Brief Paper

Expired gas kinetics during 20 m shuttle running test

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The purposes of this study were to investigate the kinetics of oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$) and ventilatry equivalent ($\dot{V}E \cdot \dot{V}O_2^{-1}$, $\dot{V}E \cdot \dot{V}CO_2^{-1}$) during a 20-meter shuttle running test (SRT) in comparison with a treadmill running test (TRT), and to determine the contribution of bicarbonate buffering capacity to SRT performance. Eleven healthy male participants (20.9±2.5 yrs, 172.4±3.0 cm, 65.7±3.9 kg) performed SRT and TRT utilizing the same running speed protocol. During both the SRT and the TRT, $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}E \cdot \dot{V}O_2^{-1}$ and $\dot{V}E \cdot \dot{V}O_2^{-1}$ data were measured by portable expired gas-analysis system. CO_2excess as an index of bicarbonate buffering capacity was calculated by the sum of $\dot{V}CO_2$ minus $\dot{V}O_2$ when respiratory exchange ratio (RER) was more than 1.00. The results of the general linear mixed model showed that no significant differences were found between TRT and SRT for $\dot{V}O_2$ kinetics (interaction: $F_{11, 182.14} = 1.12$, $P = .347$). $\dot{V}CO_2$ and $\dot{V}E \cdot \dot{V}O_2^{-1}$ during SRT were significantly higher than those during TRT ($\dot{V}CO_2$: $F_{11, 181.19} = 40.35$, $P < .001$; $\dot{V}E \cdot \dot{V}O_2^{-1}$: $F_{11, 181.16} = 17.47$, $P < .001$). Multiple regression analysis provided that the contribution (R^2 change) of CO_2excess to SRT performance was 13.9 % (standardized regression coefficients = .376, P = .013). Therefore, SRT reflects bicarbonate buffering capacity as well as aerobic capacity, and the energy demand of SRT is greater than that of straight-line running.

Key words : oxygen uptake, carbon dioxide output, general linear mixed model

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1. Introduction

The 20-meter shuttle run test (SRT) devised by Leger and Lambert (1982) is a field test used to estimate maximal oxygen uptake ($\dot{V}O_2max$). The SRT involves continuous running between two white lines positioned 20 meters apart at a starting speed at of 8.5 km • h^{-1} that increases gradually by 0.5 km • h^{-1} in accordance with a pace maker. Because it enables mass measurement of $\dot{V}O_2max$ indoors with little specialist skill, the SRT is highly useful as a field test for aerobic capacity. According to Apostolidis et al. (2004) and Cooper et al. (2005), the SRT serves as a valid measurement index for anaerobic capacity because of the high correlation (r=0.6-0.7) between the results of the SRT and the Wingate anaerobic test, an established criterion for anaerobic capacity.

Unlike straight-line running, shuttle running involves turning movement. Because it involves such motions as deceleration, stopping, turning and acceleration, shuttle running is markedly different from straight-line running in terms of running posture, skeletal muscle contraction patterns, and running velocity variability. As these differences are thought to affect the energy supply system and ventilation efficiency, it is expected that the dynamics of oxygen uptake ($\dot{V}O_2$), an index for the aerobic system during the SRT, would be different from the dynamics of straight-line running.

Compared with straight-line running, shuttle running requires a higher anaerobic energy supply and, therefore, a higher blood lactate (La) concentration. Accumulation of La contributes to the production of buffering carbon dioxide through bicarbonate buffering and to a rapid

increase in carbon dioxide output ($\dot{V}CO_2$) and ventilation ($\dot{V}E$) (Beaver et al., 1988). Further accumulation of La can intensify hyperventilation as respiratory compensation (RC) and can cause a marked decrease in ventilation efficiency. As with $\dot{V}O_2$, variables during shuttle running are, therefore, expected to be different from $\dot{V}CO_2$ and ventilation efficiency during straight-line running.

There is thought to be a remarkable difference between shuttle running and straight-line running in terms of the energy supply system, ventilation efficiency, and the bicarbonate buffering system. However, no research on expired gas variables during the SRT has been conducted. This study was conducted, therefore, to compare expired gas variables during the SRT and the treadmill running test (TRT) with the use of a treadmill ergometer and to clarify the characteristics of the energy supply system, ventilation efficiency, and the bicarbonate buffering system during the SRT.

