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RELATIONSHIP BETWEEN RUNNING KINEMATICS AND PERFORMANCE IN ELITE TRIATHLETES

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The purpose of this study was to examine the running kinematics of Elite, U23 and Junior triathletes and their relationships to performance during an Olympic or sprint distance race. A total of 238 male and female triathletes were analysed to determine ground contact time, flight time, stride rate, stride length, foot-strike type and velocity for each lap and an overall representative mean created for each variable across the race. Women displayed notably greater differences in kinematics between Junior and Elite fields than was observed in the men. Large correlations were observed for running performance with contact time (r = 0.500-0.580, $p < 0.001$) and stride length (r = 0.552-0.664, $p < 0.001$). Analysis of foot strike type revealed a significant interaction with contact time, with heel strike longer than mid-foot strike, but no relationship with running velocity.

KEY WORDS: contact time, foot strike, stride length, economy

INTRODUCTION: Triathlon is a multi-sport endurance event, involving sequential swim, bike and run disciplines. Of these three disciplines, the ability to perform during the run has been most closely linked to the athletes overall race success (Hausswirth & Brisswalter, 2008). A number of biomechanical factors have been previously related to endurance running performance and economy (Saunders, Pyne, Telford, & Hawley, 2004), of which ground contact time, and its relationship with neuromuscular factors, has been among the most commonly reported (Nummela, Keranen, & Mikkelsson, 2007; Paavolainen, Nummela, & Rusko, 1999). Foot strike type is another factor which has attracted attention with recent studies finding forefoot or mid-foot strikes to relate to shorter contact times and faster performance times compared to heel-striking (Hasegawa, Yamauchi, & Kraemer, 2007; Hayes & Caplan, 2012). These results somewhat contrast with earlier research evidence showing heel-striking runners to be more economical, a key physiological determinant of endurance running performance (Saunders et al., 2004; Williams & Cavanagh, 1987).

In comparison to pure running events, the biomechanical characteristics of elite triathletes during the run leg have not received the same amount of attention outside of the changes elicited by the cycle to run transition. Establishing relationships to performance in a triathlon-specific population is important as the multi-disciplinary nature of the sport means that the morphological and physiological characteristics required for successful performance will differ from those required for pure runners. This in turn may lead to different biomechanical profiles for triathletes. Indeed, Luna et al. (2012) reported significantly different contact times, ground reaction forces, and isokinetic strength measures between groups of well-trained triathletes and long distance runners. In relation to performance, Landers, Blanksby, & Ackland (2011) described the stride length and stride rate changes across the run leg of an elite triathlon, identifying a significant positive correlation between stride length and run speed, however contact time was not examined.

The aim of this study was to examine the running kinematics of elite triathletes in a race setting and determine relationships with performance.

METHODS: A field-based study was conducted on 238 athletes competing in the 2012 ITU Triathlon World Championships across the Junior (50 females, 68 males), Under-23 (36 females, 64 males) and Elite (48 females, 45 males) fields. Elite and U23 competitors completed an Olympic distance triathlon (1.5 km swim, 40 km bike, 10 km run), while the Juniors completed a sprint distance race (750 m swim, 20 km bike, 5 km run). Sagittal plane

video was collected at the 800m mark of each of the 2.5 km run laps, with two laps for the Junior competitors and four laps for U23 and Elite athletes. Two high-speed cameras (EX-F1, Casio) capturing at 300 Hz, placed at a height of 1.2 m on either side of the course, were used to determine temporal variables and foot strike position within an 8m analysis section. A third, high definition, camera (HDR-PJ260VE, Sony) recording at 50 Hz was positioned at a height of approximately 3 m to allow for the calculation of running velocity from a calibrated 14 m section of the course, encompassing the 8 m analysis section.
For each athlete contact time (s), flight time (s), step time (s), and foot strike type (heel, mid-foot, forefoot) were determined for up to four steps on each lap. The exact number of steps captured for each lap and individual varied due to occurrences of ground contact and toe-off being obscured. Foot strike type was classified as heel strike or forefoot strike if first ground contact was made with these parts of the foot, and mid-foot if the heel and forefoot touched simultaneously. Velocity (m/s) was calculated for each lap using Kinovea video analysis software (www.kinovea.org) to determine the time taken to pass through the 14 m timing section. Stride rate (/min) was calculated from average step time. Average stride length (m) for each lap was calculated using the equation: SL (m) = velocity (m/s) / step time (s).
Means and standard deviations (SD) were calculated for each variable. Pearson correlation coefficients were calculated to establish the strength of the relationships between kinematic variables and velocity. Magnitudes of correlation were assessed using the thresholds of 0.3, 0.5; 0.7 and 0.9 for moderate, large, very large and extremely large, respectively. Differences between age groups and foot-strike types were compared using a one-way analysis of variance (ANOVA) with statistical significance set at $p < 0.05$. All statistical analyses were conducted using IBM SPSS Statistics version 19 (IBM Corporation, Armonk, NY).

