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Original Research

Development of multistage 10-m shuttle run test for VO_2max estimation in healthy adults

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Abstract

Background and objective: The disadvantage of the traditional 20-m multistage shuttle run test (MST) is that it requires a long space for measurements and does not include various age groups to develop the test. Therefore, we developed a new MST to improve the spatial limitation by reducing the measurement to a 10-m distance and to resolve the bias via uniform distributions of gender and age. **Material and methods**: Study subjects included 120 healthy adults (60 males and 60 females) aged 20 to 50 years. All subjects performed a graded maximal exercise test (GXT) and a 10-m MST at five-day intervals. We developed a regression model using 70% of the subject's data and performed a cross-validation test using 30% of the data. **Results**: The male regression model's coefficient of determination (R^2) was 58.8%, and the standard error of estimation (*SEE*) was 4.17 mL/kg/min. The female regression model's R^2 was 69.2%, and the *SEE* was 3.39 mL/kg/min. The 10-m MST showed a high correlation with GXT on the VO_2max (males: 0.816; females: 0.821). In the cross-validation test for the developed regression models, the male's *SEE* was 4.38 mL/kg/min, and the female's *SEE* was 4.56 mL/kg/min. **Conclusion**: Thus, the 10-m MST is an accurate and valid method for estimating the VO_2max. Therefore, the 10-m MST developed by us can be used when the existing 20-m MST cannot be used due to spatial limitations and can be applied to both men and women in their 20s and 50s.

Keywords: Shuttle run test; VO_2max estimation; Exercise test; Multistage shuttle run

1. Introduction

Cardiopulmonary endurance is the most important physical factor for human health, daily life, occupational activity, leisure, and sports [1]. The VO_2max is the most representative index for evaluating cardiovascular endurance [2,3]. In prior studies, low VO_2max levels were associated with coronary heart disease [4], high blood pressure [5], type 2 diabetes [6], metabolic syndrome [7], cardiovascular disease [4], and cancer [8]. Therefore, it is crucial to determine individual cardiorespiratory fitness to be able to predict disease and to manage fitness.

We can measure the VO_2max directly or indirectly. We can perform direct measurement of VO_2max by using exercise load equipment and a respiratory gas analyzer. Indirect estimation of VO_2max is based on variables such as physical characteristics, running distance, heart rate, exercise intensity, and so forth [9,10]. The most common method of VO_2max measurement involves testing for incremental maximal exercise in a controlled laboratory setting [1,11]. However, incremental maximal exercise testing requires expensive tools and a skilled workforce. In addition, this method requires considerable time for the preparation and actual measurement, and it is limited to one subject at a time [1,9,11,12].

Researchers have developed a variety of field tests to address the limitations of the maximal exercise test and to measure multiple individuals simultaneously. Brouha *et al*. [13] estimated the VO_2max by measuring heart rate recovery after having performed lifting exercises on the bench.

Balke [14] and Cooper [15] estimated the VO_2max based on the distance covered during 15 min and 12 min intervals. In addition, Leger and Lambert [16] developed a 20-m MST covering two incremental points at 20 m distance, back and forth. This test showed a high degree of correlation (r = 0.84) with the maximal exercise load test.

The researchers were also interested in developing a method for the estimation of VO_2max using relatively simple exercise tests. Loudon *et al*. [17] estimated the VO_2max in 33 healthy adult women based on the subjects' heart rate, exercise load (watt), and age during exercise on the cycle ergometer. Leibetseder *et al*. [18] developed an equation for estimating the VO_2max have a high coefficient of determination (R^2 = 0.85) in 71 adult men and women exposed to 70% VO_2max and 90% VO_2max intensity, using a cycle ergometer. The parameters used were heart rate, exercise load, age, body mass index (BMI), and resting and exercise-induced heart rate. However, others have carried out to studies to estimate VO_2max without using an exercise test. Osborne *et al*. [19] estimated the VO_2max using physical factors (height, weight, chest circumference, fat mass, and body surface area) and the state of the left ventricle (dimension, mass, and volume). Sanada *et al.* [20] estimated the Japanese's VO_2max using 60 healthy young men's skeletal muscle mass and cardiac dimentions. Malek *et al.* [21] estimated the VO_2max in 112 healthy men who exercised regularly, using weight, height, exercise time per week, duration of continuous aerobic exercise, and exercise intensity (Borg scale). However, such simple non-exercise tests are less accurate than the maximal exercise tests [10] and separate equipment may be required to measure the independent variables [1,17,18].

