Paper

Effect of turn skill on expired gas dynamics during 20 meters shuttle running test

Yudai YOSHIDA[*1], Shinji TAKAHASHI[*2], Haruki MOMMA[*1], Tohru YUZE[*1], Tomonori CHIBA[*3] and Akinobu MAEDA[*3]

*1 human informatics, Graduate School of Tohoku Gakuin University
2-1-1, Tenjinsawa, Izumi-ku, Sendai-shi, Miyagi, 981-3193 Japan
yudaiy@ghi.tohoku-gakuin.ac.jp
*2 Department of Regional Management, Faculty of Liberal Arts, Tohoku Gakuin University
*3 Department of Human Science, Faculty of Liberal Arts, Tohoku Gakuin University

Received March 17, 2008 ; Accepted October 21, 2008

The purpose of this study was to compare the dynamics of the relative intensity of maximal oxygen uptake (%$\dot{V}O_2max$) during 20-meter shuttle running test (SRT) with that during treadmill running test (TRT), and to determine the effect of the degree of turn skill to expired gas dynamics during SRT. Subjects were 4-male rugby players (RP), 4-male long-distance runners (LD) and 4-untrained males (UM). Initially, the maximal oxygen uptake ($\dot{V}O_2max$) of all subjects was measured. Subjects then underwent SRT and TRT. The protocols of SRT and TRT were the same except that there was turn motion in SRT. Subjects continued SRT until exhaustion, while they stopped TRT at the same time as in SRT. A portable metabolic cart (MetaMax 3B) measured ventilation, oxygen uptake ($\dot{V}O_2$), and carbon dioxide output ($\dot{V}CO_2$) throughout all exercise tests. Differences in expired gas dynamics between SRT and TRT were analyzed by general liner mixed model (GLMM) with three within-subjects-factors (test-type, time, group). The relative intensity (%$\dot{V}O_2max$) of SRT was significantly higher than that of TRT. The interactions (group*time) related to the degree of turn skill were not significant in $\dot{V}O_2$ ($F_{19,187}$ = 0.70, P = .812) and $\dot{V}CO_2$ ($F_{19,187}$ = 0.57, P = .922) dynamics. These results indicate that the relative intensity of SRT is high, and that the degree of turn skill does not influence $\dot{V}O_2$ and $\dot{V}CO_2$ dynamics during SRT.

Key words : field test, maximal oxygen uptake, carbon dioxide output, lactate

Human Performance Measurement Vol. 5, 31-40 (2008)

1. Introduction

Cardiorespiratory endurance fitness is an important physical strength factor for the maintenance and promotion of sports performance and health. Cardiorespiratory endurance fitness is evaluated by maximal oxygen uptake ($\dot{V}O_2max$). There are two methods of $\dot{V}O_2max$ measurement; namely, a direct method and an indirect method, both performed as field tests. The direct method of $\dot{V}O_2max$ measurement delivers a high degree of accuracy while having the disadvantage of being inconvenient because it requires expensive experiment devices and special skills. The indirect method of $\dot{V}O_2max$ measurement is inferior to the direct method in terms of accuracy while being superior in terms of economy and convenience. In the Japan Fitness Test (targets: 6-11-year-olds; 12-19-year-olds; and 20-64-year-olds), the 20 meter-shuttle running test (SRT) (Leger et al., 1982) has been adopted as a measurement item for cardiorespiratory endurance fitness. The SRT is an incremental load test which requires a participant to shuttle a 20-meter distance at a gradual velocity. Since the SRT can be conducted indoors, it is not affected by weather or location. With the use of the SRT, it is possible to measure the $\dot{V}O_2max$ of a large number of participants in a limited space.

The SRT is characterized by motions consisting of deceleration, stops, turns, and acceleration. In terms of posture during performance, the contraction pattern of skeletal muscle, and change in running velocity, the SRT is greatly different from common indirect methods such as the long-distance running (e.g. 1,500-meter run, 3,000-meter run) and the 12-minute run. According to Grant et al. (1995), exercise efficiency in high-intensity exercises with turn movement is affected by the level of turn movement skill. Gibson et al. (1998) has suggested that SRT can underestimate the $\dot{V}O_2$max of long-distance runners with poor turn movement skills in comparison of the estimation of the $\dot{V}O_2$max of ball game players. Based on these earlier studies, it is expected that SRT performance is affected by turn movement skill.

Takahashi et al. (2007) investigated the effect of turn movement on expired gas parameters and ventilation efficiency during SRT performance. They reported that there is no significant difference between oxygen uptake ($\dot{V}O_2$) during SRT performance and $\dot{V}O_2$ during treadmill run test (TRT) conducted at the same rate of load increment and that carbon dioxide output ($\dot{V}CO_2$) and ventilation efficiency ($\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$) during SRT are significantly higher than those during TRT. These results indicate that turn movement, a characteristic of the SRT, has no effect on the oxidative system while it exerts an effect on the bicarbonate buffering or the blood lactate systems. It is possible for those who have good turn movement skills, therefore, to deliver high performance on the SRT because of their capability to conduct shuttle running without placing undue stress on the bicarbonate buffering or the blood lactate systems.