2. Methods

2.1. Subjects

Subjects in this study were 11 healthy males (age: 20.9±2.5; body height: 172.4±3.0cm; body weight: 65.7±3.9kg) (mean ± SD), who voluntarily participated in the experimental tests required for this study. Written informed consent was obtained from all the subjects before the starting of tests.

2.2. Protocol

First, the SRT, and then the TRT with the use of treadmill ergometer (O2road, Takei Sci. Instruments Co., Nigata, Japan) were conducted in a gymnasium. There was a 3-5 day interval between the conducting of the SRT and the TRT. In both tests, the participants were required to conduct a 10-minute warm-up exercise featuring stretching exercises. Subjects were then required to put on a face mask (dead space: 160ml) (Vital Signs, Totowa, NJ, USA) with which both inspired and expired gases were passed through the same valve. After taking a 5 minute rest in the sitting position, subjects performed the SRT and the TRT with beep sounds as pace signals provided by a CD produced by the National Coaching Foundation. In both tests, the subjects were directed to run at a starting speed of 8.5km • h^{-1} that then increased by 0.5km • h^{-1} every one minute. In the SRT, each of the subjects was required to stop running if 1) he became too exhausted to maintain the necessary running velocity as set by the beep sounds or 2) he failed twice in a row to accomplish a 20 meter run within a set time regardless of his will to continue to run. In the TRT, subjects were required to run as long as they had run in the SRT, without regard to their degree of exhaustion or set time. Thus, the SRT and the TRT were designed equally in terms of running velocity and exercise time. While only running velocity increased as the TRT proceeded, both running velocity and frequency of turning increased as the SRT proceeded.

Using a portable auto expired gas analyzer system (VO2000, MedGraph Co., St. Paul, MN, USA), $\dot{V}E$, $\dot{V}O_2$, $\dot{V}CO_2$, O_2 for ventilation equivalent ($\dot{V}E \cdot \dot{V}O_2^{-1}$), and CO_2 for ventilation equivalent ($\dot{V}E \cdot \dot{V}CO_2^{-1}$) during the SRT and the TRT were measured in a electronic variable sampling (EVS) method. The VO2000 system was calibrated before each exercise load test. A measurement index (CO_2excess) for bicarbonate buffering was obtained as the sum of differences between $\dot{V}CO_2$ and $\dot{V}O_2$ ($\dot{V}CO_2$ - $\dot{V}O_2$) when RER ($\dot{V}CO_2 \cdot \dot{V}O_2^{-1}$) was 1.0 or higher (Yano, 1987; Maemura et al., 2004).

Using the VO2000, $\dot{V}E$ was measured with a pneumotachograph (AeroSport Inc., Ann Arbor, MI, USA) (dynamic range: 50-2001 • min^{-1}) via the face mask. The fraction of O_2 in expired gas (FEO_2) was measured by galvanic O_2 analyzer, and the fraction of CO_2 in expired gas ($FECO_2$) was measured by infrared absorption CO_2 analyzer. According to the experiment (N=8) on measurement accuracy of the VO2000, which was conducted utilizing the Douglas bag method as a valid criterion, the measurement errors of the VO2000 respectively for $\dot{V}E$, $\dot{V}O_2$, and $\dot{V}CO_2$ were under 5% (Takahashi et al., 2002). Subjects wore the VO2000 affixed to their hip with a belt. The gross weight of the VO2000, including belt and portable battery, was 1,450 grams. In terms of measuring expired gas variables during exercise, breathing-based measurement error becomes larger when measurement time interval is too short. In order to obtain stable measurement values, expired gas variables of subjects during both tests were converted into minutely mean values.