Among the various methods used for VO_2max estimation mentioned above, the multistage 20-m shuttle run test showed a high degree of correlation with the results of the maximal exercise load test. It is widely used in field training in school physical education and by professional athletes [22–27]. Van Mechelen *et al.* [25] reported that the 20-m MST was excellent for predicting maximal exercise capacity in a study that compared a 6-min endurance running test and a 20-m MST in Dutch children. Leger and Gadoury [24] also reported that the 20-m MST was a highly effective measure of endurance in healthy adults. Therefore, in Korea, we use the 20-m MST for physical training and evaluation of professional athletes, in the Physical Activity Promotion System (PAPS), and in physical fitness testing for the selection of fire service personnel.

However, the traditional estimation formula developed by Leger and Lambert [16] has the following disadvantages. First, there is no gender distinction in estimating results [27]. Second, the subjects' age in the estimation formula is concentrated in the twenties. Third, a relatively large distance of 25 m (straight line distance of 20 m, and a safety distance of 5 m) or more is required for indoor measurement. Therefore, studies to improve the shuttle run test have been tried as follows.

Matsuzaka *et al.* [22] developed a new VO_2max estimation equation for boys, girls, and adults using shuttle run records, gender, age, and physical factors. Anderson *et al.* [28] developed a new VO_2max estimation formula (r = 0.84) for children, athletic college students, and soccer players using a modified 20-m MST (Anderson test). Mikawa and Senjyu [29] reported that the results of the 15-m shuttle run test developed for 68 middle-aged men in their 40s and 50s showed a strong correlation with the measured values (r = 0.86). These studies have partially addressed the limitations of the shuttle run test, but efforts to overcome the spatial limitations of bias such as gender and age and to target traits were relatively inadequate.

Therefore, we hypothesized that "10-m MST will be able to predict VO_2max". And to test this hypothesis, we developed a shuttle-run test by reducing the measurement distance to 10-m and separated by gender.

2. Materials and methods

2.1 Subjects

We hoped that the statistical power of the study results would be over 90%. So, we set the rho square (regression coefficient) to 0.7 [16], the statistical significance level to less than 0.05, and the number of predictors to be 5. As a result of the calculation using G*Power, the sample size was 18. However, to further increase the statistical power, we decided each male and females sample size to be 60 persons. Also, since the sample size is more than 30, citing the central limit theorem, we judged the sampling distribution is a normal distribution.

By the Institutional Review Board's approval, we recruited applicants to participate in the experiment by attaching a poster for participation in the experiment in the residential area around the institute. The study subjects included a total of 120 males and females with equal sex ratios. Their ages ranged between 20 and 50 years. We selected Korean subjects who had no history of musculoskeletal, cardiovascular, or metabolic disease during the previous six months. We hoped that the level of physical activity of the participants would not be biased. So we took people with different levels of physical activity into the experiment. Also, we instructed the test participants to maintain their physical activity as usual during the end of the two tests. Subjects' physical characteristics are as Table 1.

Table 1. Participant characteristics.

Gender	Ages	N	Height (cm)	Weight (kg)	BMI (kg/m^2)	Body fat (%)
Male	20	15	173.9 ± 7.1	69.5 ± 6.8	23.0 ± 1.7	16.4 ± 4.5
	30	15	174.9 ± 6.8	78.5 ± 9.4	25.6 ± 2.0	22.4 ± 3.2
	40	15	171.4 ± 3.8	74.4 ± 8.1	25.3 ± 2.2	23.29 ± 3.7
	50	15	170.5 ± 6.0	69.3 ± 6.9	23.8 ± 2.1	21.80 ± 3.0
Female	20	15	161.6 ± 4.1	56.8 ± 6.2	21.7 ± 2.3	25.7 ± 3.7
	30	15	161.9 ± 4.4	57.6 ± 6.9	22.0 ± 2.8	27.2 ± 5.0
	40	15	160.7 ± 6.4	58.6 ± 5.7	22.7 ± 2.3	28.5 ± 3.3
	50	15	158.6 ± 3.5	58.0 ± 6.7	23.0 ± 2.3	29.9 ± 3.8

BMI, Body Mass Index.

We divided the subjects of both genders according to a 7 : 3 ratio using Bernoulli's trials. We developed the regression model by using 70% of the subjects, and we used the remaining 30% of the subjects for cross-validation [30,31]. The actual sample size distribution according to Bernoulli's trials is shown in Table 2.

