Relationship between Classic Physiological Variables and Running Performance in Recreational Runners

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The purpose of this study was to investigate the relationship between classic physiological variables [maximal oxygen uptake ($\dot{V}O_2\text{max}$), % $\dot{V}O_2\text{max}$ at anaerobic threshold (AT), and running economy (RE)] and running performance in recreational runners. 39 recreational runners (24 males and 15 females) underwent a treadmill running test to determine the classic physiological variables and velocity at AT (vAT). AT was defined as the point at which the respiratory exchange ratio stabilized above 1.0, and it was used as an indirect performance variable. Multiple regression analysis showed that 94% of vAT values were explained by all classic physiological variables ($p < 0.001$). In addition, all variables were significantly explanatory ($\dot{V}O_2\text{max}$, $p < 0.001$; % $\dot{V}O_2\text{max}$ at AT, $p < 0.001$; and RE, $p < 0.001$). In total, 35 subjects had completed a marathon within the past year. For these subjects, single regression analysis was performed, which showed that 67% of recent marathon times was explained by vAT ($r = 0.82$, $p < 0.05$). This study indicated that during a treadmill running test, $\dot{V}O_2\text{max}$, % $\dot{V}O_2\text{max}$ at AT, and RE can precisely explain vAT, which is highly correlated with recent marathon times.

Keywords: maximal oxygen uptake, running economy, fractional utilization, anaerobic threshold

1. Introduction

The maximal oxygen uptake ($\dot{V}O_2\text{max}$), fractional utilization of $\dot{V}O_2\text{max}$ at anaerobic threshold (% $\dot{V}O_2\text{max}$ at AT), and running economy (RE) are physiological variables that determine distance running performance (Joyner, 1991). These 3 variables have been used in the classic model for predicting distance running performance in elite runners (Joyner, 1991; McLaughlin et al., 2010; Tjelta et al., 2012). For example, McLaughlin et al. (2010) have found that the classic physiological variables explain 95% of the variation in 16-km running performances.

It is well known that $\dot{V}O_2\text{max}$, % $\dot{V}O_2\text{max}$ at AT, and RE are limited by different factors. $\dot{V}O_2\text{max}$ is largely determined by the maximal cardiac output, whereas it has been suggested that peripheral factors such as muscle fiber composition and fat metabolism limit % $\dot{V}O_2\text{max}$ at AT (Joyner and Coyle, 2008). RE is a multifactorial variable, which reflects metabolic, cardiorespiratory, biomechanical, and

neuromuscular characteristics (Barnes and Kilding, 2015). Considering the training principle of specificity, the assessment of all classic physiological variables is valuable for runners to understand their physiological strengths and weaknesses (i.e., trainability). Jones and Carter (2000) have emphasized that endurance training should be conducted on the basis of trainability, as concluded from a review of the effect of endurance training on physiological variables.

Measurement of the functional capacity during a treadmill running test has the advantage of evaluating performance without being affected by the environmental factors such as climate and terrain. Many studies have reported that velocity at AT (vAT) during the treadmill running test is one of the best predictors of distance running performance (Farrell et al., 1979; Noakes et al., 1990; Rhodes and McKenzie, 1984; Roecker et al., 1998; Sjödin and Jacobs, 1981). This result is not surprising because vAT integrates $\dot{V}O_2\text{max}$, % $\dot{V}O_2\text{max}$ at AT, and RE (Joyner, 1991; Tjelta et al., 2012). Further,

during a recent study on elite runners, it was found that the classic physiological variables explain 89% of the variation in vAT (Tjelta et al., 2012).

