling part in each event, were selected for this study.
A video camera (JVC GY-DV500E) was positioned perpendicular to the longitudinal direction of the track, recording at 50 Hz of sampling frequency according to other studies (Amico *et al.*, 1989; Palazzetti *et al*., 2005; Cala *et al*., 2009). The 10km run was broken into four 2,5km laps, i.e. the triathletes were recorded four times. The kinematic analysis was performed through a photogrammetric technique in the saggital plane (2D). As the triathletes did not follow the same line, five different planes of movement were calibrated in order to choose the nearest to the trajectory of each one of athletes. The calibration system covered a surface of 7 meters width and 2 meters high. A Clausser-based kinematic model (Clausser *et al*., 1969) was used to analyse the running biomechanics. Eight anatomical landmarks (markerless digitisation method) were selected: hip, knee, ankle and toe-cap (both right and left side). An algorithm with 2D direct linear transformation (2D-DLT) was used (Abdel-Aziz & Karara, 1971) and the coordinates obtained were smoothed using quintic spline functions with the Cross Generalized Validation procedure as a method for evaluating the adjusting factor

(Woltring, 1985). The root mean error (RMS) (Allard *et al*., 1995) in the reconstruction of the coordinates in the x and y axis was 0.02 and 0.03 m, respectively. The RMS error when reconstructing the distance between two points was 1.23%. Once the coordinates of the anatomical landmarks were obtained, the following gait variables were calculated: “Stride frequency” (cycles/minute), “Stride length” (meters), “Contact time” (in seconds and in percentage), “Flight time” (in seconds and in percentage), “Knee angles at toe-off” (degrees) and “Ankle angles at toe-off” (degrees).
Intra-rater reliability of measurement was evaluated by asking the same investigator to repeat the digitizing of the same sequence 30 times. The coefficient of variation (CV) was under 2% in all the variables measured. Inter-rater reliability of measurements was assessed by three investigators who digitized the same video sequence (each video include a series of 200 frames). There was no significant difference among the operators in terms of digitizing (x-, y- coordinates recording). Validity of the measurement was evaluated analyzing the same athlete with a 3D protocol (2 cameras and a 3D-DLT algorithm) and with the 2D-DLT protocol (the same one used in the present study). There was no significant difference between the two protocols used.
Data Analysis: A one-way repeated measures analysis of variance (ANOVA) was performed. A Bonferroni adjustment was performed for multiple comparisons. All statistical measures were conducted at $\alpha < 0.05$.

RESULTS: Significant differences ($p<0.05$) were found in many of the analyzed variables between the two levels of performance. The variables that showed those differences were stride frequency, stride length, contact time (seconds and percentage), flight time (seconds and percentage), knee angle of the support and non-support leg and the ankle angle of the support leg. Higher values were found in stride frequency, stride length and flight time (percentage) for international level triathletes. However, contact times (seconds and percentage), knee angle of the support and non-support leg and ankle angle of the support leg values were higher for national level triatheles.

Table 1 Results of the variables obtained for national level triathletes in the different laps.

NATIONAL LEVEL	*LAP 1*	*LAP 2*	*LAP 3*	*LAP 4*
STRIDE FREQUENCY	86.92 ± 3.35	85.30 ± 4.17*	85.49 ± 3.71*	85.99 ± 3.30
STRIDE LENGTH	3.08 ± 0.53	3.12 ± 0.41	3.06 ± 0.45	3.06 ± 0.47
CONTACT TIME (S)	0.46 ± 0.03	0.48 ± 0.03*	0.48 ± 0.03*	0.48 ± 0.03*
CONTACT TIME (%)	67.32 ± 5.55	68.67 ± 4.89*	68.92 ± 5.67*	69.84 ± 5.60*
FLIGHT TIME (S)	0.23 ± 0.04	0.22 ± 0.03*	0.22 ± 0.04*	0.22 ± 0.04*
FLIGHT TIME (%)	32.68 ± 5.55	31.34 ± 4.89*	31.08 ± 5.67*	29.86 ± 5.60*
KNEE ANGLE NON-SUPPORT LEG	111.90 ± 12.41	112.28 ± 13.01	112.00 ± 11.13	113.27 ± 11.51
KNEE ANGLE SUPPORT LEG	166.17 ± 4.41**	166.82 ± 4.32**	166.56 ± 4.58**	166.41 ± 4.95**
ANKLE ANGLE NON-SUPPORT LEG	124.24 ± 9.33	125.72 ± 9.59*	126.04 ± 7.29*	125.84 ± 9.23*
ANKLE ANGLE SUPPORT LEG	137.33 ± 6.91**	140.77 ± 6.00**	139.33 ± 6.02**	136.91 ± 6.76**