Table 2. Divided sample size according to Bernoulli's trials.

Gender	Total sample size	For develop	For validity test	Separating rate (%)
Male	60	42	18	7 : 3
Female	60	42	18	7 : 3

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2.2 Research design

We used questionnaires and blood pressure tests to select healthy persons among the 150 volunteers. We used the questionnaire for physical activity preparation (PAR-Q & YOU) and the AHA/ACSM Health/Fitness Facilities Screening questionnaires. Based on the results of the tests above, we included 120 subjects without any risk factors in this study. We randomly assigned the test order of the subjects using Microsoft Excel's "RANDBETWEEN" function. Therefore, 120 subjects performed the treadmill GXT test and the 10-m MST test according to the order in which they were randomly assigned. We kept the interval between the two tests at least 5 days.

2.3 Methods and measurements

2.3.1 Body composition test

The subjects fasted for at least 10 hours before the test and were only lightly dressed during the test. We used a body composition analyzer (Karada Scan, Omron, Kyoto, Japan) to measure the body weight, body fat, and skeletal muscle [32]. Also, we measured the subject's height, weight, waist circumference, and hip circumference and calculated BMI and waist-hip ratio (WHR) using these measured values.

2.3.2 Respiratory gas analysis

We measured respiratory gas during rest and exercise using an automatic breathing gas analyzer (K4B2, COSMED, Rome, Italy) for the treadmill test and the 10-m shuttle run test. We warmed up the gas analyzer for more than 30 minutes before testing to improve the reliability of the measurements. We also adjusted the gas analyzer to zero using a calibration gas (16% O_2, 5% CO_2) and a 3 L syringe [33].

2.3.3 Graded exercise test using treadmill

Like the shuttle run test, we did not apply the gradient in the treadmill test. Also, to observe the subjects' physiological responses (heart rate, respiratory gas, etc.) during exercise in more detail, we created a protocol with a small increase in exercise load between the examination stages. This protocol's initial starting speed was 3.6 km/h and increased by 1.2 km/h every 2 minutes. The slope was at 0% at all stages [31]. We measured respiratory gas and heart rate continuously during the maximal exercise testing. We stopped the exercise test when the oxygen uptake stopped increasing despite the increase in exercise intensity [34,35] and when the respiratory exchange rate exceeded 1.15 [36].

2.3.4 10-m multistage shuttle run test

We used nine sound sources as Do, Re, Mi, Fa, So, La, Ti, Do, and a buzzer sound in the 10-m MST. We reproduced the speed of the sound sources to be similar to the speed increase between the stages of the graded exercise test. Thus, we converted the speed of each stage of the graded exercise test to beats per minute (bpm) and adjusted the playback speed of sound accordingly. The subjects had a rest time of 5 min before the test. A researcher demonstrated the test method. We stopped the test when the subject either requested that we stop or when the subject was unable to follow the playback speed on more than one occasion. We also considered breath gas data in deciding when to stop such tests as the treadmill test. The detailed protocol of the 10-m MST is shown in Table 3.

2.4 Data analysis

For data analysis, we used the IBM SPSS 26.0 software for Windows and the Excel 2016 spreadsheet. We calculated the descriptive statistics for all measured data and performed multiple regression analyses to develop an equation to estimate VO_2max of the 10-m MST.

We used 70% of the data to develop regression models and 30% of the data for validity testing. We used Pearson's correlation analysis to correlate the actual and the predicted values. Using the residuals of the predicted values, we calculated the standard error of the estimation, as shown in Eqn. 1 [31]. We set the statistical significance level to be less than 5% for all tests.

$$SEE(mL/kg/min) = \sqrt{\frac{\sum (VO_2max_{real} - VO_2max_{pred.})^2}{n-2}} \quad (1)$$

SEE is standard error of the estimate (mL/kg/min). VO_2max_{real} is the actual measured value of the maximal oxygen consumption, and $VO_2max_{pred.}$ is the predicted value of the maximal oxygen consumption. The '*n*' is sample size.

3. Results

3.1 Comparison of GXT and 10-m MST

The males' 10-m MST reached the VO_2max and HRmax faster than did the GXT, as shown in Fig. 1. The VO_2max and HRmax did not significantly differ between 10-m MST and GXT. Further, the VO_2max and HRmax showed a significant ($p < 0.05$) correlation between the 10-m MST and the GXT (VO_2max: r = 0.816; HRmax: r = 0.954).