2.3. Statistical Analysis

All data were shown with mean ± SD. The experimental design of this study was a within-subject-design with $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}E \cdot \dot{V}O_2^{-1}$, $\dot{V}E \cdot \dot{V}CO_2^{-1}$ and CO_2excess as dependent variables, and test types (2 levels: the TRT and the SRT) and exercise times (12 levels; see the results) as independent variables. Suitable statistical models for a within-subject-design are a fully repeated 2-way ANOVA and a general linear mixed model (GLMM). Considering that the exercise times of the SRT in this study varied by subject (7-12 minutes), it was expected that data would have a significant number of missing values. In the data set with missing values, the statistical power of the GLMM is higher than that of the fully repeated 2-way ANOVA. In this study, therefore, the GLMM was used for a comparison between the SRT and the TRT. When statistical significance is observed in an interaction (test type * exercise time) using the GLMM, it can be determined that there is a difference in expired gas kinetics between the SRT and the TRT. When significant interaction and main effect of test type were observed in the GLMM, a paired t test was conducted for each time level. Significance level in the GLMM was set at α=0.5, and significance levels in the paired t tests was set at $\alpha \approx 0.004$ through Bonferroni's correction ($\alpha/12$). Based on the set significance level and sample size (number of subjects * number of test types * exercise time), the statistical power ($1 - \beta$) of this study was calculated. The effect size (ES) required for statistical power calculation was set at F=0.421 (partial eta square = 0.15) in the GLMM and d=0.80 in the paired t test. The calculated statistical powers were as follows: GLMM: statistical power of the main effect of test type = 0.991 (critical value: $F_{1, 106} = 3.931$); statistical power of the main effect of exercise time = 0.813 (critical value: $F_{11, 96} = 1.890$); statistical power of interaction = 0.807 (critical value: $F_{11, 84} = 1.905$); and paired test: statistical power = 0.007 – 0.117.

In order to examine the contribution of aerobic capacity and bicarbonate buffering capacity to SRT performance, a multiple regression analysis was conducted with the SRT performance as a dependent variable and peak of $\dot{V}O_2$ ($\dot{V}O_2$peak) and CO_2 excess as independent variables. Estimation of regression coefficient was conducted utilizing the Stepwise method (criteria: Probability of F to enter = 0.050; Probability of F to remove = 0.100). Using the determination coefficient (R^2) and standardized regression coefficient (beta) that were obtained, the contribution of $\dot{V}O_2$peak and CO_2excess to the SRT were examined.

SPSS for Windows Version 13.0J (SPSS Japan Inc., Tokyo, Japan) was used for the GLMM, paired t test, and multiple regression analysis. G • Power for Macintosh version 2.1.2 (free download soft) was used for the calculation of statistical power.

3. Results

Table 1 shows the SRT performance, exercise times, the $\dot{V}O_2$peaks, $\dot{V}CO_2$peaks and CO_2 excesses during the SRT and the TRT. Frequency of shuttles: 95.2±19.9 shuttles; exercise time: 9.8±1.6min; $\dot{V}O_2$peak during the SRT: 52.3±4.5 ml • kg^{-1} • min^{-1}; CO_2excess during the SRT: 82.0±29.7 ml • kg^{-1}; $\dot{V}O_2$peak during the TRT: 53.4±3.1 ml • kg^{-1} • min^{-1}; $\dot{V}CO_2$peaks during the TRT: 51.8±3.9 ml • kg^{-1} • min^{-1}; and CO_2excess during the TRT: 0.0±1.2 ml • kg^{-1}.

Table 2 shows the GLMM results. As it was not observed in 9 out of 11 subjects (RER < 1.0), CO_2excess during the TRT was excluded from analysis items. Figure 1 and Table 3 show, respectively, comparison of expired gas variables between the TRT and the SRT, and the statistical power and ES of paired t test. Statistical significance was not observed in the interaction of $\dot{V}O_2$

Table 1. SRT performance and expired gas parameters during SRT and TRT

	SRT		TRT	
	mean±SD	(minimum -maximum)	mean±SD	(minimum -maximum)
Performance (shuttles)	95.2 ± 19.9	61 - 123		
Exercise times (mins)	9.8 ± 1.6	7 - 12		
$\dot{V}O_2$peak (ml・kg^{-1}・min^{-1})	52.3 ± 4.5	46.4 - 60.3	53.4 ± 3.1	48.0 - 60.2
$\dot{V}CO_2$peak (ml・kg^{-1}・min^{-1})	78.5 ± 7.4	68.9 - 92.7	51.8 ± 3.9	47.0 - 60.0
CO_2excess (ml・kg^{-1})	82.0 ± 29.7	39.2 - 132.9	0.6 ± 1.2	0.0 - 3.6

