MECHANICAL WORK CALCULATION METHODS TO EVALUATE DISTANCE RUNNERS

Keitaro Seki[1], Kohei Yamamoto[1], Kiyonobu Kigoshi[2] and Yasushi Enomoto[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 main purpose of this study was to discuss mechanical work calculation methods for evaluating the effectiveness of running at six different speed. Nineteen male middle and long distance runners were participated in the study, as subjects. Biomechanical measurements were in order to record running motion and ground reaction force. Mechanical work was calculated using two methods: the joint torque power method (W_{TP}) and the mechanical energy method (W_{ME}). Physiological measurements were recorded using submaximal and maximal incremental exercise tests on a treadmill. These results were as follows: 1) W_{TP} was significantly larger than W_{ME}. 2) $W_{TP/W/TIME}$ was stronger related to velocity and aerobic demands. These findings suggest that regression equation between $W_{TP/W/TIME}$ and velocity evaluate effectiveness of distance runner.

KEY WORDS: mechanical work, joint torque power method, mechanical energy method.

INTRODUCTION: Techniques in distance runners have been evaluated using efficiency (Cavanagh and Kram, 1985). Previous studies have used the effectiveness index (Cavanagh & Kram, 1985; Ae & Fujii, 1996) as ratio of performance and mechanical work. However, in this study we have two questions about the effectiveness index. Since there is a relationship between the running velocity and effectiveness, it is difficult to assess using effectiveness index for several levels of runners. Thus, running velocity must be normalized to evaluate effectiveness in distance running. Second, it is considered that the calculation methods used in relation to mechanical work may need to consider. Mechanical work calculation method for human movement has been studied, and many calculation methods were proposed by previous studies. Currently, mechanical work is calculated using two methods: joint torque power method (Winter, 1983) and mechanical energy method (Pierrynowski et al., 1980). It is necessary to investigate mechanical work calculation method in distance running to compare physiological energy measured oxygen consumption. We hypothesize that there was relationship between mechanical work and physiological energy. Therefore the purpose of this study is to discuss methods used in evaluating the effectiveness of running at six different speed levels.

METHODS: Nineteen male Japanese distance runners (age: 20.84 ± 2.18 years; height: 1.72 ± 0.05m; weight: 60.16 ± 5.17 kg) participated in this study after writing informed consents. The subjects were asked to run at six speeds, 3.3, 3.7, 4.2, 4.8, 5.6 and 6.0 m/s on the 30m runway in the experimental floor. 3D coordinates data of reflective markers placed on the body (47 points) were captured using a motion capture system (Vicon MX+, 250 Hz), and ground reaction force data was simultaneously recorded using force platforms (Kistler, 1000 Hz). The coordinate data were smoothed using a Butterworth digital filter at 2.5-25 Hz, as a result of residual analysis for each point. In addition, the mass, center of mass location and moments of inertia of the body segments were estimated from the body segment parameters of Ae et al. (1992). Joint torque was calculated by an inverse dynamics approach using 15 segments rigid body model. First, the mechanical work was calculated using the joint torque power method (W_{TP}), by integrating the joint torque power, which is an inner product of joint torque and joint angular velocity; and second using mechanical energy method (W_{ME}), which calculate it by sum of absolute changes in segment energy for all

segments over time (Pierrynowski et al., 1980). Futhermore, the results of both methods used to calculate the mechanical work were normalised by weight ($W_{TP/W}$ and $W_{ME/W}$) and by time of a running cycle ($W_{TP/W/TIME}$ and $W_{ME/W/TIME}$).
Physiological measurements were recorded on a treadmill using the sub maximal and maximal incremental exercise test. $\dot{V}O_2$ was analyzed using an expired gas analyzers (Minato AE-301s). $\dot{V}O_2max$, $v\dot{V}O_2max$ and aerobic demands were calculated at six speeds, Differences between the running velocities and the calculation methods were then tested using the 2-way ANOVA. Relationships between mechanical work and velocity or aerobic demands were tested using the Pearson product-moment correlation coefficient. Regression analysis were used to generate individual regression equation estimating mechanical work from velocity. The level of statistical significance was set at 5%.