However, the design of the study by Takahashi et al (2007) lacked 3 significant factors; that is, 1) $\dot{V}O_2$ measurement, 2) blood lactate concentration (La) measurement, and 3) evaluation of turn movement skill. In their study, $\dot{V}O_2$ was analyzed by each physical exercise intensity level (running velocity; km/h) with the aim of comparing the mobilization of the oxidative system during SRT and that during TRT. Since the physical fitness characteristics of the subjects cannot be clarified through their physical intensity, it is necessary to measure $\dot{V}O_2$max and to examine physiological exercise intensity (%$\dot{V}O_2$max) in order to investigate the mobilization of the oxidative system. Takahashi et al. estimated the effect of turn movement on the blood lactate system from $\dot{V}CO_2$. La should have been measured to verify that turn movement skill promoted the mobilization of the oxidative system. Furthermore, turn movement skill should have been used as an independent variable in the investigation of expired gas parameters and turn movement skill.

Considering these issues, this study aimed to compare respective %$\dot{V}O_2$max during SRT and TRT and to investigate the effect of turn movement skill on the dynamics of expired gas parameters and La during SRT.

2. Methods

2.1. Experimental Design

Considering that turn movement skill was handled as an independent variable in this study, long distance runners (hereinafter referred to LD) whose performance involved no turn movement, rugby players (hereinafter referred to as RP) whose performance involved turn movement, and healthy male university students with no regular sports activity (hereinafter referred to as UM <untrained men>) were selected as the subjects of this study. The subjects were required to undergo 3 types of exercise load tests; namely, 1) $\dot{V}O_2$ max measurement, 2) the SRT, and 3) the TRT utilizing the same protocol as that of the SRT. Since the exercise duration of the TRT depended upon that of the SRT, the TRT was conducted after the SRT was conducted. $\dot{V}O_2$max measurement for the respective subjects was performed in random order in consideration of the potential order effect.

The experiment in this study was designed as a 3-factor mixed design with the test-type (2 levels: the SRT and the TRT), the group (3 levels: RP, LD, UM), and the exercise duration (14 levels: see Figure 1) as independent variables, and $\dot{V}CO_2$ as dependent variable.

2.2. Subjects

The subjects of this study consisted of 3 groups; the LD group (4 individuals), the RP group (4 individuals), and the UM group (4 individuals). Both the LD and the RP groups had a minimum of a 5-year athletic career and trained at least 6 times per week on a regular basis. The LD group was excellent in running ability but not in turn movement skill. The RP group was excellent in running ability, though inferior to the LD, and also excellent in turn movement skill. The UM group had inferior running ability and turn movement skill compared to both the LD and the RP groups. There was no significant difference in age and morphological attributes among these 3 groups (Table 1).

Prior to entry into the experiment, the subjects submitted written informed consent for voluntary participation in this study after being thoroughly informed of all the risks associated with the exercise protocol and experiment. The subjects were requested to avoid alcohol, smoking, and intense exercise from the day before the start of the experiment; to avoid ingestion of any food or beverage from 3 hours before the start of the experiment; and to arise at least 4 hours earlier than the starting time of the experiment on each of the days of experiment. Each subject participated in 1 session of the experiment per day. The experiment was conducted at 3-day or longer intervals.

2.3. $\dot{V}O_2max$ Measurement

After a 5-minute rest period, the subjects performed a 3-minute warm-up exercise on the treadmill (O2 road, Takei Sci. Instruments Co., Niigata, Japan) and then underwent the exercise load test. Considering the expected physical fitness level of the respective subjects, the running velocity was set at a level at which the subjects were expected to become exhausted after 15-20 minutes. The velocity of the warm-up exercise was set at 7.2 -12.0km/h. The test started at a velocity of 9.6 -15.6km/h and increased by 1.2km/h every 3 minutes. When the velocity reached 18.0km/h, the treadmill angle began to increase by 1% every 1 minute.

The primary criterion for the judgment of $\dot{V}O_2max$ was the leveling-off of $\dot{V}O_2$ increase, which was under 150ml/min. If no leveling-off was observed, the maximum value of $\dot{V}O_2$, whose respiratory exchange ratio was 1.15 or higher, was regarded as the $\dot{V}O_2max$ (Tanaka et al., 1986).

2.4. SRT and TRT

After a 5-minute seated rest period, the subjects performed warm-up exercises for approximately 10 minutes on an individual and voluntary basis. After the warm-up, subjects underwent SRT and TRT with the use of the beep tone recorded in a CD produced by the National Coaching Foundation as per protocol. In both the SRT and the TRT, the subjects started running at a velocity of 8.5km/h. The velocity increased by 0.0km/h every 1 minute. The SRT was conducted until either (1) the subjects became exhausted and unable to keep up with the speed set by the beep tone or (2) the subjects failed to run 20 meters within a given time period twice in a succession. The length of the time for the TRT was the same as the length of time for the SRT; namely, no specific time limit was enforced, and the tests were conducted without regard to the subjects' degree of exhaustion. Thus, the SRT and the TRT were designed equally in terms of running velocity and exercise duration. While only running velocity increased as the TRT proceeded, both running velocity and turning movement frequency increased as the SRT proceeded.