Countless recreational runners train hard to improve their distance performance (García-Pinillos et al., 2017). At present, many laboratories and sports facilities have expired gas analyzers, and the treadmill running test may be more accessible to recreational runners. In the past, compared with $\dot{V}O_{2\max}$, RE had not been considered as an important physiological factor for determining distance running performance in recreational runners (Engeroff et al., 2016). Engeroff et al. (2016) recently investigated the relationship between RE and vAT in recreational runners, and reported that runners with superior RE had a higher vAT among the runners with equivalent $\dot{V}O_{2\max}$. These data suggest that RE influence performance even in recreational runners. However, to our knowledge, no previous study has sought to elucidate the relationship between $\dot{V}O_{2\max}$, % $\dot{V}O_{2\max}$ at AT, and RE and performance in recreational runners.

Given the characteristic of recreational runners, it is preferable that the test to measure classic physiological variables and vAT is less invasive and easy to quantify. It has been previously reported that AT, which is defined as a respiratory exchange ratio (RER) greater than 1.0 (RER1.0) in the maximal incremental test where velocity is increased every minute, allowed a fair estimation of the velocity at maximal lactate steady state (MLSS) (Leti et al., 2012) and was reproducible with a low intra-individual variability (Laplaud and Menier, 2003). The RER1.0 method has the advantage that it can be quantified without using invasive procedures (i.e., blood sampling), which would be particularly important for recreational runners. Moreover, unlike other ventilatory methods, the RER1.0 method is easy to perform and does not require individual subject data slope-fitting techniques (Chin et al., 2010). Therefore, RER1.0 is a useful method for measuring distance performance in recreational runners. A recent study has indicated that there were significant relationships between vAT, which was quantified by the RER1.0 method, and recent marathon time in 11 recreational runners who completed the same race one week before the test (Takayama et al., 2017). In that study, however, the sample size was relatively small and the detailed relationship between classic physiological variables

and performance was not reported (Takayama et al., 2017).

The purpose of the present study was to investigate the relationship between classic physiological variables and vAT in recreational runners. Based on the previous findings discussed above, we hypothesized that $\dot{V}O_{2\max}$, % $\dot{V}O_{2\max}$ at AT, and RE can precisely explain vAT.

2. Methods

2.1. Subjects

39 recreational runners (24 males and 15 females) participated in the present study. Descriptive characteristics of the subjects are presented in **Table 1**. The inclusion criteria were as follows: (1) the subjects regularly trained for at least 1 day per week; (2) they were healthy and reported no cardiorespiratory and musculoskeletal disorders; and (3) they had completed a marathon (42.195 km) at least once. Before participation, the subjects were provided with information sheets regarding the study process, and they provided written informed consent. The study was approved by the Ethics Committee of the University of Tsukuba and was performed in accordance with the principles of the Declaration of Helsinki.

2.2. Treadmill running test

The treadmill running test was performed on a motorized treadmill (ORK-7000, Ohtake Root Kogyo, Japan) set at 1% gradient, which accurately reflects the energy cost of outdoor running (Jones and Doust, 1996). The subjects consumed a light meal at least 3 h before the test, and during the 3 h prior to the test, only ad libitum water intake was allowed. Body weight was measured before the test (TBF-102, Tanita, Japan).

The subjects completed a two-part test that consisted of an RE test and a maximal incremental test. Expired gas analysis was continuously performed on a breath-by-breath basis using the computerized standard open circuit technique, and the data were then converted into 20-s time-binned mean values (AE-310s, Minato Medical Science, Japan). Before each test, the oxygen and carbon dioxide analyzers were calibrated using known gas concentrations, and flow calibration was performed using a 2-L

Table 1 Descriptive data of the subjects.

