ASSOCIATION BETWEEN BIOMECHANICAL CRITICAL SPEED AND THE SPEED AT ANAEROBIC THRESHOLD

Ting-Hung Huang[1], Yi-Cheng Chou[2], Yin-Shin Lee[2], Philip Xaver Fuchs[1], Tzyy-Yuang Shiang[2]
[1]Department of Physical Education and Sport Sciences, National Taiwan Normal University, Taipei, Taiwan
[2]Department of Athletic Performance, National Taiwan Normal University, Taipei, Republic of China

This study investigated the associations between the running speeds corresponding to deflection points in biomechanical parameters and the speed at the anaerobic threshold. Fifteen male recreational runners participated, running on a treadmill with gradual speed increases until perceived exhaustion. The anaerobic threshold was measured using a spiroergometry device, and kinematic data were recorded by four inertial sensors on their shanks and trunk. Stepwise regression analysis indicated that the running speeds at the deflection points of angular velocity of thorax rotation and peak tibial acceleration were the most effective predictors of the speed at the anaerobic threshold (adjusted R^2 = 0.65). The running speed at a kinematic deflection point proves to be an effective predictor of anaerobic threshold speed, providing a valuable tool for tailoring training intensities.

KEYWORDS: wearable device, long-distance running, running economy

INTRODUCTION: During exercise, the anaerobic threshold (AT) is reached when oxygen consumption surpasses the level at which aerobic energy production is supplemented by anaerobic mechanisms. This leads to a notable rise in both lactate levels and oxygen consumption. The significance of this power output lies in its functional implications, serving as a delineation for the workload beyond which metabolic acidosis intensifies. This prompts an acceleration in breathing stimulation and a subsequent decrease in exercise endurance (Wasserman, 1984).

Various methods, such as lactate threshold, gas exchange threshold, and critical speed, can be employed to evaluate AT. To enhance the efficiency of running training, researchers have sought to identify the speed at anaerobic threshold (SAT) by determining the fastest speed at which runners experience sudden changes in various physiological indicators (Maffulli et al., 1991). A close relationship between SAT and maximal oxygen uptake has been observed in elite male distance runners (Tjelta et al., 2012).

Given that the associations between SAT and maximal oxygen uptake and running economy have been examined (de Aguiar et al., 2012; Luhtanen et al., 1990), it is warranted to explore the relationship between SAT and biomechanical parameters during running. Folland et al. (2017) indicated that with an increase in running speed, corresponding changes in biomechanical parameters occurred, such as reduced ground contact time, increased loading rate, and greater oscillation of the center of mass. Similar to physiological indicators, including energy consumption and velocity of lactate turn point, changes in these biomechanical parameters followed a linear trend initially but exhibited nonlinear variations at a specific speed (Li et al., 2022), corresponding to the definition of SAT. However, there has been limited research discussing the speed at a deflection point of any biomechanical parameter, which may be potentially linked to SAT. Utilizing this information can aid in predicting a runner's SAT, assisting runners in adjusting their movements to enhance long-distance running performance.

This study aimed to examine the associations between the running speeds corresponding to deflection points in biomechanical parameters including ground contact time (GCT), flight time (FT), angular velocity of thorax rotation (TRAV), trunk vertical acceleration (TVA), peak tibial acceleration (PTA) and cadence (CA), and the SAT. We hypothesized a positive correlation between the running speeds corresponding to deflection points in biomechanical parameters and the SAT.

METHODS: This study recruited 15 male recreational runners with an average age of 28.79 ± 4.90 years. Participants had an average training experience of 2.64 ± 0.74 years, covered a minimum weekly training distance of 15 km, and demonstrated a maximum oxygen consumption of 57.14 ± 7.56 ml/min/kg.

Participants engaged in a walking warm-up on a treadmill, followed by a gradual increase in speed up to 8 km/hr. Subsequently, the speed was increased by 1.6 km/hr every minute. If a runner exceeded 17.6 km/hr, the speed increment was adjusted to 0.8 km/hr per minute. The running activity continued until participants voluntarily stopped due to perceived exhaustion.