Table 2. F (df_1, df_2) on the results of the GLMM

Items (unit)	Main effect of Type		Main effect of Time		Interaction	
$\dot{V}O_2$ (ml・kg^{-1}・min^{-1})	4.03 (1, 182.14)	(P = .046)	333.13 (11, 182.92)	(P < .001)	1.12 (11, 182.14)	(P = .347)
$\dot{V}CO_2$ (ml・kg^{-1}・min^{-1})	909.44 (1, 181.99)	(P < .001)	372.05 (11, 182.42)	(P < .001)	40.35 (11, 181.99)	(P < .001)
$\dot{V}E.VO_2^{-1}$	279.76 (1, 182.16)	(P < .001)	26.10 (11, 182.93)	(P < .001)	17.47 (11, 182.16)	(P < .001)
$\dot{V}E・VCO_2^{-1}$	4.93 (1, 181.98)	(P = .028)	16.14 (11, 182.11)	(P < .001)	4.21 (11, 181.98)	(P < .001)

df_1= Numerator df , df_2 = Denominator df

Priori powers of main effect and interaction were more than 0.80.

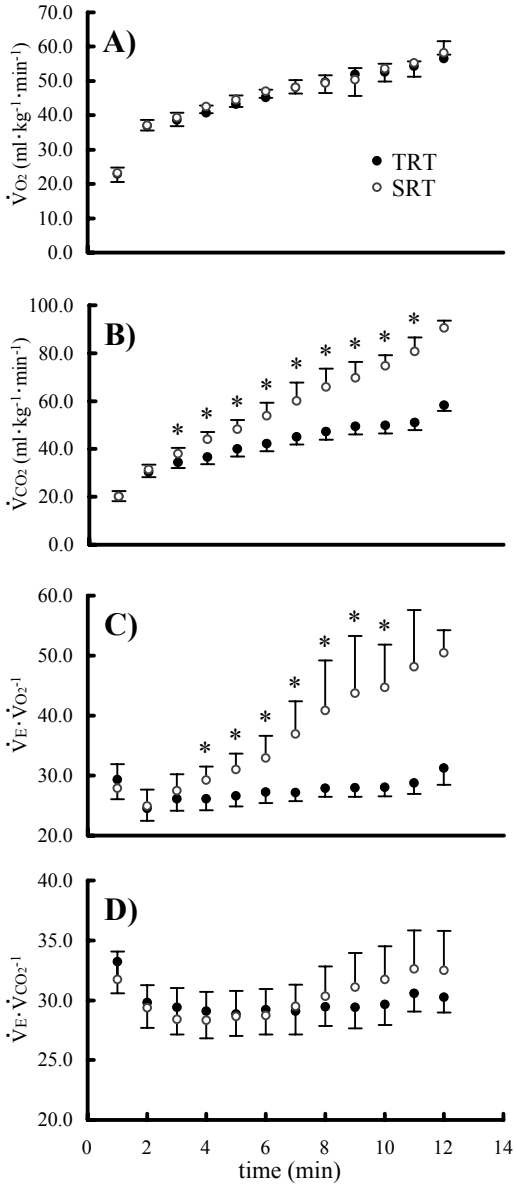

Figure 1. Comparisons of expired gas parameters between TRT and SRT
A) oxygen uptake, B) carbon dioxide output, C) O_2 for ventilatory equivalent, D) CO_2 for ventilatory equivalent. The closed symbol (●) represents TRT data, and the open symbol (○) represents SRT. Asterisks (*) represent significant differences between TRT and SRT (P < .004).

($F_{11, 182.14}$ = 1.12, P = 0.347); however, it was observed in the main effects of test types ($F_{1, 182.14}$ = 4.03, P = 0.046) and exercise times ($F_{11, 182.92}$ = 4.03, P < 0.001). Because statistical significance was observed in the main effect of test type, comparison of the SRT and the TRT for each exercise time was conducted. As a result, no significant difference was observed.

Significant interaction was observed in $\dot{V}CO_2$ ($F_{11, 181.19}$ = 40.35, P < 0.001). Significant interaction indicates that $\dot{V}CO_2$ dynamics between the SRT and the TRT are different. In the comparison of the SRT and the TRT for each exercise time, significant differences were observed between 3 and 11 minutes. At 12 minutes, too, a large difference (ES = 11.59) was observed; however, as a result of a decline in statistical power (power = 0.007) due to small sampling (N = 2), no significant difference was obtained.