	Fair (n = 18)	Good (n = 9)	Excellent (n = 12)	All (n = 39)
Sex (M/W)	7/11	6/3	11/1	24/15
Age (years)	40.9 ± 11.7 (35.5–46.3)	40.3 ± 8.0 (35.1–45.6)	31.8 ± 11.4 (25.4–38.3)	38.0 ± 11.4 (34.4–41.5)
Height (cm)	163 ± 8 (159–166)	169 ± 8 (164–174)	170 ± 5 ^a (167–173)	166 ± 8 (164–169)
Weight (kg)	55.7 ± 7.8 (52.1–59.3)	57.1 ± 5.9 (53.2–60.9)	59.1 ± 6.9 (55.3–63.0)	57.1 ± 7.1 (54.8–59.3)
Training volume (h/week)	4.0 ± 1.6 (3.2–4.7)	8.5 ± 5.3 ^a (5.1–11.9)	5.5 ± 2.6 (4.0–7.0)	5.5 ± 3.5 (4.4–6.6)
Training frequency (times/week)	3.2 ± 1.1 (2.7–3.7)	4.7 ± 1.4 ^a (3.7–5.6)	4.5 ± 1.4 ^a (3.7–5.3)	3.9 ± 1.4 (3.5–4.4)
Longest training session (km)	30.2 ± 15.6 (23.0–37.4)	69.3 ± 42.8 ^a (41.3–97.3)	58.8 ± 49.3 (30.8–86.7)	48.0 ± 38.7 (35.9–60.2)
Recent marathon time (min)	256.7 ± 30.7 (242.6–270.9)	201.8 ± 12.9 ^a (193.4–210.2)	176.3 ± 19.3 ^a (165.3–187.2)	219.3 ± 43.4 (205.7–232.9)

Values are expressed as mean ± SD and 95%CI.

^a Significantly different from the fair group.

syringe.

The subjects underwent a 5-min RE test at a sub-maximal intensity. The previous study revealed that O_2 cost did not differ from 85% to 110% of the average velocity of the best marathon (di Prampero et al., 2009). Therefore, the treadmill velocity was set to 85%, corresponding to the average velocity of a recent marathon. However, as the O_2 cost of walking and running are equal at a velocity of approximately 8.0 km/h; at a velocity lower than this, walking is more efficient (Hagberg and Coyle, 1984). The treadmill velocity was set at 8.0 km/h if the runner's recent marathon time was 270 min or more. Because there was no significant increase in $\dot{V}\text{O}_2$ during the last 2 min of the RE test, the data obtained from gas analysis during the last 1 min were used in the analysis. In the RE test, the respiratory exchange ratio (RER) of all the subjects were <1.0, and RE was expressed as the O_2 cost (ml/kg/km).

Following a 5-min recovery period after the RE test, the maximal incremental test was performed to determine % $\dot{V}\text{O}_{2\text{max}}$ at AT, vAT, and $\dot{V}\text{O}_{2\text{max}}$. The initial velocity was set at 8.4 km/h and was increased by 0.6 km/h every 60 s until volitional exhaustion, which was defined as the point at which the subject could no longer run at the required velocity. AT was defined as the point at which RER stabilized above 1.0 (RER1.0) (Solberg et al., 2005). $\dot{V}\text{O}_{2\text{max}}$ was defined as the attainment of at least 2

of the following 4 criteria: (1) a leveling-off of $\dot{V}\text{O}_2$ despite an increase in treadmill velocity, (2) maximal RER ≥ 1.1 , (3) maximal heart rate $\geq 90\%$ of the subject's age-predicted maximal heart rate (i.e., $220 - \text{age}$), and (4) perceived exertion rating ≥ 19 (Howley et al., 1995).

2.3. Training status

Before the treadmill running test, the subjects were asked to complete the questionnaires regarding the training volume, training frequency, and longest training session during the previous 3 months.

2.4. Statistical analysis

Data are expressed as mean and standard deviation (SD), with 95% confidence interval (CI). Statistical analyses were performed using SPSS Statistics 24 (IBM Japan, Japan). Simultaneous multiple regression analysis was used to explain vAT according to a classic model that included $\dot{V}\text{O}_{2\text{max}}$, % $\dot{V}\text{O}_{2\text{max}}$ at AT, and RE. A Pearson correlation analysis was performed for men, women, and both together. For subjects who completed a marathon within the past year, single regression analysis was performed between vAT and recent marathon times. All the subjects were classified in 3 subgroups based on their vAT using percentile values (fair, percentile ≤ 33 ; good, percentile between 33 and 66;

and excellent, percentile >66) (Fernandes-da-Silva et al., 2016). For comparison of the classic physiological variables and training status between subgroups, one-way analysis of variance (ANOVA) and Tukey's post hoc test were performed. An unpaired t-test was performed to compare classic physiological variables and vAT between men and women. The significance level for all the comparisons was set at $p < 0.05$.