Throughout the process, the anaerobic threshold was measured using a spiroergometry device (METALYZER® 3B, CORTEX Biophysik GmbH, DE). Additionally, four inertial measurement units (Blue Trident, Vicon Motion Systems Ltd, UK) were placed on the participant's shanks, sacrum, and thoracic spine (Figure 1).

The AT was determined using the V-slope method (Levett et al., 2018), and the running speed at the AT point was subsequently calculated. Kinematic data obtained were computed by respective formulas, which were further analyzed using the D-max mathematical model as outlined by Cheng et al. (1992) to identify deflection points representing significant changes in various biomechanical parameters. The D-max method involves conducting a third-order polynomial regression and drawing a straight line connecting the two endpoints of the curve. The deflection point, or D-max, is determined as the point with the greatest distance between the polynomial trend line and the straight line. Subsequently, this study calculated the running speed corresponding to each identified deflection point for every biomechanical parameter.

Bivariate correlation analysis (one-tailed) was conducted to investigate the relationship between the running speeds corresponding to deflection points in each biomechanical parameter and the SAT. Additionally, stepwise regression analysis was employed to identify the most effective predictors of the SAT, with adjusted R-square values reported. All statistical analyses were performed using SPSS 24.0 with a significance level of .05. To diagnose the multicollinearity among the predictors, the value of variance inflation factor (VIF) was calculated for each predictor in the regression model.

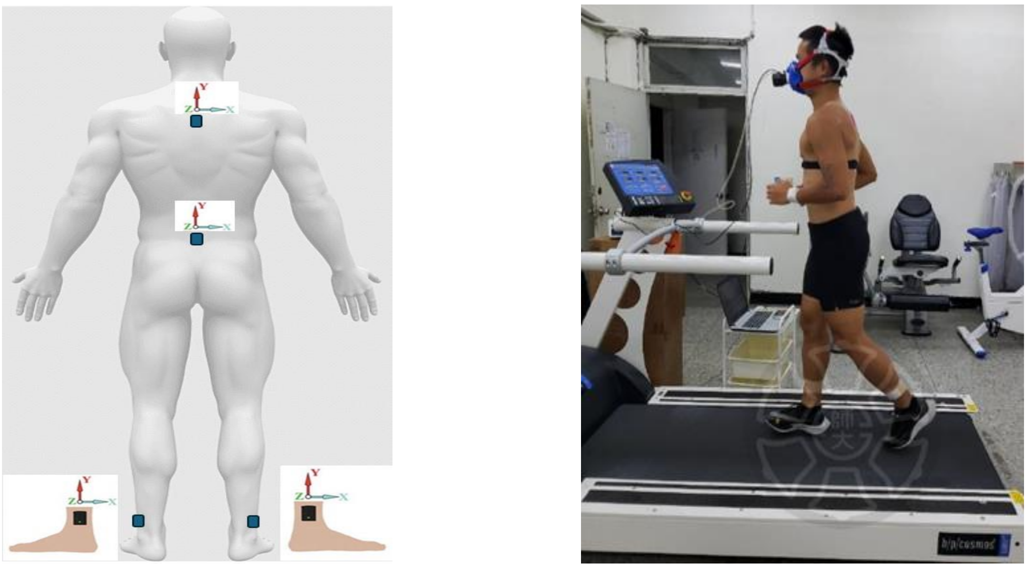

Figure 1: The placement of four inertial measurement units and treadmill running.