2.5. Materials

Takahashi et al. (2007) measured expired gas parameters by the electric variable sampling (EVS) method, a variation of the mixing-chamber method. Considering the breath-by-breath method to be superior to the EVS method in terms of analysis speed, expired gas parameters were measured by the breath-by-breath method in this study with the use of a portable auto expired gas analyzer system (MetaMax 3B, Cortex, Leipzig, Germany). The portable auto expired gas analyzer system was calibrated once per day by atmosphere and mixed standard reference gas (O_2: 15.94 %, CO_2: 3.967 %) and only by atmosphere prior to the start of each test. The values measured by the breath-by-breath method were converted into mean values for each minute. The portable auto expired gas analyzer system was placed on the subject's chest with a belt specific designed for the purpose.

La was also measured in the SRT and the TRT. A 25μL sample of blood was collected from one ear lobe of each subject during the 5-minute rest period, immediately after the test, and at 3, 5, 7, and 10 minutes after the test. The collected blood was immediately analyzed by a blood lactate analyzer (1500 SPORT, YSI Incorporated, Ohio, USA). If an increase in La was observed 10 minutes after the test, a subsequent measurement was conducted 15 minutes after the test. The blood lactate analyzer was calibrated with the use of the standard solution (5.00mmol/L) prior to the test.

2.6. Statistical Analysis

All data were shown as mean±SD. The highest values of the expired gas parameters obtained in the SRT and the TRT were defined as peak values (e.g. $\dot{V}O_2$peak, $\dot{V}CO_2$peak). An increase in La produced by each test from the initial La measured when the subject was at rest was expressed as ΔLa (ΔLa: La peak – resting La). Intergroup comparisons were conducted by 1-way ANOVA (dependent variables: $\dot{V}O_2$max and ΔLa; independent variables: 3 group levels) and Scheffe's test. The significance level was set as $a = 0.05$.

2.6.1. Evaluation of Turn Movement Skill

In this study, the effect of turn movement skill on expired gas parameters and La during the SRT was investigated. Based on the content validity, turn movement skill, an independent variable in this study, was defined as an ordinal scale, the 3-level group (the LD, RP, and UN groups). In order to confirm the appropriateness of this grouping based on the content validity, the 3 groups were compared in terms of %$\dot{V}O_2$max during the SRT and the TRT. Evaluation of turn movement skill was conducted by mixed design 2-way ANOVA with %$\dot{V}O_2$max as dependent variable and 3-level group and 2-level tests as independent variables. When any significant interaction (the test-type × the group) was recognized, it could be understood that relative intensity during exercise varied by each group depending on the presence or absence of turn movement and that the level of the respective groups reflected their respective turn movement skills.

2.6.2. The Effect of Turn Movement Skill on Expired Gas Dynamics

The suitable statistical models for the 3-factor mixed design of this study were the repeated 3-way ANOVA and the 3-way general linear mixed model (GLMM). Since exercise duration varied in this study depending on the physical fitness of each subject, the data set was expected to have numerous missing values. In the event of missing values, the 3-way GLMM is superior to the repeated 3-way ANOVA in terms of statistical power. Thus, the 3-way GLMM was used in this study for the comparison of the SRT and the TRT. If any significance was recognized in the interaction of the 3 factors (the test-type × the exercise duration × the group), this would prove that the dependent variables were not adequately analyzed by the independent variable in this study. The significant interaction of the group × the exercise duration would prove that turn movement skill affected the dynamics of expired gas parameters. The interaction of the group × the exercise duration analyzed by the 3-way GLMM involved not only the expired gas parameters during the SRT but also those during the TRT. When there was significance in the interaction of the group × the exercise duration analyzed by the 3-way GLMM, the expired gas parameters during the SRT were analyzed by the 2-way GLMM to investigate the effect of turn movement skill on the expired gas dynamics during the SRT. Significant interaction analyzed by the 2-way GLMM could prove that turn movement skill affected the dynamics of expired gas parameters. The significant interaction of the test-type × the exercise duration would prove that there was a difference in expired gas parameter between the SRT and the TRT. When significance was observed in the interaction analyzed by the 3- and 2-way GLMM and the main effect of the test-type, the SRT and the TRT were compared by paired test according to time level. The significance in each GLMM is set as $\alpha = 0.05$, and that in paired test as $\alpha = 0.00036$ (0.05/14) after being adjusted by Bonferroni's inequality.

La was analyzed by multiple comparison (Tukey's HSD test) with ΔLa as dependent variable and the test-type (2 levels) and the group (3 levels) as independent variables. The significance was set as $\alpha = 0.05$.