RESULTS: Comparison of age groups (Table 1) revealed a number of significant differences between age groups. The most prominent trends where increases in velocity and stride rate and decreases in contact time from Junior to U23 to Elite. This was evident in both the men and women however the magnitude of differences were larger in the female triathletes. Although significant differences between groups were also observed for stride length and flight time, there were no systematic trends in terms of age-related development.

Table 1
Mean and standard deviation of each kinematic variable by gender and age group.

	Velocity (m/s)	Stride Rate (stride/min)	Stride Length (m)	Contact Time (s)	Flight Time (s)
Men					
Junior	4.85 ± 0.28 [c]	89.7 ± 4.6 [b,c]	3.37 ± 0.22 [b]	0.22 ± 0.02 [b,c]	0.11 ± 0.02 [b]
U-23	4.95 ± 0.24	91.8 ± 3.5 [a]	3.24 ± 0.18 [a,c]	0.21 ± 0.02 [a]	0.13 ± 0.04 [a,c]
Elite	5.01 ± 0.26 [a]	92.5 ± 4.2 [a]	3.44 ± 0.20 [b]	0.21 ± 0.01 [a]	0.11 ± 0.02 [b]
Women					
Junior	4.30 ± 0.26 [c]	91.5 ± 4.1 [b,c]	2.81 ± 0.18	0.22 ± 0.02 [c]	0.11 ± 0.02
U-23	4.36 ± 0.21 [c]	94.3 ± 2.7 [a]	2.85 ± 0.17	0.22 ± 0.01 [c]	0.10 ± 0.01
Elite	4.56 ± 0.19 [a,b]	95.9 ± 4.0 [a]	2.85 ± 0.18	0.20 ± 0.01 [a,b]	0.11 ± 0.01

[a] Significantly different ($p < 0.05$) from Junior; [b] Sig. different from U-23; [c] Sig. different from Elite

Relationships between kinematic variables and performance (average running velocity) are presented in Table 2. Both men and women displayed large correlations with performance for stride length and contact time. Only small to moderate correlations were found for stride rate and flight time with run speed.

Table 2

Correlation between kinematic variables and average velocity for the entire run leg

	Stride Rate	Stride Length	Contact Time	Flight Time
Men	0.392*	0.552*	-0.580*	0.130
Women	0.265	0.664*	-0.500*	0.367*

* p < 0.001

A substantial interaction was observed between foot-strike type and ground contact time. Athletes displaying a heel strike (HS) gait pattern had significantly longer contact times than those displaying mid-foot (MFS) strikes in both men (HS: 0.22 ± 0.02, MFS: 0.20 ± 0.01, p<0.001) and women (HS: 0.23 ± 0.02, MFS: 0.21 ± 0.01, p<0.001). Despite the average contact time for forefoot strikers (FFS) being similar to MFS (Figure 1), the difference between FFS and HS did not reach the level of significance due to the low numbers in the FFS groups (men, n = 3; women, n = 8). There were no notable differences between foot strike groups in relation to running velocity.