3. Results

3.1. Relationship between classic physiological variables, vAT, and recent marathon times

Multiple regression analysis showed that 94% of vAT values could be explained by $\dot{V}O_{2\max}$, % $\dot{V}O_{2\max}$ at AT, and RE ($p < 0.001$). In addition, all variables were significantly explanatory ($\dot{V}O_{2\max}$, $p < 0.001$; % $\dot{V}O_{2\max}$ at AT, $p < 0.001$; and RE, $p < 0.001$) (Table 2).

In total, 35 subjects had completed a marathon within the past year (154 ± 111 days). For these subjects, single regression analysis was performed, which showed that 67% of recent marathon times was explained by vAT ($r = 0.82$, $p < 0.001$).

3.2. Classic physiological variables and vAT among subgroups

Age and weight were not significantly different among the subgroups (Table 1). Height was in the excellent group was higher than that in the fair group.

Table 3 shows $\dot{V}O_{2\max}$, % $\dot{V}O_{2\max}$ at AT, RE,

Table 2 Simultaneous multiple regression with velocity at anaerobic threshold as classic physiological variables.

	B	SEE	β
(Constant)	2.643	2.160	
$\dot{V}O_{2\max}$	0.202	0.011	0.827*
% $\dot{V}O_{2\max}$ at AT	0.078	0.015	0.225*
RE	-0.031	0.005	-0.309*
SEE	0.539		
R ²	0.937		

$\dot{V}O_{2\max}$, maximal oxygen uptake; % $\dot{V}O_{2\max}$ at AT, fractional utilization of $\dot{V}O_{2\max}$ at anaerobic threshold; RE, running economy (expressed as oxygen cost); B, unstandardized regression coefficient; SEE, standard error of measurement; β , regression coefficient; R², coefficient of determination; * $p < 0.001$

and vAT among the subgroups. One-way ANOVA demonstrated overall significant subgroup differences in $\dot{V}O_{2\max}$ RE, and vAT. Tukey's post hoc test demonstrated a stair-step pattern in $\dot{V}O_{2\max}$ (fair < good < excellent). O_2 cost in the excellent group was better (i.e., lower) than that in the fair group. % $\dot{V}O_{2\max}$ at AT showed no significant differences among the subgroups. As expected, vAT showed a stair-step pattern among the subgroups.

3.3. Training status among subgroups

Table 1 shows the training volume, training frequency, and longest training session for each subgroup. Training volume, training frequency, and longest training session in the good group was higher than those in fair group. Moreover, training frequency between fair and excellent groups was also significantly different. There were no differences between the good and excellent groups in terms of training status.

Recent marathon time in the fair group was significantly lower than that in the good and excellent groups (Table 1). Although recent marathon time between good and excellent groups was not significantly different, the value approached significance ($p = 0.058$).

3.4. Classic physiological variables and vAT between men and women

Table 4 shows classic physiological variables and

Table 3 Comparison of classic physiological variables and velocity at anaerobic threshold among subgroups.