All the statistical analyses were conducted with the use of SPSS for Windows 11.5J (SPSS Japan Inc., Tokyo, Japan).

3. Results

Table 1 shows the physical characteristics of the subjects and $\dot{V}O_2$max test results. The $\dot{V}O_2$max values of the LD, RP, and UM groups were 68.4±9.6 ml/kg/min, 56.0±2.2 ml/kg/min, 46.8±5.1 ml/kg/min, respectively. There was a significant difference between the LD and UM groups. ΔLa values of the LD, RP, and the UM groups were 6.7±1.4 mmol/L, 8.2±1.8 mmol/L, 11.3 ± 2.5 mmol/L, respectively, showing no significant difference. Table 2 shows the results of the tests by each group. As the result of a comparison of the turn movement skills of the respective groups by mixed design 2-way ANOVA, significance was observed in the interaction of test-type × the group ($F_{2,9}$ = 5.55, *P* = .027).

Table 3 shows the results of the 3-way GLMM. When analyzed by the 3-way GLMM, the interaction of test-type × the exercise duration × the group showed no significance for any of the dependent variables. It can be concluded, therefore, that the independent variables in this study provided an appropriate analysis of the dependent variables.

Figure 1 shows the %$\dot{V}O_2$max, $\dot{V}O_2$, and $\dot{V}CO_2$ during SRT and TRT. In terms of %$\dot{V}O_2$max, significance was recognized in the interaction of the test-type×the exercise duration ($F_{13,187}$ = 8.71, *P* < .001). In terms of $\dot{V}O_2$, significance was recognized in the interaction of test-type×the exercise duration ($F_{13,187}$ = 9.04, *P* < .001). In terms of $\dot{V}CO_2$, significance was recognized in the interaction of test-type×the exercise duration ($F_{13,187}$ = 44.99, *P* < .001). In the paired tests (SRT vs. TRT) conducted as post hoc comparisons, significance was observed in %$\dot{V}O_2$max, $\dot{V}O_2$, and $\dot{V}CO_2$ for the time period of 6-12 minutes.

For a more extensive investigation of the effect of turn movement skill in the SRT, the 2-way GLMM

Table 1. Physical characteristics in subject.

		n	Height (cm)	Weight (kg)	Age (year)	$\dot{V}O_2$max (ml/kg/min)	ΔLa (mmol/l)
Long-distance runners	(LD)	4	171.3 ± 1.9	59.5 ± 4.6	21.0 ± 1.6	68.4 ± 9.6	8.4 ± 0.6
Rugby players	(RP)	4	167.0 ± 9.8	67.5 ± 9.2	20.5 ± 1.0	56.0 ± 2.2	9.4 ± 2.0
Untrained men	(UM)	4	173.3 ± 4.1	71.5 ± 12.0	22.0 ± 0.0	46.8 ± 5.1	7.7 ± 1.7
total		12	170.6 ± 6.0	66.2 ± 9.3	21.2 ± 1.1	55.8 ± 9.0	8.7 ± 2.7

Table 2. SRT performance and expired gas parameters during SRT and TRT.

	SRT			TRT		
	LD	RP	UM	LD	RP	UM
Performance (shttles)	135.8 ± 16.6	109.5 ± 5.8	75.0 ± 9.9			
Exercise time (mins)	13.8 ± 1.3	11.5 ± 0.6	8.5 ± 0.6			
$\dot{V}O_2$peak (ml/kg/min)	61.8 ± 5.0	55.8 ± 3.4	45.5 ± 6.0	46.8 ± 3.2	45.5 ± 3.4	40.8 ± 5.3
$\dot{V}CO_2$peak (ml/kg/min)	91.5 ± 7.4	72.7 ± 7.5	58.9 ± 7.8	49.5 ± 1.7	50.0 ± 9.0	42.3 ± 4.2
%$\dot{V}O_2$max peak (ml/kg/mi	95.6 ± 3.1	99.7 ± 7.0	97.2 ± 3.5	72.5 ± 4.1	81.4 ± 8.1	87.1 ± 4.2

The most largest value at each test was peak value.

Table 3. Result of 3-way GLMM.

		F value		
		$\dot{V}O_2$max	$\dot{V}O_2$	$\dot{V}CO_2$
TEST-TYPE	F(1 , 187)	363.37 (P < .001)	355.64 (P < .001)	1168.53 (P < .001)
TIME	F(13 , 187)	161.60 (P < .001)	153.16 (P < .001)	280.58 (P < .001)
GROUP	F(2 , 9)	15.64 (P < .001)	0.38 (P = .694)	0.07 (P = .931)
TEST-TYPE * TIME	F(13 , 187)	8.71 (P < .001)	9.04 (P < .001)	44.99 (P < .001)
TEST-TYPE * GROUP	F(2 , 187)	11.65 (P < .001)	11.12 (P < .001)	1.03 (P = .359)
TIME * GROUP	F(19 , 187)	0.78 (P = .731)	0.57 (P = .922)	1.20 (P = .257)
TEST-TYPE * TIME * GROUP	F(19 , 187)	0.57 (P = .927)	0.70 (P = .812)	0.57 (P = .922)

