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Research Article

BIOMECHANICAL ANALYSIS OF THE 10KM-RUN IN A TRIATHLON WORLD CUP EVENT: DIFFERENCES PRESENTED BY WOMEN GOLD MEDAL

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ABSTRACT

In most of the triathlon races, the 10km-run is critical to win and, just a few seconds, may separate the gold and the silver medal. To our best knowledge, no study has analyzed the biomechanical differences among the first qualified triathletes during a top-level competition. The aims of the present study were: (1) to examine the different responses to the previous cycling between the gold medal and the other participants, and (2) to compare the biomechanical profiles during the 10km-run presented by the top-ranked triathletes. 16 women, participants at Madrid 2008 Triathlon World Cup, were analyzed. The first qualified triathlete (gold medal) showed significant differences ($p<0.05$) with the other participants in many of the analyzed variables. A higher stride length, a smaller stride frequency, a higher and more consistent horizontal distance hip- toe cap and a more extended knee angle of the support-leg at toe-off could explain the differences in 10km-run time between gold medal and the other participants.

***Key words*:** triathlon, cycle-run transition, competition**,** kinematics.

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INTRODUCTION

In triathlon, the cycle-run transition has been widely studied in laboratory-conditions (Quigley and Richards, 1996; Hausswirth et al., 1996; Millet et al., 2001; Millet and Bentley, 2004; Palazzetti et al., 2005) but, to our best knowledge, only one studied 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.

Triathlon has increased its competitiveness these last years. The speed and precision in the execution of the transitions is a major factor in performance described. The smaller distance, the more importance is the cycle-run transition (Cejuela et al., 2007). At the same time, triathlon competitions are being won very often by just a few seconds between the gold medal and the other participants. As the competitiveness increases, the differences are getting closer among the participants.

In most of the races, the 10km-run is critical to win or not and, just a few seconds, may separate the gold and the silver medal. According to the literature reviewed, no study has analyzed the biomechanical differences among the first qualified triathletes during a top-level competition.

Therefore, the aims of the present study are: (1) to examine the different responses to the previous cycling between the gold medal and the other participants, and (2) to compare the biomechanical profiles during the 10km-run presented by the top-ranked triathletes.

METHODS

Participants
Women's race at Madrid 2008 Triathlon World Cup was analyzed. The sample size was 16 triathletes (women) and all of them were ranked among the first sixteen competitors at the end of the cycling part.

Procedure
A video camera (JVC GY-DV500E) was positioned perpendicular to the longitudinal direction of the track, at 200 meters after the transition area between the cycling and running parts. The running part was divided into four laps of 2.5 km each, i.e. the triathletes were recorded four times. The sampling frequency was selected at 50 Hz according to other studies (Amico et al., 1989; Hausswirth et al., 1997; Palazzetti et al., 2005; Cala et al., 2009).

A Clausser-based kinematic model (Clausser et al., 1969) of eight anatomical landmarks (hip, knee, ankle and toe-cap; both right and left side) was used to analyse the running biomechanics. Five different planes of movement were calibrated in order to choose the nearest to the trajectory of each one of athletes. Each calibration system covered a surface of 7 meters width and 2 meters high. 2D-DLT based algorithms were used (Abdel-Aziz and 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).

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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 ($p<0.05$) between the two protocols used. Also, 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%. 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) ($p<0.05$). 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.

The variables calculated in the present study were: “Stride frequency” (cycles/minute) and “Stride length” (meters) were measured between successive points of toe-cap contact of the right foot. “Support time” (seconds) and “Flight time” (seconds) represent the time when any part of the foot was in contact with the ground or not, respectively. “Support time” (percentage) and “Flight time” (percentage) mean the percent of each time according to the total time of a cycle (2 strides). “Horizontal distance hip-toe cap” was the distance measured from the hip’s vertical projection to the heel position at foot strike. “Knee angles at toe-off” were knee angles of the support and non-support leg measured at toe-off. And finally, “Ankle angles at toe-off” (degrees) were the ankle angles of the support and non-support leg measured at toe-off.