Significant interaction was observed in $\dot{V}E \cdot \dot{V}O_2^{-1}$ ($F_{11, 182.16}$ = 17.47, P < 0.001). In $\dot{V}E \cdot \dot{V}O_2^{-1}$ during the SRT and the TRT for each exercise time, significant difference was observed between 4 and 10 minutes. As with $\dot{V}CO_2$, no statistical significance was observed due to a decline in statistical power for the 11 and 12 minute times; however, large differences were observed (ES = 3.44 and 5.81).

Statistical significance was observed in $\dot{V}E \cdot \dot{V}CO_2^{-1}$ in main effects of interaction ($F_{11, 182.98}$ = 4.21, P < 0.001), test types ($F_{1, 182.98}$ = 4.93, P = 0.028) and exercise times ($F_{11, 182.11}$ = 16.14, P < 0.001). No significant difference was observed between the SRT and the TRT for any exercise time; however, a difference larger than ES = 0.80 was noted for the 10-12 minute times.

Table 4 shows multiple regression analysis results. A significant regression equation was obtained with the SRT performance as a dependent variable and $\dot{V}O_2$peaks and CO_2excesses as independent variables (R^2 = 0.869, $F_{2, 9}$ = 29.90, P < 0.001). The betas of $\dot{V}O_2$peak and CO_2excess to the SRT performance were 0. 805 (P < 0.001) and 0.376 (P = 0.013), respectively.

Table 3. Powers and observed effect sizes (ES) of paired t tests for each exercise time

Time (min)	Sample (N)	Power (1-β)	ES (d) $\dot{V}O_2$	$\dot{V}CO_2$	$\dot{V}E \cdot \dot{V}O_2^{-1}$	$\dot{V}E \cdot \dot{V}CO_2^{-1}$
1	11	.117	0.08	-0.03	-0.40	-0.60
2	11	.117	0.07	0.44	0.17	-0.21
3	11	.117	0.30	1.48	0.56	-0.40
4	11	.117	0.91	2.54	1.52	-0.33
5	11	.117	0.54	2.46	2.02	-0.11
6	11	.117	0.89	2.80	2.05	-0.22
7	11	.117	0.01	2.82	2.83	0.23
8	10	.099	-0.13	3.40	2.66	0.44
9	9	.083	-0.47	4.15	2.88	0.73
10	6	.040	0.31	6.31	3.83	0.94
11	4	.019	0.37	6.71	3.44	0.86
12	2	.007	0.58	11.59	5.81	0.99

Power was calculated at ES (d) = .80 and alpha = .004.
ES (d) = (mean of SRT - mean of TRT) / total SD.

Table 4. Contribution of aerobic capacity (VO_2peak) and bicarbonate buffering capacity (CO_2excess) to SRT performance

Variables	R^2	F value	R^2 change	Standardized Regression Coefficients	
$\dot{V}O_2$peak	.730	F(1, 10) = 27.08, P < .001	.730	.805	(t = 6.62, P < .001)
CO_2excess	.869	F(2, 9) = 29.90, P < .001	.139	.376	(t = 3.09, P = .013)

4. Disccusion

In this study, the energy supply system, ventilation efficiency, and bicarbonate buffering during the SRT were examined. While $\dot{V}O_2$ during the SRT exhibited a ranged similar to $\dot{V}O_2$ during the TRT, $\dot{V}CO_2$ and $\dot{V}E \cdot \dot{V}O_2^{-1}$ during the SRT were significantly higher than those during the TRT. In the multiple regression analysis, bicarbonate buffering showed a moderate contribution to the SRT performance. It has been revealed, therefore, that the aerobic system during the SRT is equivalent to that during the TRT, and that the anaerobic system strongly affects the SRT performance.

4.1. Aerobic system during the SRT

The average ES of $\dot{V}O_2$ between the SRT and the TRT was 0.29. An earlier study on the effect of muscle contraction during constant load exercise on $\dot{V}O_2$ dynamics (Williams et al., 2001) has reported that muscle contraction during running with 85%$\dot{V}O_2$max (velocity: 15.6±1.9km • h^{-1}, $\dot{V}O2$: 46.4±2.1ml • kg^{-1} • min^{-1}) affected $\dot{V}O_2$ dynamics by 0.7 ml • kg^{-1} • min^{-1}. Based on the above-mentioned results, the ES in this earlier study may be calculated as ES = 0.36. This ES value is nearly equivalent to the average ES of $\dot{V}O_2$ of this study, though the results of the SRT, an incremental load test, cannot be directly compared to those of a constant load test. The difference in $\dot{V}O_2$ dynamics between the SRT and the TRT, which was obtained in this study, may, therefore, be considered valid.