$F(df_1,df_2)$

df_1 = Numerator df , df_2 = Denominator df was conducted exclusively for the SRT (Table 4). No significance was observed in the interaction of test-type × the exercise duration for any of the dependent variables. Concerning the main effect of the group, significance was revealed in $\%\dot{V}O_2max$ ($F_{2,9}$ = 13.45, P = .002) but not in $\dot{V}O_2$ ($F_{2,9}$ = 1.87, P = .209) and $\dot{V}CO_2$ ($F_{2,9}$ = 0.07, P = .929). These results indicate that turn movement skill did not affect the dynamics of expired gas parameters during the SRT and that $\%\dot{V}O_2max$ increased in all groups without regard to the difference in turn movement skill, though the increase rate varied in relation to time.

Figure 2 shows ΔLa (La peak-resting La) during the SRT and the TRT. In ΔLa, no significance was observed in the interaction (the group×the test-type) ($F_{2,9}$ = 0.61, P = .563); however significance was seen in the main effects of the test-type ($F_{1,9}$ = 105.12, P < .001) and the group ($F_{1,9}$ = 15.14, P < .001).

4. Discussion

In this study, $\%\dot{V}O_2max$ during the SRT and TRT were compared, and the effect of turn movement skill on the expired gas parameters and La during the SRT were investigated. As the main findings of this study, significance was revealed in the interaction of test-type × the exercise duration in terms of $\%\dot{V}O_2max$, while no significance was found in the interaction of test-type × the exercise duration in terms of the respective dependent variables. These results indicate that the energy supply during SRT was higher than that during TRT in terms

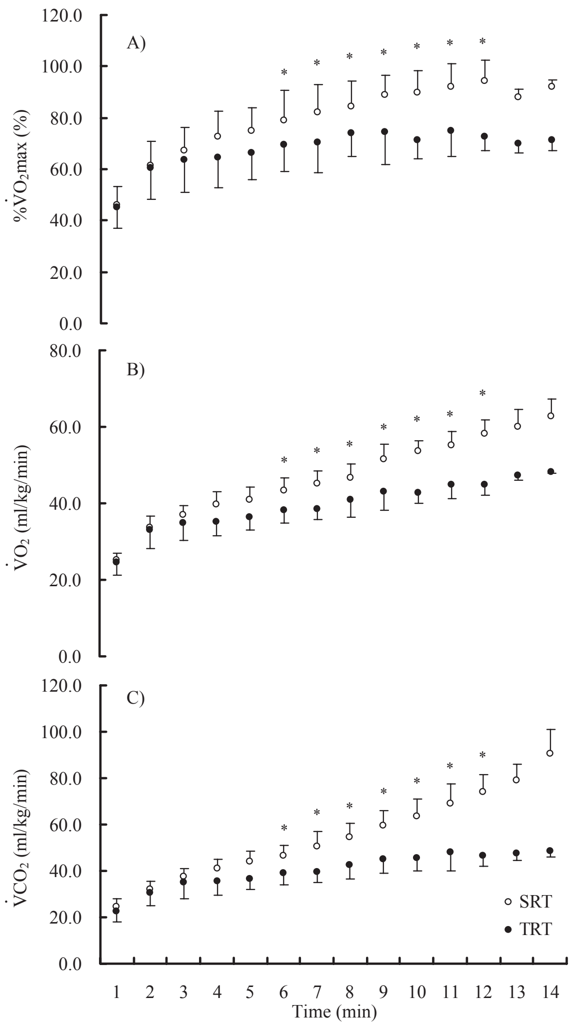

Figure 1. Comparison of expired gas parameters between SRT and TRT. A) percent maximal oxygen uptake, B) oxygen uptake, C) carbon dioxide output. The open symbol (○) represented mean values and standard deviation of SRT, and the closed symbol(●) represented mean values and standard deviation of TRT. Each sample size were 12 at 1 to 8 min, 10 at 9 min, 8 at 10 and 11 min, 6 at 12 min, and 3 at 13 to 14 min, respectively.Asterisks (*) detected significant difference between SRT and TRT (P < .0036).

of the oxidative and blood lactate systems, and that turn movement skill did not affect the expired gas parameters during the SRT.

4.1. Evaluation of Turn Movement Skill

In this study, turn movement skill was not evaluated qualitatively (ordinal scale) based on the content validity. In order to evaluate turn movement skill quantitatively, mixed design 2-way ANOVA was conducted in a post-hoc procedure with %$\dot{V}O_2$max as a independent variable. As a result, significance was revealed in the interaction of test-type × the group. This result indicates that the effect of turn movement varied in the variation of relative intensity (%$\dot{V}O_2$max). Thus, it was confirmed that the 3 levels of the group in this study expressed the levels of turn movement skill and that there was validity in the groups as independent variables in this study.