	Fair (n = 18)	Good (n = 9)	Excellent (n = 12)
$\dot{V}O_{2\max}$ (ml/kg/min)	49.4 ± 5.0 (47.1–51.7)	58.0 ± 5.1 ^b (54.7–61.4)	64.5 ± 5.6 ^a (61.3–67.7)
% $\dot{V}O_{2\max}$ at AT (%)	91.6 ± 3.5 (85.8–92.6)	89.4 ± 5.1 (86.1–92.8)	88.5 ± 4.3 (86.1–91.0)
RE (ml/kg/km)	234.3 ± 21.5 (224.4–244.3)	218.3 ± 18.5 (206.2–230.4)	210.0 ± 10.0 ^b (204.3–215.6)
vAT (km/h)	12.4 ± 1.2 (11.9–13.0)	14.4 ± 0.0 ^b (14.4–14.4)	16.4 ± 1.4 ^a (15.6–17.2)

$\dot{V}O_{2\max}$ = maximal oxygen uptake; % $\dot{V}O_{2\max}$ at AT, fractional utilization of $\dot{V}O_{2\max}$ at anaerobic threshold; RE, running economy (expressed as oxygen cost); vAT, velocity at anaerobic threshold. Values are expressed as mean ± SD and 95% CI.

^a Significantly different ($p < 0.05$) from fair and good groups.

^b Significantly different ($p < 0.05$) from the fair group.

Figure 1 Relationship between maximal oxygen uptake (A), fractional utilization of maximal oxygen uptake at anaerobic threshold (B), and running economy (C) and velocity at anaerobic threshold. Closed circles indicate men and open circles indicate women.

Table 4 Comparison of classic physiological variables and velocity at anaerobic threshold between men and women.

	Men (n = 24)	Women (n = 15)	All (n = 39)
$\dot{V}O_2\text{max}$ (ml/kg/min)	59.6 ± 7.8 (56.4–62.7)	50.4 ± 5.9^a (47.4–53.4)	56.0 ± 8.4 (53.4–58.7)
% $\dot{V}O_2\text{max}$ at AT (%)	88.7 ± 5.6 (86.5–91.0)	89.6 ± 6.5 (86.3–92.9)	89.1 ± 5.9 (87.2–90.9)
RE (ml/kg/km)	222.4 ± 21.5 (213.8–231.0)	224.3 ± 19.9 (214.2–234.4)	223.1 ± 20.7 (216.6–229.6)
vAT (km/h)	14.9 ± 2.0 (14.0–15.7)	12.9 ± 1.5^a (12.1–13.7)	14.1 ± 2.1 (13.5–14.8)

$\dot{V}O_2\text{max}$ = maximal oxygen uptake; % $\dot{V}O_2\text{max}$ at AT, fractional utilization of $\dot{V}O_2\text{max}$ at anaerobic threshold; RE, running economy (expressed as oxygen cost); vAT, velocity at anaerobic threshold. Values are expressed as mean $\pm$ SD and 95% CI.

^a Significantly different ($p < 0.05$) from men.

vAT between men and women. $\dot{V}O_2\text{max}$ and vAT in men were significantly higher than that in women. % $\dot{V}O_2\text{max}$ at AT and RE were not significantly different between men and women.

Figure 1 shows the relationship between classic physiological variables and vAT. The significant relationships of $\dot{V}O_2\text{max}$ and RE were unchanged between men and women.

4. Discussion

The present study investigated the relationship between classic physiological variables and performance in recreational runners. The main finding of our study was that $\dot{V}O_2\text{max}$, % $\dot{V}O_2\text{max}$ at AT, and

RE can precisely explain vAT , which is highly correlated with recent marathon times. This finding indicates that vAT is a representative performance index reflecting classic physiological variables.

Measuring functional capacity during a treadmill test has the advantage of evaluating performance without being affected by the environmental factors. Furthermore, a time lag existed between treadmill running test and recent marathon race in the present study ($n = 35$, 154 ± 111 days), suggesting that the classic physiological variables may change somewhat from those in the race. Takayama et al. (2017) showed that approximately 80% of recent marathon time could be explained using vAT ($r = 0.897$, $p < 0.001$) in 11 recreational runners who completed the same race one week before the test. Compared with that previous report, the explanatory rate in this study was relatively lower (67%). The vAT was used as performance index, because we wanted to focus on physiological aspects.