The females' 10-m MST reached the VO_2max and HRmax more quickly than did the GXT, as shown in Fig. 2. The heart rate increased similarly in both the 10-m MST and the GXT in all stages. The values of VO_2max and HRmax did not significantly differ between the 10-m MST and the GXT. Furthermore, the VO_2max and the HRmax showed a significant (p <0.05) correlation between 10-m MST and GXT (VO_2max: r = 0.821; HRmax: r = 0.823).

Table 3. Table 3. Protocol of multistage 10-m shuttle run test (converting from speed to beats).

Start time	Finish time	Speed (km/h)	Moving time per 10-m (s)	(Moving time per 10-m)/9 (s)	Beats per min	Number of shuttles
0:00:00	0:01:00	3.6	10.00	1.11	54	6
0:01:00	0:02:00	4.8	7.50	0.83	72	8
0:02:00	0:03:00	6.0	6.00	0.67	90	10
0:03:00	0:04:00	6.0	6.00	0.67	90	10
0:04:00	0:05:00	7.2	5.00	0.56	108	12
0:05:00	0:06:00	7.2	5.00	0.56	108	12
0:06:00	0:07:00	8.4	4.29	0.48	126	14
0:07:00	0:08:00	8.4	4.29	0.48	126	14
0:08:00	0:09:00	9.6	3.75	0.42	144	16
0:09:00	0:10:00	9.6	3.75	0.42	144	16
0:10:00	0:11:00	10.8	3.33	0.37	162	18
0:11:00	0:12:00	10.8	3.33	0.37	162	18
0:12:00	0:13:00	12.0	3.00	0.33	180	20
0:13:00	0:14:00	12.0	3.00	0.33	180	20
0:14:00	0:15:00	13.2	2.73	0.30	198	22
0:15:00	0:16:00	13.2	2.73	0.30	198	22
0:16:00	0:17:00	14.4	2.50	0.28	216	24
0:17:00	0:18:00	14.4	2.50	0.28	216	24
0:18:00	0:19:00	15.6	2.31	0.26	234	26
0:19:00	0:20:00	15.6	2.31	0.26	234	26
0:20:00	0:21:00	16.8	2.14	0.24	252	28
0:21:00	0:22:00	16.8	2.14	0.24	252	28

The reason for dividing the 10-m moving time by nine is that we split the shuttle-run section into nine sections (Do, Re, Mi, Pa, Sol, La, Si, Do, turn). And we calculated the beats per minute using this section-time (the moving time per 10-m divide nine).

3.2 Selection of independent variables for multiple regression analysis

We selected independent variables for multiple regression analysis to estimate the VO_2max of 10-m MST via correlation analysis. As a result, shuttle count, final speed, percent body fat, percent skeletal muscle, BMI, waist-hip ratio (WHR), and age were included as independent variables. Therefore, we performed a multiple regression analysis using these parameters as independent variables, as shown in Table 4.

Table 4. Correlation of each independent variable vs. measured VO_2max by 10-m MST.

Independent variables	Gender	r	*p*-value	n
Shuttle count	Male	0.738	<0.000	42
	Female	0.795	<0.000	42
Final speed	Male	0.614	<0.000	42
	Female	0.648	<0.000	42
% Body fat	Male	−0.531	<0.000	42
	Female	−0.585	<0.000	42
% Skeletal muscle	Male	0.383	0.012	42
	Female	0.518	<0.000	42
BMI	Male	−0.352	0.022	42
	Female	−0.393	0.010	42
WHR	Male	−0.490	0.001	42
	Female	−0.311	0.045	42
Age	Male	−0.247	0.115	42
	Female	−0.469	0.002	42

Dependent variable: Measured VO_2max by 10-m MST. WHR means the waist to hip ratio.

3.3 Development of equations to estimate VO_2max using 10-m MST

3.3.1 F-test for regression models

We conducted an F-test to confirm the developed regression models' statistical validity to predict VO_2max using the 10-m MST. As a result, we found all the regression models to be statistically valid (Table 5).