4.2. Oxidative Energy Supply System in the SRT

In terms of %$\dot{V}O_2$max and $\dot{V}O_2$, significance was revealed in the interaction of test-type × the exercise duration by 3-way GLMM. With increase in exercise duration, differences in %$\dot{V}O_2$max and in $\dot{V}O_2$ between the SRT and the TRT increased (Figure 1: A and B). These results were markedly different from the results of Takahashi et al. (2007), who reported that the variations of $\dot{V}O_2$ in the SRT and the TRT were similar. In their

Table 4. Result of 2-way GLMM.

		F value					
		$\dot{V}O_2$max		$\dot{V}O_2$		$\dot{V}CO_2$	
TIME	F(13 , 187)	291.46	P < .001	256.85	P < .001	262.50	P < .001
GROUP	F(2 , 9)	13.45	P = .002	1.87	P = .209	0.07	P = .929
TIME * GROUP	F(19 , 187)	1.26	P = .731	1.69	P = .053	0.91	P = .567

The result of GLMM in SRT. Independent variable was $\dot{V}$O2,$\dot{V}$CO2 and %$\dot{V}$O2max,and dependen variable was TIME and GROUP.
F(df_1,df_2)
df_1 = Numerator df , df_2 = Denominator df

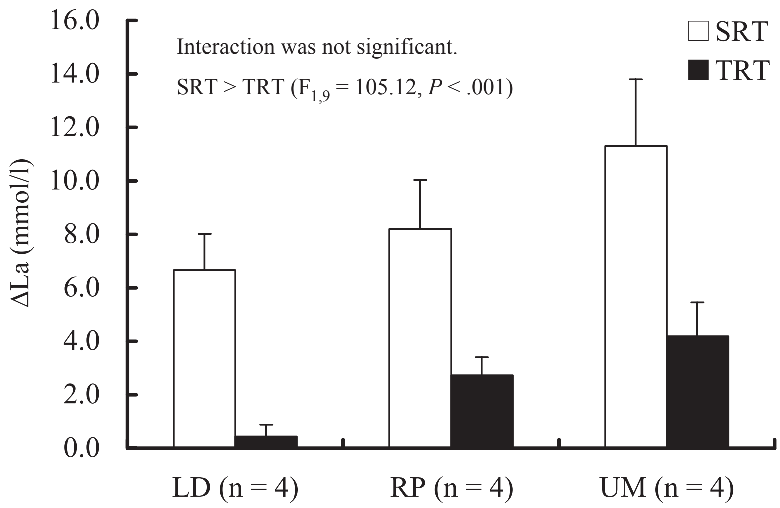

Figure 2. Comparison of increase of blood lactate concentration(ΔLa) after SRT and TRT from rest. The open bar (white bar) represented meanvalues and standard deviation of SRT, and the closed bar (black bar) represented mean values and standard deviation of TRT.

study, they formed the hypothesis that $\dot{V}O_2$, an index for the oxidative system during the SRT, showed different dynamics from those of the SRT based on the fact that the SRT was significantly different from the TRT in terms of running posture and the variation of running velocity. While this hypothesis supports the results of this study, no significance was observed in the interaction of test-type × the exercise duration ($F_{11,\ 182.14} = 1.12$, $P = .347$) regarding $\dot{V}O_2$ in their study results.

The methods employed in this and the earlier study (Takahashi et al., 2007) are different in terms of subjects and measurement devices. The subjects of the earlier study were ordinary healthy males (N=11), who may have differed to varying degrees from the subjects of this study, which included athletes (LD and RP), in terms of the level of physical fitness. Therefore, the difference between the results of this study and those of the earlier study may be attributable to the difference in the level of physical fitness of the subjects of the respective studies. Considering that the independent variables (the group: the LD, the RP, and the UM) which expressed the characteristics of the subjects in this study did not affect $\dot{V}O_2$ dynamics and %$\dot{V}O_2$max dynamics and that the degree of the effect of the difference between the SRT and the TRT on the $\dot{V}O_2$ dynamics and %$\dot{V}O_2$max dynamics (interaction of the test-type × exercise duration; $F_{13,187} = 9.0$) was not greatly different from that of the earlier study ($F_{11,\ 182.14} = 1.12$), however, it should not be concluded that the difference in characteristics of the subjects resulted in the difference in data between the two studies.

In the earlier study, measurement of expired gas parameters was conducted with the use of a device based on the EVS method, a variation of the mixing-chamber method. In this study, measurement of expired gas parameters was conducted with the use of a device based on the breath-by-breath method, which is superior to the mixing-chamber method in terms of analysis speed. Changing the sampling volume of expired gas according to ventilator volume, the EVS method allows faster measurement than the ordinary mixing-chamber method. The one-minute interval data of the EVS method has been reported to be equivalent to the smoothed 1-minute interval data of the breath-by-breath method (Byard and Dengel, 2002). However, the exercise protocol of the study by Byard and Dengel (2002), which was conducted to compare the accuracy of measurement of the EVS method and the breath-by-breath method, was a lumped loading test using a bicycle ergometer.