$\dot{V}O_2\text{max}$ is limited by the capacity of the cardiorespiratory system to deliver O_2 to the exercising muscles (Bassett and Howley, 2000). In the present study, $\dot{V}O_2\text{max}$ showed a stair-step pattern among the subgroups (fair < good < excellent). Moreover, the highest correlation coefficient value was observed between $\dot{V}O_2\text{max}$ and vAT ($r = 0.882$). It is well established that a high $\dot{V}O_2\text{max}$ is a prerequisite for success in distance running performance (Foster, 1983; Hagan et al., 1981; Sjödín and Svedenhag, 1985). For example, Foster (1983) has investigated the relationship between $\dot{V}O_2\text{max}$ and marathon time in 25 well-trained male runners and has reported that the marathon time was highly correlated with $\dot{V}O_2\text{max}$ ($r = -0.96$). The data collected in the present study support these previous findings.

Morgan et al. (1995) investigated the O_2 cost in 4 subgroups at different levels (elite, subelite, good, and untrained runners) and showed that untrained runners were uneconomical than other runners, whereas, subelite and good runners were uneconomical than elite runners. They also showed that the average within-group variability in the O_2 cost was similar across categories and that a marked overlap of minimum, mean, and maximal economy values existed across groups. In the present study, the excellent group was more economical than the fair group. In addition, 95% CI values of the O_2 cost overlapped between the excellent and good groups

(Table 3). These results are in agreement with those reported by Morgan et al. (1995). In the past, RE in recreational runners had not been considered as an important physiological factor for determining distance running performance (Engeroff et al., 2016). However, a recent study has provided evidence that RE influences distance running performance even in recreational runners (Engeroff et al., 2016). Taken together, we would like to emphasize that recreational runners should pay attention not only to $\dot{V}O_2\text{max}$ but also to improvement in RE (i.e., reduction of O_2 cost).

$\% \dot{V}O_2\text{max}$ at AT showed no significant subgroup differences. Moreover, the lowest correlation coefficient value was observed between $\% \dot{V}O_2\text{max}$ at AT and vAT (Figure 1). It has been reported by several investigators that the $\% \dot{V}O_2\text{max}$ has a minor impact on endurance performance compared with $\dot{V}O_2\text{max}$ and RE (McLaughlin et al., 2010; Storen et al., 2013). Londeree and Ames (1975) have reported $\% \dot{V}O_2\text{max}$ at MLSS in subjects with different states of conditioning, considering the frequency, quantity, and quality of conditioning during the previous 6 months and have shown that $\% \dot{V}O_2\text{max}$ at MLSS highly correlates with conditioning ($r = 0.82$). Despite the significant difference in the training status of the subgroups in this study, all the groups were well trained. Taken together, it may be assumed that the absence of differences in $\% \dot{V}O_2\text{max}$ at AT among subgroups is attributable to the condition of the runners in this study. Furthermore, previous and present results lead us to presume that $\% \dot{V}O_2\text{max}$ at AT is an aerobic conditioning marker rather than a performance determining factor.

This study included male and female recreational runners. It is well established that $\dot{V}O_2\text{max}$ in women is lower than that in men because of higher body fat and lower red cell mass for a given body weight (Joyner, 2017). However, there seems to be no sex difference in relationship between classic physiological variables and performance (Joyner, 1993, 2017). In fact, the significant relationship between $\dot{V}O_2\text{max}$ (men: $r = 0.856$, women: $r = 0.821$) and RE (men: $r = -0.654$, women: $r = -0.640$) and vAT was unchanged between men and women (Figure 1). Thus, we believe that the mixed-sex subjects did not affect the results of this study.

5. Conclusions

The present study indicated that during a treadmill running test, $\dot{V}O_{2\max}$, $\% \dot{V}O_{2\max}$ at AT, and RE can precisely explain vAT , which is highly correlated with recent marathon times.

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