Data analysis

Mean and standard deviations were calculated for all variables. An independent-samples t test was performed. All statistical measures were conducted at $\alpha < 0.05$.

RESULTS

Tables 1 and 2 show all the biomechanical values (as mean ± standard deviation) obtained in the present study for all the triathletes analyzed.

Comparison with gold medal values (average values)

Significant differences ($p<0.05$) in many of the analyzed variables were found between the gold medal and the other participants (Table 1 and 2). The variables that showed differences in more participants were stride frequency, stride length, horizontal distance hip-toe cap and flight time (in seconds).

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Table 1. *Mean and SD values of stride frequency, stride length, horizontal distance hip-toe cap and knee angle of the support-leg at toe-off obtained in all the triathletes analyzed.*

POSITION	10KM-RUN TIME (seconds)	STRIDE FREQUENCY (cycles/min)	STRIDE LENGTH (meters)	HORIZONTAL DISTANCE HIP-TOE CAP (meters)	KNEE ANGLE SUPPORT LEG (degrees)
GOLD MEDAL	2084	89.61 ± 2.60	3.41 ± 0.08	0.46 ± 0.03	166.34 ± 3.67
2	2111	93.75 ± 0.25*	2.85 ± 0.12*	0.36 ± 0.02*	162.99 ± 4.42
3	2129	92.33 ± 1.64	3.14 ± 0.15*	0.42 ± 0.06	164.82 ± 3.39
4	2135	93.75 ± 0.32*	2.86 ± 0.14*	0.40 ± 0.03*	163.89 ± 2.97
5	2149	90.95 ± 0.19	3.40 ± 0.09	0.42 ± 0.01	159.32 ± 2.78*
6	2150	95.36 ± 1.46*	3.02 ± 0.18*	0.39 ± 0.04	159.81 ± 6.03*
7	2167	93.75 ± 1.64*	3.12 ± 0.05*	0.41 ± 0.03*	167.19 ± 1.90
8	2172	92.33 ± 2.25	3.15 ± 0.11*	0.41 ± 0.04	159.06 ± 4.90*
9	2174	93.04 ± 3.91	3.03 ± 0.06*	0.36 ± 0.06*	166.33 ± 3.06
10	2186	86.97 ± 1.42	3.12 ± 0.07*	0.41 ± 0.03	158.18 ± 3.64*
11	2207	90.95 ± 2.25	3.19 ± 0.16*	0.42 ± 0.02	161.75 ± 2.69
12	2227	90.24 ± 1.34	3.04 ± 0.24*	0.43 ± 0.05	165.05 ± 3.11
13	2237	93.80 ± 2.40*	3.21 ± 0.04*	0.42 ± 0.01	163.87 ± 2.04
14	2243	91.62 ± 2.93	3.29 ± 0.13	0.43 ± 0.02	164.47 ± 3.61
15	2285	92.38 ± 1.42	2.93 ± 0.12*	0.43 ± 0.03	162.85 ± 2.78
16	2312	91.62 ± 1.42	3.16 ± 0.14*	0.41 ± 0.03	161.69 ± 5.64

**Significant differences (p<0.05) with the gold medal.*

On the other hand, knee angles, support time (in seconds and in percentage) and flight time (in percentage) showed significant differences ($p<0.05$) in less participants.

Gold medal presented higher values for stride length, horizontal distance hip-toe cap, support time (in seconds) and knee angle of the support-leg. However, it showed lower stride frequency's values. Other variables as support time (in percentage), flight time (in seconds and in percentage) and knee angle of the non-support-leg did not show clear tendencies among the participants.