The bicycle pedaling exercise is conducted at 50-70 rpm in a near uniform rhythm. On the other hand, shuttle running involves deceleration, stops, and acceleration in association with turn movement. The change in exercise rhythm in shuttle running is estimated to be greater compared with that in pedaling exercise. Considering that exercise rhythm is known to affect respiratory rate (Takano, 1998), respiratory rate in the SRT may be different from that in the pedaling exercise. Investigation of the respiratory rates in the SRT and the TRT in this study showed a variation similar to the variations of $\dot{V}O_2$ and $\dot{V}CO_2$ (Figure 3). Since expired gas sampling volume changes according to ventilator volume in the EVS method, it is important to measure ventilation volume accurately in order to make the EVS method work accurately. Ventilation volume is the product of respiratory rate and respiratory minute volume. Hypothetically speaking, if the respiratory rate in the SRT had been different from that in Byard and Dengel (2002) and had produced a significant difference in ventilation volume, it would have been doubtful that the EVS method had proven to have measurement accuracy that was equivalent to that in the earlier study (Byard and Dengel, 2002). Though this hypothesis has not yet been verified, it is rational to judge that the difference between the results of the earlier studies and those of this study can be attributed to the measurement devices.

Considering that the results of this study accord with the hypothesis of Takahashi et al. (2007) and that the breath-by-breath method is superior to the EVS method in terms of analysis speed, it can be concluded that the oxidative energy supply system in shuttle running becomes higher than in one-way running. Since the frequency of turn movement increases with the length of exercise duration in the SRT protocol, the study result showing that the difference between the SRT and the TRT in terms of $\dot{V}O_2$ and %$\dot{V}O_2$max increased with the extension of exercise duration can be judged to have depended on turn movement frequency.

4.3. Blood Lactate Energy Supply System in the SRT

In terms of ΔLa in the SRT and the TRT, significance was seen in the interaction of the 2-way GLMM. In terms of $\dot{V}CO_2$, significance was seen in the interaction of the test-type × the exercise duration in the 3-way GLMM. These results indicate that the mobilization of energy by the blood lactate system increased in the SRT and that the production of La and the increase in buffering $\dot{V}CO_2$ associated with the increase in energy mobilization were significant. In terms of $\dot{V}CO_2$, the value of the interaction of the test-type × the exercise duration in this study ($F_{13, 187}$ = 45.0) was higher than the value reported in the study by Takahashi et al. (2007) ($F_{11,181.99}$ = 40.35). This result may also have been attributable to the difference between the EVT method and the breath-by-breath method.

The increase in ΔLa was larger in the SRT than in the TRT. From this result, it is supposed that buffering $\dot{V}CO_2$, which was produced by the bicarbonate buffering effect on La, worked to make the increase in $\dot{V}CO_2$ in the SRT larger than that in the TRT (Beaver et al., 1986). In other words, the increase in $\dot{V}CO_2$ in the SRT means an increase in the energy supply of the blood lactate system and an increase in the bicarbonate buffering system. A comparison of the F values of the interactions of the test-type × the exercise duration in terms of $\dot{V}O_2$ and $\dot{V}CO_2$, showed that the F value of $\dot{V}CO_2$ was higher than that of $\dot{V}CO_2$ (Table 3). Considering these results, it is supposed that the increase of energy supply volume induced by shuttle running occurs concurrently in the blood lactate system and the bicarbonate buffering system, and that the level of increase is higher in the blood lactate system than in the bicarbonate buffering system.

4.4. Effect of Turn Movement Skill and Limiting Factor of Performance in the SRT

No significance was revealed in the interaction of the 2-way GLMM in terms of %$\dot{V}O_2$max, $\dot{V}O_2$, and $\dot{V}CO_2$ (Table 4). This result indicates that the change in $\dot{V}O_2$ and $\dot{V}CO_2$ over time is equal in the SRT and the TRT when compared among the groups, and that the dynamics of expired gas parameters is not affected by turn movement skill. This is supported by the result that no significance was seen in the interaction of the group × the test-type in terms of ΔLa (Figure 2).

When examining earlier studies, the $\dot{V}O_2$max of long distance runners has been underestimated in the SRT (Gibson et al., 1998) because of the affect of turn movement skill on exercise efficiency (Grant et al., 1995). According to the results of this study, however, turn movement skill does not affect exercise efficiency. SRT performance is not supposed to be affected by turn movement skill. Therefore, the tendency to underestimate the $\dot{V}O_2$max of long distance runners in the SRT is supposed to be attributable to a factor other than turn movement skill.

