RELATIONSHIP BETWEEN PERFORMANCE AND VERTICAL STIFFNESS IN TRIATHLON RUNNING DURING A COMPETITION

Keigo Takahashi[1], Yoshiharu Nabekura[2]

Graduate School of Comprehensive Human Sciences, University of Tsukuba, Tsukuba, Japan[1]
Faculty of Health and Sports Sciences, University of Tsukuba, Tsukuba, Japan[2]

The purpose of this study was to clarify the relationship between performance and vertical stiffness of triathletes in isolated running (IR; running without a prior swim and cycling) and triathlon running (TR; running preceded by a 1.5-km swim and 40-km cycling). The mean running speed during 10-km run and the vertical stiffness in IR and TR conditions were assessed. The vertical stiffness was positively related to the running speed in both, the IR and TR conditions. The relationship between the running speed and the vertical stiffness were stronger in TR than in IR. Improvement of vertical stiffness should be important to enhance the performance in TR.

KEY WORDS: triathlon, performance, running, vertical stiffness.

INTRODUCTION: Triathlon is a multi-disciplinary endurance sport that involves consecutive swimming, cycling, and running. This sport requires the ability to produce energy for a long time and continue to transform the energy to performance (O'Toole et al., 1995). The run section is widely recognized to have the greatest relative bearing on success in Olympic distance triathlon (Dengel et al., 1989; Vleck et al., 2006).
Athletes' performance in triathlon running (TR; run preceded by a 1.5-km swim and 40-km cycling) is decreasing when compared with that in isolated running (IR; without a prior swim and cycling). Therefore, a specific issue in triathlon is how to minimise the decrement in performance between TR and IR. The primary factor of the decrement in performance is the increase in energy cost (i.e., decrease in running economy) (Hausswirth et al., 1996; Hue et al., 1998; Millet et al., 2000). One of primary biomechanical factors that influences running economy (RE) is vertical stiffness (Heise et al., 1998). A high vertical stiffness during running is associated with a superior RE (Heise et al., 1998). Thus, it is assumed that the decrement of RE in between TR and IR is caused by a decrease in vertical stiffness.
Many studies suggested that vertical stiffness increased with an increase in running performance (Arampatzis et al., 1999; Morin et al., 2005). Considering the decrement in RE and vertical stiffness between TR and IR, the relationship between performance and the vertical stiffness in TR may be closely as with IR. However, this relationship has not been clarified yet. We considered the suggestion that enhanced performance in TR can be obtained by clarifying this relationship. Thus, the purpose of this study was to clarify the relationship between performance and vertical stiffness of triathletes in IR and TR.

METHODS: Eleven university triathletes (age, 19.5 ± 1.2 years; height, 167.7 ± 7.3 cm; weight, 60.1 ± 7.6 kg) participated in a 10-km running time trial (i.e., IR), and 8 male university triathletes (age, 19.8 ± 0.9 years; height, 169.6 ± 7.1 cm; weight, 58.8 ± 5.0 kg) participated in the Japan Student Triathlon Championship (i.e., TR). IR involved 25 laps of a 400-m outdoor tartan track circuit. TR involved 4 laps of a 2435-m outdoor circuit. The wind was blowing at < 3 m during IR and TR. Each subject was filmed with a high-speed camera (EXILIM EX-SC100, Casio, Japan) at a sampling rate of 120 fps. The camera was placed 5 m behind a straight segment of the runway. The filming location was flat ground. Each subjects was filmed 4 times during IR and TR over the following sections: 1.1 km (lap 1), 3.5 km (lap 2), 5.9 km (lap 3), and 8.4 km (lap 4).
Vertical stiffness was calculated for 2-6 consecutive steps, in accordance with a method based on the modelling of the vertical force-time curve during contact (Morin et al., 2005) Vertical stiffness (K_{vert} in kN/m) was calculated as follows:

$$K_{vert} = F_{max} \times \Delta y^{-1} \quad (1)$$

$$F_{max} = mg \frac{\pi}{2} \left(\frac{t_f}{t_c} + 1 \right) \quad (2)$$

$$\Delta y = \frac{F_{max}\, t_c^2}{m\, \pi^2} + g\, \frac{t_c^2}{8} \quad (3)$$

where F_{max} is the maximal ground reaction force during contact (in kN), Δy is the vertical displacement of the centre of mass (in m), m is the subject's body mass (in kg), t_f is the flight time (in s), and t_c is the contact time (in s). The t_c was calculated by determining the number of contact frames. The t_f was calculated by determining the number of flight frames.

All values are presented as mean ± SD. Pearson's product-moment correlation coefficients were calculated to determine the relationship between the mean running speed and vertical stiffness in both conditions. An interaction in the two-way analysis of variance was used to test for the difference in simple regression line angle. This analysis tests whether the relationship between the mean running speed and vertical stiffness in IR and TR differ or not. A significance level of $p < 0.05$ was preset.