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Table 2. *Mean and SD values of support time (in seconds and in percentage), flight time (in seconds and in percentage) and knee angle of the non support-leg at toe-off obtained in all the triathletes analyzed.*

POSITION	SUPPORT TIME (seconds)	SUPPORT TIME (percentage)	FLIGHT TIME (seconds)	FLIGHT TIME (percentage)	KNEE ANGLE NON-SUPPORT LEG (degrees)
GOLD MEDAL	0.46 ± 0.02	68.66 ± 1.43	0.21 ± 0.01	31.34 ± 1.43	104.80 ± 3.55
2	0.41 ± 0.01*	64.06 ± 1.80*	0.23 ± 0.01*	35.94 ± 1.80*	105.95 ± 6.04
3	0.44 ± 0.01	66.93 ± 1.31	0.22 ± 0.01	33.07 ± 1.31	101.79 ± 3.44
4	0.45 ± 0.01	70.31 ± 1.80	0.19 ± 0.01*	29.69 ± 1.80	108.93 ± 5.59
5	0.42 ± 0.02*	63.62 ± 0.90*	0.24 ± 0.01*	36.38 ± 0.90*	100.12 ± 8.08
6	0.45 ± 0.03	71.44 ± 3.32	0.18 ± 0.02*	28.56 ± 3.32	113.51 ± 7.85
7	0.44 ± 0.01	68.75 ± 0.01	0.20 ± 0.01	31.25 ± 0.01	108.84 ± 2.85
8	0.44 ± 0.02	67.71 ± 2.82	0.21 ± 0.02	32.29 ± 2.82	103.07 ± 1.10
9	0.42 ± 0.01*	64.35 ± 1.55*	0.23 ± 0.01*	35.65 ± 1.55*	95.55 ± 6.51*
10	0.47 ± 0.02	67.37 ± 1.83	0.23 ± 0.01*	32.63 ± 1.83	109.83 ± 3.72
11	0.46 ± 0.03	69.71 ± 4.12	0.20 ± 0.03	30.29 ± 4.12	112.35 ± 5.09
12	0.47 ± 0.02	70.66 ± 1.92	0.20 ± 0.01	29.34 ± 1.92	97.90 ± 2.48*
13	0.42 ± 0.03	64.80 ± 2.39	0.23 ± 0.01*	35.20 ± 2.39*	92.98 ± 2.74*
14	0.45 ± 0.01	67.95 ± 1.53	0.21 ± 0.01	32.05 ± 1.53	100.33 ± 3.63
15	0.45 ± 0.03	68.50 ± 4.12	0.21 ± 0.03	31.50 ± 4.12	121.79 ± 12.95*
16	0.44 ± 0.02	67.16 ± 1.76	0.22 ± 0.01	32.84 ± 1.76	114.48 ± 4.51*

**Significant differences (p<0.05) with the gold medal.*

Biomechanical profiles during the 10km-run.

Figures 1 and 2 show the different tendencies presented by the participants for stride length and horizontal distance hip-toe cap, respectively. Despite the tendencies are different among the triathletes, gold medal (boss line) always present the highest values during the laps.

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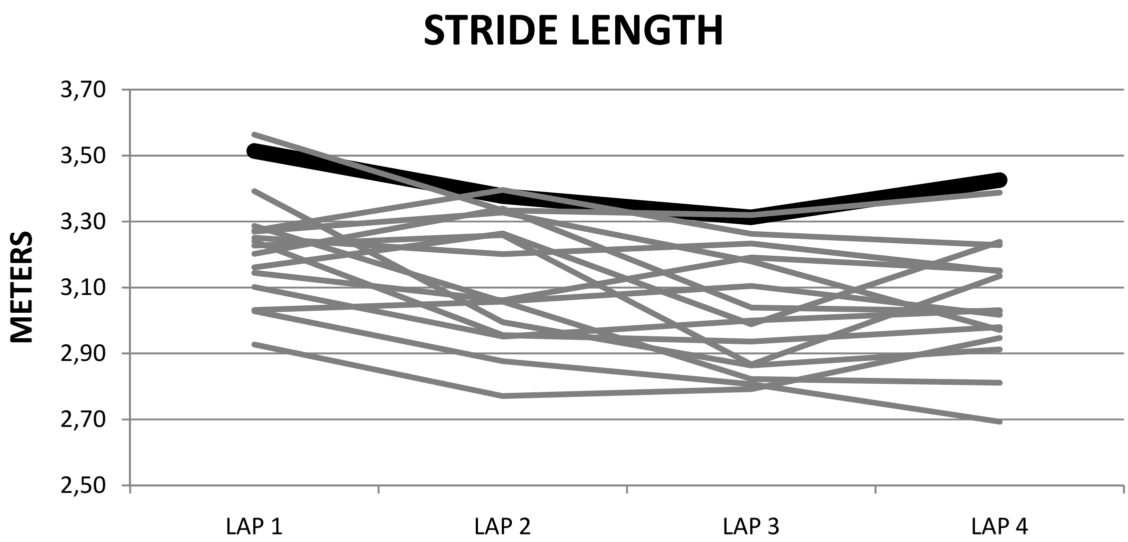