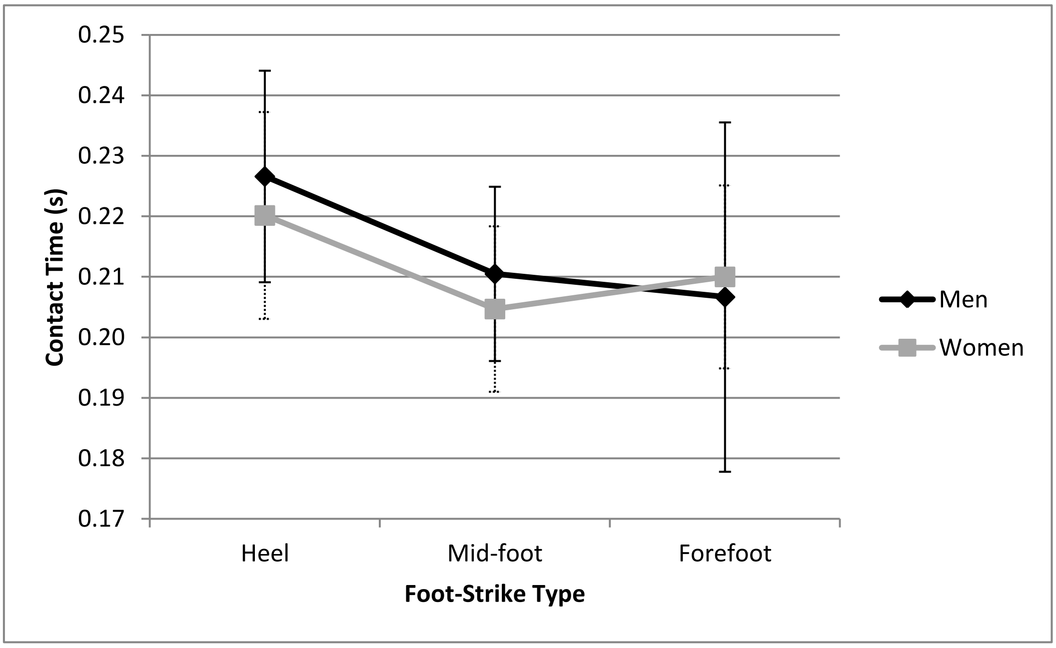

Figure 1: Ground contact times in relation to foot-strike type for men and women.

DISCUSSION: This study aimed to characterise the running kinematics of elite triathletes in order to better understand the determinants of performance in the crucial run discipline. Comparisons were also made between genders and development versus elite athletes.

There was relatively little change in the average performance between the men's fields from Junior (under-19) to Elite, with an increase in run velocity of only 3% and similar magnitude changes for stride length, stride rate and contact time. In comparison, the average run velocity of female triathletes was 6% higher in the Elite race than the Junior race, accompanied by an 8% decrease in contact time and a 5% increase in stride rate. Although differences in absolute values for kinematic variables were expected between male and female athletes, the different rate of development observed between genders is a finding which does not appear to have been previously reported. This may be an indication of later athletic maturation in female triathletes compared to their male counterparts, a finding which may have implications for talent identification and development programmes.

With regard to the relationships between kinematic factors and running performance, the two variables that demonstrated the strongest correlations were ground contact time and stride rate, irrespective of gender. The link between shorter contact time and improved running performance has been previously established in terms of both running speed (Hayes & Caplan, 2012; Paavolainen et al., 1999) and economy (Nummela et al., 2007; Saunders et al., 2004). However, to our knowledge this is the first study to confirm that this relationship is maintained in competitive triathlon despite the potential neuromotor disruptions caused by running after cycling (Chapman, Vicenzino, Blanch, Dowlan, & Hodges, 2008). In comparison, the link between stride length and distance running performance is not as well documented, however this finding is in agreement with those of Landers et al. (2011) who observed similarly large to very large correlations for run time with stride length, and only small to moderate relationships with stride rate. Although self-selected stride length has typically been shown to be optimal with respect to running economy (Saunders et al., 2004; Williams & Cavanagh, 1987), the positive relationship of stride length with performance points towards the need for training interventions that develop a runners/triathletes structural and functional characteristics in a way that enables a longer “natural” stride length.

The final part of this study was to examine the potential influence of foot-strike type on other kinematic variables and run performance in triathletes. We found significant differences in the ground contact times of heel strikers and both mid- and forefoot strikers, a finding which was in line with previous research in middle distance and marathon running (Hasegawa et al., 2007; Hayes & Caplan, 2012). However, in contrast with those studies, and despite the observed relationship between shorter contact time and greater running velocity, there was no apparent link between foot strike type and performance. One possible explanation is that this reflects the less developed muscular capability of triathletes compared to pure runners (Luna et al., 2012), in particular in terms of stiffness and storage and release of elastic energy via the triceps surae complex. It may be that, while landing on the mid- or fore-foot reduces contact time by minimising the time spent in braking phase during early contact, triathletes are unable to transfer the additional muscle-tendon loading associated with this type of foot strike into forward motion as efficiently as pure runners. More research into this area could examine the differences in muscular characteristics more closely, and how this information could be used to target training interventions for triathletes.

CONCLUSIONS: Stride length and ground contact time were found to have strong relationships with running speed in triathletes. Examination of foot-strike type showed heel strikers to have longer contact times compared to those landing on the mid- or forefoot; however there was no apparent link between foot strike type and performance. These findings suggest that interventions targeting neuromuscular development may be beneficial for improving run performance in triathletes.

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