*** Significant differences (p<0.05) with the lap 1**
**** P value of 1.00**

Two different tendencies were found during the 10km running according to the performance level of the triathletes. Significant differences ($p<0.05$) between the lap 1 and the other laps were found in stride frequency, contact time (seconds and percentage), flight time (seconds and percentage) and in the ankle angle of the non-support leg for national level triathletes (table 1). On the other hand, international level triathletes showed a p value of 1.00 among the 4 laps in contact time (percentage), flight time (percentage) and ankle angle of non-support leg (table 2).
Table 2 Results of the variables obtained for international level triathletes in the different laps.

INTERNATIONAL LEVEL	*LAP 1*	*LAP 2*	*LAP 3*	*LAP 4*
STRIDE FREQUENCY (cycles/min)	91.13 ± 3.56	90.15 ± 2.94*	89.84 ± 3.30*	90.00 ± 3.20*
STRIDE LENGTH (m)	3.47 ± 0.32	3.44 ± 0.38	3.35 ± 0.38	3.38 ± 0.37
CONTACT TIME (s)	0.43 ± 0.02	0.43 ± 0.02	0.44 ± 0.02	0.44 ± 0.02
CONTACT TIME (%)	65.22 ± 3.53**	64.85 ± 3.41**	65.52 ± 3.10**	65.54 ± 4.32**
FLIGHT TIME (s)	0.22 ± 0.02	0.23 ± 0.02	0.23 ± 0.02	0.23 ± 0.03
FLIGHT TIME (%)	34.77 ± 3.53**	35.14 ± 3.41**	34.48 ± 3.10**	34.45 ± 4.32**
KNEE ANGLE NON-SUPPORT LEG	101.63 ± 10.19	99.38 ± 10.66	101.44 ± 11.39	102.89 ± 12.87
KNEE ANGLE SUPPORT LEG	162.60 ± 3.24**	163.69 ± 4.63**	163.94 ± 4.05**	163.27 ± 3.74**
ANKLE ANGLE NON-SUPPORT LEG	126.52 ± 5.76**	126.18 ± 6.52**	127.00 ± 5.79**	128.53 ± 6.82**
ANKLE ANGLE SUPPORT LEG	135.76 ± 7.77**	137.05 ± 5.62**	136.67 ± 4.59**	135.38 ± 5.27**

*** Significant differences ($p<0.05$) with the lap 1**
**** P value of 1.00**

DISCUSSION: The most important result found in the present study was the existence of two different tendencies of the biomechanics during the 10km running depending on the performance level of the triathlete. International level triathletes presented similar values ($p = 1.00$) in the four laps in several variables: contact time (percentage), flight time (percentage) and ankle angle of non-support leg. On the other hand, national level triathletes showed significant differences ($p<0.05$) between the lap 1 and the other laps in stride frequency, contact time (seconds and percentage), flight time (seconds and percentage) and in the ankle angle of the non-support leg. These two different tendencies can be explained by the differences in the performance level of the triathletes. Millet *et al.* (2000) found a significant effect of the triathlon performance level on the change of the running energy cost after cycling, but the study was carried out in laboratory conditions. To the best of our knowledge, only one study in the literature has performed a biomechanical analysis of the running part during a triathlon competition (Cala *et al.,* 2009) and they only focused in elite triathletes. The results of the present study show how top-level group could maintain the same values during the 10km running, whereas national-level group could not do so. It seems the accumulated fatigue would be the reason of these two different trends.
Other important result found in this study was the existence of significant differences ($p<0.05$) in absolute values found in many of the analyzed variables between the two levels of performance. Cala *et al.* (2009) found that differences in some variables could be related to the triathlete's gender, as stride frequency, stride length and ankle angles values. In the present study, we found stride frequency, stride length, ankle angles may be related to performance level as well. Furthermore, contact time (seconds and percentage), flight time (percentage) and knee angles may be related only to the performance level. These differences can be explained by the different velocities values reached by each group of performance. International-level triathletes showed an average velocity of 3min 15sec per kilometre, while national-level triathletes presented an average velocity of 3min 50sec per kilometre. Probably, the biomechanical requirements will be different to achieve each velocity and that would be the reason that could explain the differences found.