RESULTS: Table 1 displays the descriptive statistics and correlations between running speed at deflection points for each biomechanical parameter and the SAT. The correlations between SAT and running speeds at deflection points of GCT (r = .58, p = .012), FT (r = .62, p = .007), TRAV (r = .66, p = .004), PTA (r = .63, p = .006) and CA (r = .54, p = .018) were statistically significant ($p < .05$), except for TVA ($r = .20$, $p = .239$). Stepwise regression analysis indicated that the most robust formula for predicting SAT is -11.282 + 0.75 * TRAV + 1.113 * PTA (R^2 = 0.67, adjusted R^2 = 0.65). The VIF values for TRAV and PTA were both 1.02, suggesting a very low multi-collinearity of each independent variable in the regression model.

Table 1: Summary of bivariate correlations, means and standard deviations.

	1	2	3	4	5	6	7
1. SAT	-						
2. GCT	.58*	-					
3. FT	.62*	.71*	-				
4. TRAV	.66*	.76*	.54*	-			
5. TVA	.20	.20	.50	.04	-		
6. PTA	.63*	.18	.24	.25	.28	-	
7. CA	.54*	.26	.33	.52*	.53*	.75*	-
Mean**(km/hr)**	13.33	12.39	12.43	13.27	12.97	12.96	13.81
SD	1.98	1.47	1.41	1.35	0.60	0.93	0.82

Note: SAT = the speed at anaerobic threshold; GCT = ground contact time; FT = flight time; TRAV = angular velocity of thorax rotation; TVA = trunk vertical acceleration; PTA =peak tibial acceleration; CA = cadence; $^*p < .05$, one-tailed.

DISCUSSION: This study aimed to investigate the associations between SAT and the running speeds corresponding to deflection points in various biomechanical parameters. The results revealed significant correlations between the speed at anaerobic threshold and the running speeds at deflection points of ground contact time, flight time, angular velocity of thorax rotation, peak tibial acceleration, and cadence. Importantly, angular velocity of thorax rotation and peak tibial acceleration and were the most effective predictors of the speed at anaerobic threshold.

During running, the degree of trunk rotation tends to increase with higher speeds. This augmentation in trunk rotation is closely associated with lower limb dynamics. Larger trunk rotation is correlated with an increased stride length at equivalent speeds. Similarly, amateur runners demonstrated an elevation in the horizontal plane rotation of the trunk with increasing running speeds (Fisher et al., 2018). Given that trunk rotation involves substantial muscle movement, changes in its magnitude during running appear to be more readily observable.

Peak tibial acceleration emerges as a robust predictor of SAT, substantiated by its validation as a reflection of the loading rate during running—a ratio of the first peak to the time when the runner makes contact with the ground (Ueda et al., 2016). Consequently, the utility of peak tibial acceleration extends to portraying the impact on the lower limbs with each landing, with this impact magnitude exhibiting a strong correlation with fatigue (Pohl et al., 2008). Beyond its correlation with landing strategies (forefoot, midfoot, heel strike), peak tibial acceleration also demonstrates an increase with higher running speeds (Van den Berghe et al., 2019).

Additionally, this study observed that the deflection points for most kinematic parameters occurred at speeds earlier than the anaerobic threshold speed. This phenomenon could be attributed to the idea that as physiological changes manifest with escalating exercise intensity, the biomechanical characteristics of the runners may have already undergone alterations.

This study has several limitations that warrant caution. Firstly, the research design is cross-sectional, restricting the establishment of causal relationships between relevant variables. Future research, particularly through experimental manipulation, is needed to address this limitation. Secondly, the small sample size increases the potential bias of our findings. Therefore, a larger sample size is recommended to enhance the generalizability of the results.

CONCLUSION: This study emphasizes the predictive value of running speeds at the deflection points of angular velocity of thorax rotation and peak tibial acceleration for the speed at the anaerobic threshold. The biomechanical critical speed not only holds significance in the mechanics of running but also proves to be an effective predictor of anaerobic threshold speed, comparable to traditional physiological thresholds. In practical applications, this indicator can be utilized to estimate the anaerobic threshold and customize training intensities. As future research unfolds, there is an opportunity for further exploration into the relationship between biomechanical and physiological deflection points.

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