RESULTS: Table 1 shows the mean running speed and vertical stiffness in both conditions. The relationship between the mean running speed and the vertical stiffness is shown in Table 2 and Figure 1. The vertical stiffness correlated with the running speed in both conditions ($r = 0.92$, $p < 0.01$ and $r = 0.93$, $p < 0.01$, respectively). In the test for the difference in simple regression line angle, the interaction was nearly significant ($p = 0.096$).

Table 1: The mean running speed and the vertical stiffness in both conditions.

	Running Speed (km/h)	Vertical Stiffness (kN/m)				
	Mean during 10 km	Lap 1	Lap 2	Lap 3	Lap 4	Mean of Lap 1-4
IR (n =11)	15.0±1.4	23.9±7.5	20.6±7.5	20.9±7.8	18.4±6.0	20.8±7.0
TR (n = 8)	13.4±1.4	15.8±4.7	15.3±5.6	15.0±5.5	16.2±3.9	15.2±4.9

TR; run preceded by a 1.5-km swim and 40-km cycling, IR; without a prior swim and cycling
Lap 1 (1.1 km), Lap 2 (3.5 km), Lap 3 (5.9 km), and Lap 4 (8.4 km)

Table 2: Correlations of the mean running speed with the vertical stiffness of each lap and mean in both conditions.

	Vertical Stiffness (kN/m)				
	Lap 1	Lap 2	Lap 3	Lap 4	Mean of Lap 1-4
IR (n =11)	0.90**	0.91**	0.93**	0.91**	0.92**
TR (n = 8)	0.88**	0.98**	0.93**	0.87*	0.93**

*p < 0.05, **p < 0.01

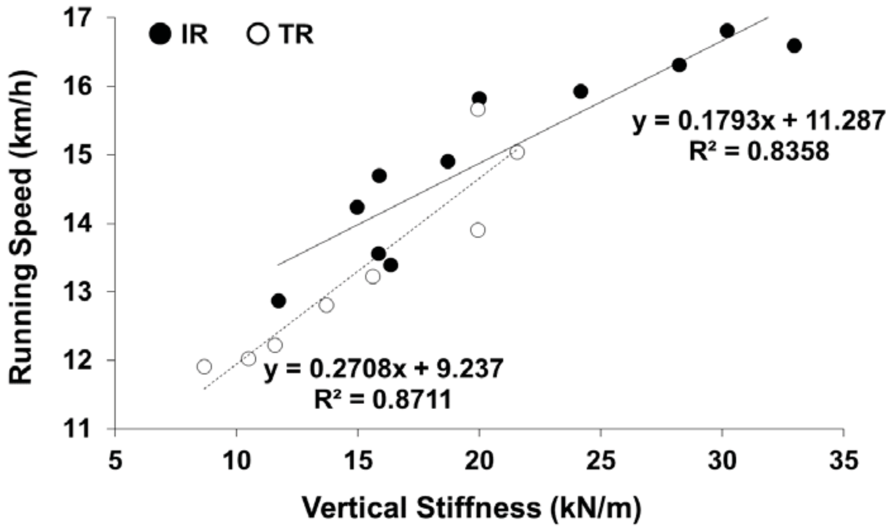

Figure 1: Relationship between the mean running speed and the vertical stiffness in both conditions.

DISCUSSION: In the present study, the relationship between performance and vertical stiffness in IR is consistent with the findings of previous studies (Arampatzis et al., 1999; Morin et al., 2005). This relationship was also confirmed in TR. In the evaluation of the difference in simple regression line angle, the interaction was nearly significant. However, the difference in regression slope between IR and TR is not considerable. For instance, when the vertical stiffness increased by a 1 kN/m, the increment in running speed was about 0.18 km/h in IR. However, the increment in running speed in TR was about 0.27 km/h. Vertical stiffness contributes strongly to performance in TR.
The primary factor of the decrement in performance between TR and IR is the decrease in RE (Hausswirth et al., 1996; Hue et al., 1998; Millet et al., 2000). Differences in performance level can affect the decline in RE (Bentley et al., 2008). Millet et al (2000) suggested that the decline in RE was greater in non-elite triathletes than in elite triathletes. The RE in TR could reflect the performance better. Vertical stiffness is complicated in RE (Heise et al., 1998), so the relationship between performance and vertical stiffness is stronger in TR than in IR. However, further investigation with more and widely subjects are required in the future because the number of subjects in this study is small. In the present study, vertical stiffness during a competition was evaluated. A fatigue caused by a 1.5-km swim and 40-km cycling depend on the competitor. Therefore, it is essential to investigate the relationship between the decrement in performance and vertical stiffness of TR to IR.

CONCLUSION: This study examined the relationship between performance and vertical stiffness of triathletes in IR and TR. Vertical stiffness was positively related to performance in both conditions and contributes strongly to performance in TR. Improvement of vertical stiffness should be more important to enhance the performance in TR.

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