CONCLUSION: Two different tendencies on the biomechanics during the 10km-running were found depending on the performance level of the triathlete. International-level triathletes presented similar values ($p = 1.00$) in the four laps in several variables while national-level triathletes showed significant differences ($p<0.05$) between the lap 1 and the other laps. The accumulated fatigue could be the reason to explain this phenomenon. Significant differences ($p<0.05$) in absolute values were found in many of the analyzed variables between the two levels of performance. The main reason that could explain this situation was the different velocities achieved by the two level of performance.

REFERENCES:

Abdel-Aziz, Y.I., Karara, H.M. (1971). Direct linear transformation from comparator coordinates into space coordinates in close range photogrammetry. In the American Society of Photogrammetry (Ed.), *Proceedings of the Symposium on close range photogrammetry* (pp.1-18).

Amico, A.D., Ferrigno, G., Rodano, R. (1989). Frequency content of different track and field basis movements. In W. Morrison (Ed*), Proceedings of the VII International Symposium of Biomechanics in sports* (pp.177-193). Melbourne, Australia.

Allard, P., Blanchi, J.P., Aïssaqui, R. (1995). Bases of three-dimensional reconstruction. In P. Allard, I.A.F. Stokes & J.P. Bianchi (Eds.), *Three Dimensional Analysis of Human Movement*,(pp.19-40). Champaign, IL: Human Kinetics.

Cala, A., Veiga, S., Garcia, A., Navarro, E. (2009). Previous cycling does not affect running efficiency during a triathlon World Cup competition, *Journal of Sport Medicine and Physical Fitness*, In press

Clauser, C. E., McConville, J. T., Young, J. W. (1969). Weight, volume and centre of mass of segments of the human body. *Wright-Patterson Air Force Base* (pp. 69-70).

Hausswirth, C., Bigard, A.X., Berthelot, M., Thomaidis, M., Guezennec, C.Y. (1996). Variability in energy cost of running at the end of a triathlon and a marathon. *International Journal of Sport Medicine*, 17, 572-579.

Hue, O., Le Gallais, D., Boussana, A., Galy, O., Chamari, K., Mercier, B. (2000). Catecholamine, blood lactate and ventilatory responses to multi-cycle run blocks. *Medicine & Science in Sport & Exercise*, 32, 1582-1586.

Hue, O., Le Gallais, D., Chollet, D., Boussana, A., Préfaut, C. (1998). The influence of prior cycling on biomechanical and cardiorespiratory response profiles during running in triathletes. *European Journal of Applied Physiology*, 77, 98-105.

Millet, G. P., Bentley, D. J. (2004). The physiological responses to running after cycling in elite junior and senior triathletes. *International Journal of Sports Medicine*, 25(3), 191-197

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 Sport Medicine and Physical Fitness*, 41, 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 Sport Medicine*, 21, 127-132.

Palazzetti, S., Margaritis, I., Guezennec, C.Y. (2005). Swimming and cycling overloaded training in triathlon has no effect on running kinematics and economy. *International Journal of Sport Medicine*, 26(3), 193-199.

Quigley, E. J., & Richards, J. G. (1996). The effects of cycling on running mechanics. *Journal of Applied Biomechanics*, 12(4), 470-479.

Rowlands D.S., Downey B. (2000). Physiology of Triathlon. In K. D. Garret WEJ (Ed.). *Exercise and Sport Science*. (pp. 919-39).Philadelphia: Lippincott Williams & Wilkins,

Woltring, H.J. (1985). An optimal smoothing and derivate estimation from noisy displacement data in biomechanics. *Human Movement Sciences*, 4, 229-45.