Figure 1. *Different profiles showed in the 10km-run by the gold medal (bold line) and the other participants for stride length.*

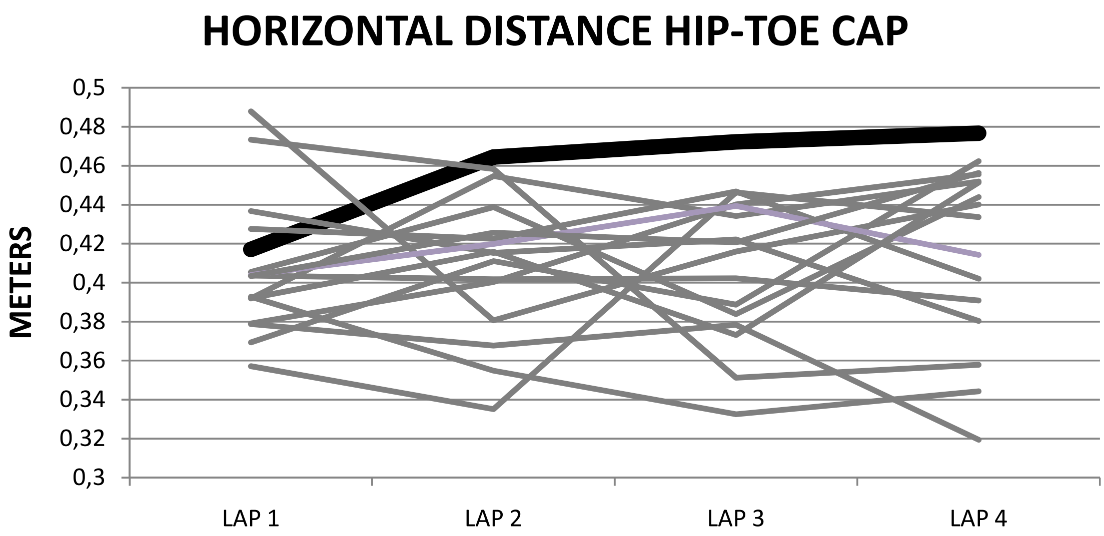

Figure 2. *Different profiles showed in the 10km-run by the gold medal (bold line) and the other participants for horizontal distance hip-toe cap.*

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DISCUSSION AND CONCLUSIONS

The main objective of this study was to examine the different responses to the previous cycling between the gold medal and the other participants. The main finding of the present study was that the first triathlete qualified (gold medal) presented significant differences ($p<0.05$) with the other participants in many of the analyzed variables.

For stride length values, 14 of 15 triathletes presented significant differences ($p<0.05$) with the gold medal triathlete, who presented the highest values during the competition (3.41 ± 0.08 meters). The average value of all the triathletes analyzed in this study was 3.12 ± 0.12 meters, i.e. gold medal was 0.29 meters over the average.