RESULTS: Table 1 shows mechanical work calculated two different methods in the biomechanical measurements. The W_{TP} at the speed of 3.3, 3.7, 4.2, 4.8, 5.6, and 6.0 m/s were 443.37 ± 62.48, 508.35 ± 70.52, 570.16 ± 90.10, 664.82 ± 87.00, 798.75 ± 96.27 and 897.99 ± 103.93 J, respectively. The W_{ME} at the speed of 3.3, 3.7, 4.2, 4.8, 5.6, and 6.0 m/s were 364.44 ± 59.05, 406.39 ± 64.17, 433.53 ± 83.48, 517.28 ± 115.39, 578.02 ± 120.85 and 673.68 ± 116.54 J, respectively. W_{TP} and W_{ME} were increased as the running velocity increased (Fig. 1). The 2-way ANOVA showed that there were significant differences between the two calculation methods used at all velocities. In addition, there were significant differences among all velocities for W_{TP} and W_{ME} (Table 2). $\dot{V}O_2max$ and $v\dot{V}O_2max$ were 66.33 ± 7.31 ml/min/kg and 5.01 ± 0.32 m/s, respectively. Aerobic demands at the speed of 3.3, 3.7, 4.2, 4.8, 5.6, and 6.0 m/s were 42.39 ± 4.15, 47.81 ± 4.50, 54.35 ± 5.69, 63.23 ± 6.49, 73.53 ± 8.34 and 80.91 ± 9.10 ml/min/kg, respectively.

Table 1: Mechanical work calculated by two methods.

	Privided velocity					
	3.3 m/s	3.7 m/s	4.2 m/s	4.8 m/s	5.6 m/s	6.0 m/s
W_{TP} (J)	443.37±62.48	508.35±70.52	570.16±90.10	664.82±87.00	798.75±96.27	897.99±103.93
$W_{TP/W}$ (J/kg)	7.49±0.89	8.58±0.84	9.61±1.00	11.22±0.89	13.49±0.98	15.19±1.28
$W_{TP/W/TIME}$ (J/kg/sec)	10.51±0.99	12.18±1.04	14.07±1.27	16.86±1.27	21.41±1.86	25.30±2.64
W_{ME} (J)	364.44±59.05	406.39±64.17	433.53±83.48	517.28±115.39	578.02±120.85	673.68±116.54
$W_{ME/W}$ (J/kg)	6.18±0.73	6.86±0.86	7.32±1.18	8.71±1.55	9.71±1.38	11.38±1.64
$W_{ME/W/TIME}$ (J/kg/sec)	8.66±0.83	9.72±0.99	10.69±1.35	13.06±2.16	15.36±2.00	18.85±2.31

Table 2: 2-way ANOVA results of a mechanical work comparison using different methods and velocities.

Source	df	F	p	partial η^2	multiple comparison
Method	1	239.35	<0.001	0.93	all: $W_{ME}<W_{TP}$
Velocity	5	178.94	<0.001	0.91	W_{TP}: 3.3<3.7<4.2<4.8<5.6<6.0 W_{ME}: 3.3<3.7<4.2<6.0, 4.2<4.8<6.0
Method×Velocity	5	18.25	<0.001	0.50	

Figure 1 shows relationships between mechanical work and velocity, and between mechanical work and aerobic demands. There were significant relationships between $W_{TP/W/TIME}$ and velocity (r = 0.96; p<0.001), between $W_{ME/W/TIME}$ and velocity (r = 0.90;

p<0.001), between $W_{TP/W/TIME}$ and aerobic demands ($r = 0.89$; $p<0.001$) and between $W_{ME/W/TIME}$ and aerobic demands ($r = 0.83$; $p<0.001$). The correlation coefficient between $W_{TP/W/TIME}$ and velocity or aerobic demands was larger than that between $W_{ME/W/TIME}$ and velocity or aerobic demands. The coefficient of determine of individual regression equation in $W_{TP/W/TIME}$ and $W_{ME/W/TIME}$ were 0.97 ± 0.02 and 0.88 ± 0.08, respectively.