Considering SRT motion characteristics, frequency of turning increases as exercise proceeds. It was, therefore, expected that a difference between $\dot{V}O_2$ dynamics during the SRT and $\dot{V}O_2$ dynamics during the TRT would gradually increase. In other words, statistical significance was expected in interaction by the GLMM. However, no significant interaction was observed in $\dot{V}O_2$ during the SRT and the TRT. Considering that the statistical power of the GLMM was 0.80 or higher, it can be interpreted that $\dot{V}O_2$ during the SRT and the TRT changed in correspondence with running velocities. Statistical significance was observed in the main effect of the test type of $\dot{V}O_2$ but not in exercise time (Figure 1. A). Judging from these results, it can be said that there is a slight difference in $\dot{V}O_2$ between the SRT and the TRT and that the $\dot{V}O_2$ for each running velocity is the same. It is also inferred that the significant main effect between the tests in the GLMM reflected the effect of differences in warm-up exercise intensity on the SRT and the TRT, and did not reflect motion characteristics of the SRT and the TRT.

4.2. Ventilation efficiency during the SRT

Significant interaction was observed between $\dot{V}CO_2$ and $\dot{V}E \cdot \dot{V}O_2^{-1}$, about which significant difference was observed between the SRT and the TRT (Figure 1. B and C). With increase in running velocity, difference in $\dot{V}CO_2$ and in $\dot{V}E \cdot \dot{V}O_2^{-1}$ between the SRT and the TRT increased (Table 3). These results indicate that buffering $\dot{V}CO_2$ and $\dot{V}E$ during the SRT increase significantly as anaerobic energy is supplied.

While significant interaction was observed in $\dot{V}E \cdot \dot{V}O_2^{-1}$, no significant difference was observed between the SRT and the TRT in a paired t test (Figure 1. D). The level of physical fitness of the respective subjects was not considered in the experimental design of this study. In other words, the relative intensity (%$\dot{V}O_2$peak) was not controlled. It can be inferred, therefore, that an effect of RC on $\dot{V}E \cdot \dot{V}O_2^{-1}$ was not found in paired t test for absolute intensity (running velocity). Considering that the statistical power of the paired t test conducted in this study was low and that a significant interaction was observed between the TRT and the SRT in $\dot{V}E \cdot \dot{V}O_2^{-1}$, however, it is inferred that expired gas variables during the SRT were affected by RC. Figure 2 shows $\dot{V}E \cdot \dot{V}O_2^{-1}$ of the subject with the highest SRT performance (Sub. A) and that of the subject with the lowest SRT performance (Sub. B). RC threshold was present in the SRT of all subjects. It can be determined that $\dot{V}E \cdot \dot{V}O_2^{-1}$ during the SRT was high in comparison to that during the TRT. This proves that ventilation efficiency during the SRT is lower than that during the TRT.

4.3. The contribution of bicarbonate buffering to the SRT performance

There was little CO_2excess, an index for bicarbonate buffering during the TRT (0.6±1.2 ml • kg^{-1}), while CO_2excess was 82.0±29.7ml • kg^{-1} during the SRT. These indicate that the anaerobic system (lactate system) was

recruited during the SRT, and that there was notable non-metabolic CO_2 production with the recruiting of the lactate system. The multiple regression analysis results indicate a significant contribution of bicarbonate buffering capacity (Beta = 0.376, R^2change = 0.139) to SRT performance (Table 4). Judging from these results, it is determined that the energy required for the SRT is high in comparison with the energy required for the TRT, and that majority of such energy is supplied by the lactate system.

Though $\dot{V}O_2$peaks during the SRT and the TRT were equivalent, none of the participants reached the stage of exhaustion in the TRT. During the TRT, the RER values of 9 out of 11 subjects were under 1.00. These results suggest that it is possible to engage in exercise required for TRT longer than that required for SRT, and that $\dot{V}O_2$peak during the SRT was lower in value than $\dot{V}O_2$max. Although all SRT subjects reached the stage of exhaustion, a judgment condition for $\dot{V}O_2$max, they did not reach $\dot{V}O_2$max. This indicates that the aerobic system is not a limiting factor for SRT performance.