Quigley and Richards (1996), obtained values of 3.06 meters for stride length in well-trained triathletes, but the study was carried out in laboratory conditions. In competition, Cala et al. (2009) found an average stride length value of 3.06 meters for top-level women triathletes during a World Cup Event in 2006. Two years later, it seems the values are quite similar. The differences between the participants in a top-level triathlon competition are usually very small and, just a few seconds, may separate the gold and the silver medal. Probably, these differences in stride length will provoke a higher running velocity (e.g. the triathlete will cover a longer distance per stride) and, as a consequence, a faster 10km-run time.

For stride frequency, 5 of 15 triathletes presented significant differences ($p<0.05$) with the gold medal triathlete. In this case, gold medal showed one of the smallest values (89.61 ± 2.60). Also, the standard deviation value was one of the highest, probably due to the situation in competition (the first qualified run the last 2 laps with a big difference to the second qualified). This situation could explain the lower values found for the gold medal.

For horizontal distance hip-toe cap 4 of 15 participants presented significant differences ($p<0.05$) with the gold medal triathlete, who presented the highest value (0.46 ± 0.03 meters). Non many studies have analyzed this parameter. Cala et al. (2009) analyzed a similar variable (horizontal distance from hip vertical projection to the heel) and higher values were found for men than for women. In the present study, the higher values were found for the gold medal, so it seems this variable is related to the running velocity.

4 of 15 triathletes showed significant differences ($p<0.05$) with the gold medal values for knee angle of the support leg at toe-off. The first qualified showed one of the highest values (166.34 ± 3.67º). Hausswirth et al. (1997), found angles of 139.6º in laboratory conditions, while Palazzetti et al. (2005) obtained values of 151.6º and 153.4º for overloaded and not overloaded triathletes. Cala et al. (2009) found values of 159.8º during a World Cup Event, and 161.18º for women values. It is due to the level of the triathletes. Best running technique in this angle, should be defined as completely extension of the leg (near to 0º), so it seems the higher running speed, the higher knee angle of the support leg at toe-off.

Gold medal showed support times of 0.46 ± 0.02 seconds and 68.66 ± 1.43%. Only 3 triathletes of 15 showed significant differences ($p<0.05$) for both variables, respectively. Despite the tendencies were not very clear, most of the participants showed lower contact times than gold

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medal values. On the other hand, flight times (in seconds and in percentage) presented a different situation. 7 of 15, and 4 of 15 triathletes showed significant differences ($p<0.05$) with the first qualified for flight time (in seconds and in percentage), respectively. However, higher and lower values than gold medal's one were found in both variables, so the situation remains unclear.

For knee angle of the non-support leg at toe-off, 5 of 15 participants presented significant differences ($p<0.05$) with the gold medal triathlete, who presented a value of 104.80 ± 3.55º. In this case, some of the fastest triathletes presented smaller values and others higher values than the first qualified. This situation is similar to one obtained by Cala et al. (2008), who found different tendencies of this variable according to the gender.

The second objective of this study was to compare the biomechanical profiles during the 10km-run presented by the top-ranked triathletes. We found many different tendencies depending on the triathlete to achieve different performances on the 10km-run. The fastest triathletes did not present the same tendency during the laps for the variables analyzed.

Figure 1 shows the tendencies for stride length values of all the participants analyzed. Despite the tendencies are different among the competitors, gold medal triathlete always present the higher values during the four laps and, as a consequence, she gets the fastest 10km-run time.

Figure 2 represents the different profiles showed by the participants for horizontal distance hip-toe cap. During the first lap nothing seems to be clear, but in the other 3 laps gold medal present the highest and the most consistent tendency.

These two variables may be related to each other. Probably, the longer horizontal distance hip-toe cap, the longer distance the triathlete can cover per stride and, the higher stride length.

In summary, we can conclude the small differences at the running part between the gold medal and the other participants in a women's triathlon competition may be explained by the following differences found:

1. A higher stride length.
2. A smaller stride frequency
3. A higher and more consistent horizontal distance hip- toe cap
4. A more extended knee angle of the support-leg at toe-off.

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