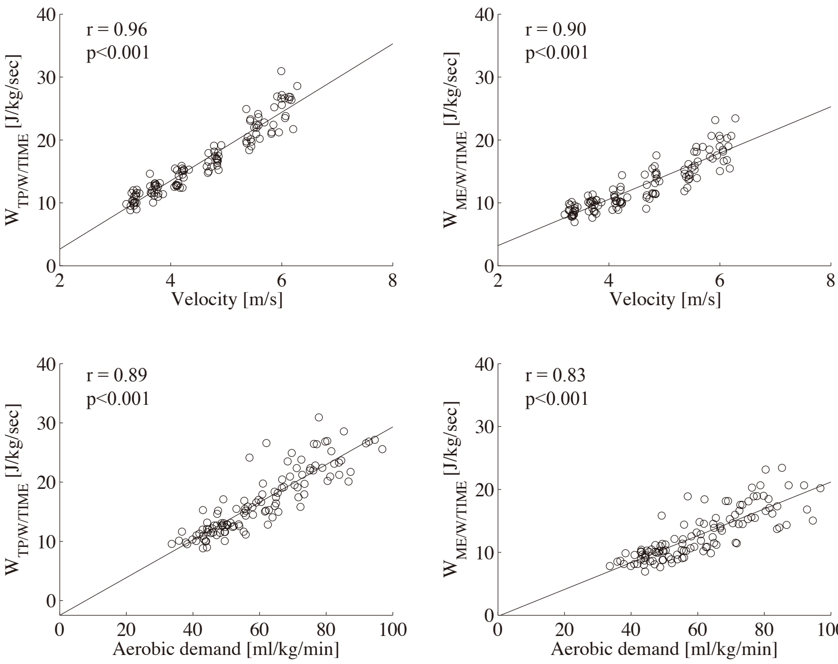

Figure 1: Relationships between Mechanical work calculated two methods, velocity and aerobic demands.

DISCUSSION: In relation to the differences in mechanical work, W_{TP} was significantly larger than W_{ME} at each velocity. Since W_{ME} is algebraic sum of the segmental energy changed, if mechanical energy generated by one joint and absorbed by another then the mechanical energy generated is equal to that absorbed and thus W_{ME} is cancelled. In running, since much of mechanical energy is generated and absorbed simultaneously, this suggests that the mechanical energy method underestimates mechanical work. Moreover, it makes it difficult to determine the amount of mechanical energy changed generated or absorbed by transfer.

The correlation coefficients between $W_{TP/W/TIME}$ and velocity or aerobic demands were greater than between $W_{ME/W/TIME}$ and velocity or aerobic demands. The coefficient of determine of individual regression equation using $W_{TP/W/TIME}$ also greater than that using $W_{ME/W/TIME}$. In addition, we could generate regression equation between velocity and $W_{TP/W/TIME}$, and p value of individual regression equation using $W_{TP/W/TIME}$ was smaller than that using $W_{ME/W/TIME}$ in most of subjects. It is assumed mechanical work increase with velocity, and aerobic demands also increase with mechanical work. Thus, it is implied that using joint torque power method could accurately estimate mechanical work in distance running than using mechanical energy method.

Furthermore, using individual regression equation could evaluate effectiveness of distance runner. The inclination and intercept of regression equation could be used to evaluate for effectiveness in distance running. Lower inclination and lower intercept suggest highly effectiveness through all velocity.

CONCLUSION: When mechanical work was calculated using the joint torque power method (W_{TP}), the values were significantly larger than when calculated using the mechanical energy method (W_{ME}) at all velocities. In addition, $W_{TP/W/TIME}$ were stronger related to velocity and aerobic demands than $W_{ME/W/TIME}$. These results suggest that mechanical work calculation method desire to use joint torque power method. Furthermore, individual regression equation between $W_{TP/W/TIME}$ and velocity may evaluate effectiveness of distance runner.

REFERENCES:

Ae, M. & Fujii, N. (1996) Effectiveness of mechanical energy utilization and its index in human movement. *The Bulletin of Institute of Health & Sport Sciences, University of Tsukuba*, 19, 127-137.

Ae M., Tang, H. & Yokoi, T. (1992) Estimation of inertia properties of the body segments in japanese athletes. *Biomechanism*, 11, 22-23.

Cavagna, G. A. (2009) The two asymmetries of the bouncing step. European Journal of Applied Physiology, 107:739-742.

Cavanagh, P. R. & Kram, R. (1985) The efficiency of human movement—a statement of problem. *Medicine and Science in Sports and exercise.* 17(3), 304-308.

Martin, D. E. & Coe, P. N. (1997) Better training for distance runner. Human Kinetics.

Pierrynowski, M. R., Winter, D. A. & Norman, R. W. (1980) Transfers of mechanical energy within the total body and mechanical efficiency during treadmill walking. *Ergonomics*, 23, 147-156.

Winter, D. A. (1983) Moments of force and mechanical power in jogging. *Journal of Biomechanics*, 16(1), 91-97.