According to Takahashi et al. (2007), the oxidative system is not a limiting factor of SRT performance. Metabolic acidosis produced from the over-accumulation of La as the result of the mobilization of the blood

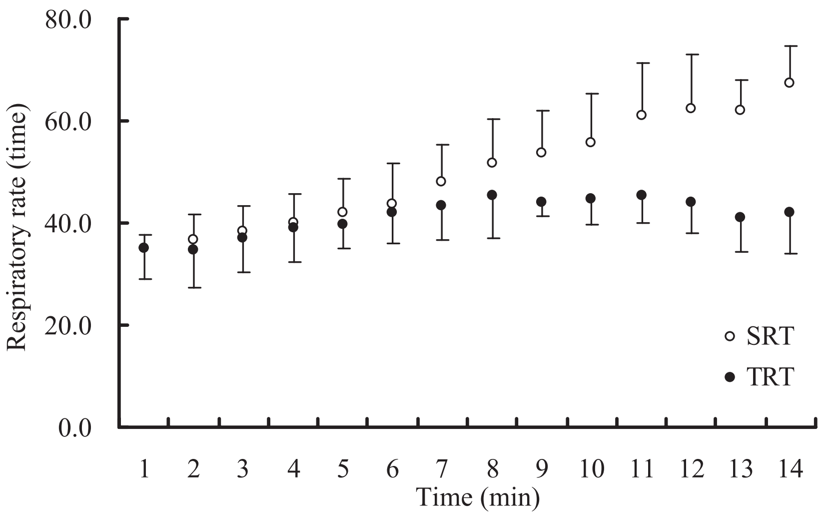

Figure 3. Respiratory rate between SRT and TRT. The open symbol (○) represented mean values and standard deviation of SRT, and the closed symbol (●) represented mean values and standard deviation of TRT. Each sample size were 12 at 1 to 8 min, 10 at 9 min, 8 at 10 and 11 min, 6 at 12 min, and 3 at 13 to 14 min, respectively.

lactate system is one of the limiting factors of exercise adherence (Röcker et al., 1994). According to Takahashi et al. (2007), this metabolic acidosis is the major limiting factor of SRT performance. This idea was supported by the result of %$\dot{V}O_2$max peak of the LD (95.1±3.1 %) in this study. However, the results of the RP (99.7±7.0 %) and the UM (97.2±3.5 %) groups indicate that the oxidative system is a limiting factor of SRT performance. There was a significant difference between the LD and the UM groups in terms of $\dot{V}O_2$max. When analyzed by the 2-way GLMM, a significant difference was revealed among the main effects of the groups in terms of %$\dot{V}O_2$max but not $\dot{V}O_2$ and $\dot{V}CO_2$ (Table 4). Considering these results, it is supposed that the LD group became unable to continue the exercise in spite of the sufficient potential of their oxidative energy supply system. In terms of the ΔLa of the LD group, no significant difference was seen between the peak value at the measurement point of $\dot{V}O_2$max and the measurement point during the SRT (8.43±0.57 vs. 6.66±1.36, P = .116). Based on these results, it is estimated that the energy supply system of the non-oxidative system serves as the main limiting factor of SRT performance for those who specialize in straight-line running as represented by long distance runners.

References

Beaver, W.L., Wasserman, K., and Whipp, B.J. (1986) A new method for detecting anaerobic threshold by gas exchange. J. Appl. Physiol., 60: 20-27.

Byard, A, D., Dengel, D, R. (2002) Validity of a portable metabolic measurement system. Medicine & Science in Sports & Exercise., 34: 149.

Gibson, A.ST.C., Broomhead, S., Lambert, M.I., and Hawley, J.A. (1998) Prediction of maximal oxygen uptake from a 20-m shuttle run as measured directly in runners and squash players. J. Sports Sci., 16: 331-335.

Grant, S., Corbett, K., Amjad, A.M., Wilson, J., and Aitchison, T. (1995) A comparison of methods of predicting maximum oxygen up take. Br. J. Sports Med., 29: 147-152.

Leger, L.A., and Lambert, J. (1982) A maximal multistage 20-m shuttle run test to predict VO2max. Eur. J. Appl. Physiol. Occup. Physiol., 49: 1-12.

Röcker, K., Striegel, S., Freund, T., and Dickhuth, H.H. (1994) Relative functional buffering capacity in 400-m runners, long-distance runners and untrained individuals. Eur. J. Appl. Physiol. Occup. Physiol., 68: 430-434.

Takahasi, S., Chiba, T., Matsubara, S., Ishii, H., and Maeda, A. (2007) Expired gas kinetics during 20 m shuttle running test. Human Performance Measurement 4: 9-16.

Tanaka, K., Watanabe, H., Konishi, Y., Mitsuzono, R., Sumida, S., Tanaka, S., Fukuda, T., and Nakadomo, F. (1986) Logtitudinal associations between anaerobic threshold and distance running performance. Eur. J. Appl. Physiol. Occup. Physiol. 55: 248-252.

Taylor, H.L., Busirk, E., and Henschel, A. (1955) Maximal oxygen uptake measure of cardio-respiratory performance. J. Appl. Physiol. 8: 73-80.

Takano, N. (1998) Tempo of exercise and breathing rhythm. (In) Respiratory adaptation to exercise. NAP Limited, Tokyo, Japan. In Japanese. 30-41.