Metabolic acidosis, which is produced by hyper-accumulation of La as a result of the recruitment of the lactate system, is a limiting factor for the continuation of exercise (Röcker et al., 1994). During the SRT, notable La-based non-metabolic CO_2 production was observed. This suggests that the major limiting factor for SRT performance is the bicarbonate buffering system. It has thus been clarified that the SRT is a test which is affected by not only aerobic capacity but also by the anaerobic system.

5. Limitations

In this study, a comparison of the SRT and the TRT was conducted in order to clarify the characteristics of the energy supply system, ventilation efficiency, and bicarbonate buffering system during the SRT. Generalization of the results of this study has the following limitations:

1) Limitations based on analytical instruments: In this study, expired gas was measured by EVS, a Mixing Chamber method variation, which is more accurate than the breath-by-breath (BB) method in terms of the investigation of energy metabolism. In order to investigate expired gas variables during the SRT in further detail, however, it is necessary to analyze measurement values

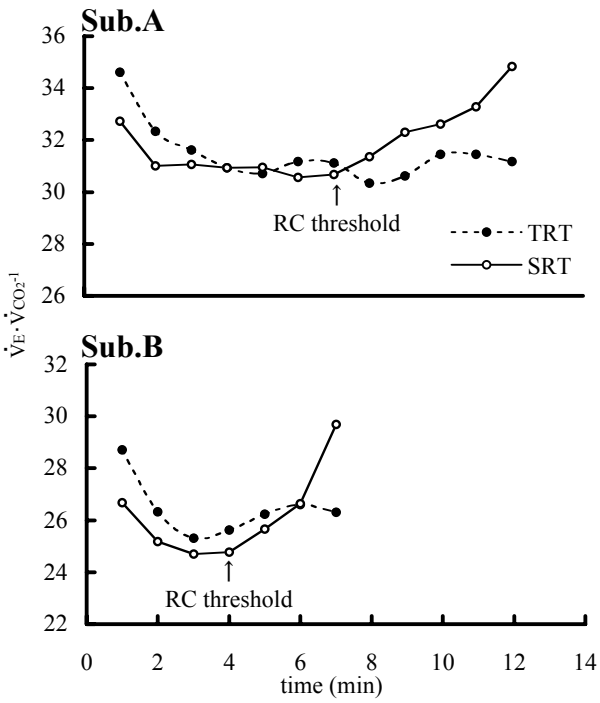

Figure 2. Dynamics of remarkable CO_2 for ventilatory equivalent ($\dot{V}E \cdot \dot{V}CO_2^{-1}$) in two subjects
In eleven subjects, Sub.A showed the highest performance (12 min) and Sub.B showed the lowest performance (7 min) in SRT. In both subjects, RC threshold was present in SRT, but was not found in TRT. The closed symbol (●) represents TRT data, and the open symbol (○) represents SRT.

obtained by the BB method, which is superior to the EVS method in terms of analysis speed.

2) Problems associated with experimental design: The experimental design of this study was a within-subject-design with expired gas variables as dependent variables and the TRT, SRT and exercise time as independent variables. In order to clarify shuttle running characteristics, the TRT and the SRT were compared with respect to each level of absolute intensity (running velocity). Meanwhile, it is preferable that $\dot{V}CO_2$ dynamics and ventilation efficiency parameter dynamics be expressed in absolute intensity (%$\dot{V}O_2$max) with respect to each subject. $\dot{V}O_2$peak during the SRT and that during the TRT in this study are the same in value and do not bear the criteria for $\dot{V}O_2$max. If each expired gas variable were converted into relative intensity to be analyzed with $\dot{V}O_2$peak during the SRT as a criterion, the same results could be obtained as this study results. In order to examine SRT characteristics with more consideration of the physical characteristics of subjects, it is necessary to conduct an exercise load test for the determination of $\dot{V}O_2$max in addition to the SRT and the TRT. For further investigation of expired gas variables during the SRT, it will be necessary to have an experiment design with relative intensity as an independent variable.

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