3.3.2 Student's t-test for regression coefficient of each independent variable

We performed a t-test to confirm the statistical significance of the regression coefficients of each independent

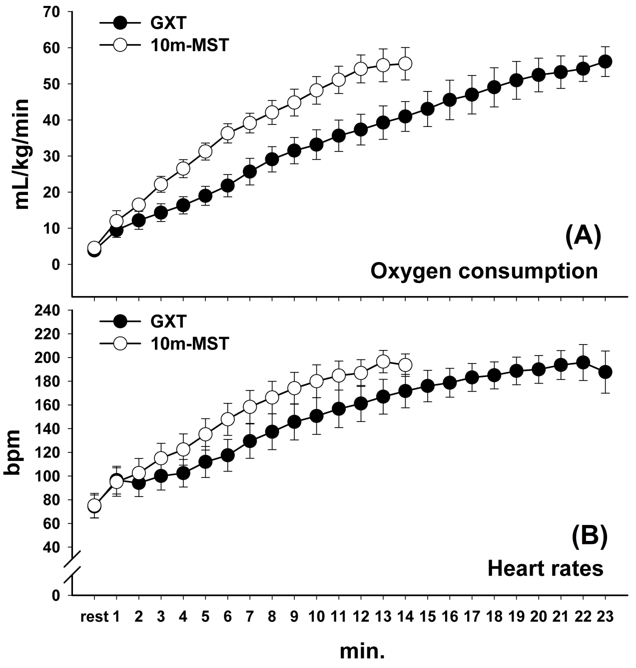

Fig. 1. Oxygen uptake and heart rates comparison of GXT and 10-m MST in males. GXT means gradually maximal exercise test and MST means multistage shuttle-run test. The X-axis is exercise duration time by the minute, and the Y-axis of (A) is oxygen consumption during exercise, and the Y-axis of (B) is heart rate per minute during exercise.

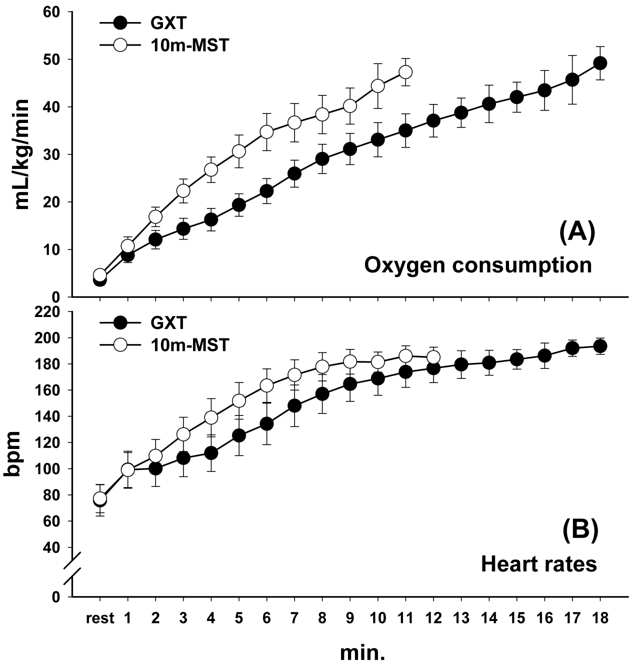

Fig. 2. Oxygen uptake and heart rates comparison of GXT and 10-m MST in females. GXT means gradually maximal exercise test and MST means multistage shuttle-run test. The X-axis is exercise duration time by the minute, and the Y-axis of (A) is oxygen consumption during exercise, and the Y-axis of (B) is heart rate per minute during exercise.

Table 5. Results of *F*-test for each regression model.

Regression model	*F*-value	*p*-value
Males' regression model	13.212	<0.000
Females' regression model	16.140	<0.000

variable. The shuttle count was a statistically significant independent variable in the case of males. Both the shuttle count and the BMI were statistically significant independent variables in the females (Table 6).

Table 6. Results of *t*-test for regression coefficients of each independent variable.

Regression model	Variation	*t*-value	*p*-value
Regression model for males	Shuttle count	3.803	0.001
	Final speed	−1.218	0.231
	BMI	−0.216	0.830
	WHR	−1.500	0.142
Regression model for females	Shuttle count	4.117	<0.000
	Final speed	−0.934	0.357
	BMI	−2.084	0.044
	WHR	0.965	0.341
	Age	−0.488	0.629

BMI, Body Mass Index; WHR, the waist to hip ratio.

3.3.3 The goodness-of-fit for regression models

We calculated the coefficient of determination and the standard error of estimate (*SEE*) to confirm the goodness-of-fit for regression models. As a result, the regression model explained about 54% of the value of VO_2max in males. The regression model explained about 65% for the value of VO_2max in females. Further, the *SEE* values of the regression model for both males and females were 4.17 mL/kg/min and 3.39 mL/kg/min (Table 7).

Table 7. Coefficient of determination (R^2) and standard error of estimate (*SEE*) in each regression model.

Regression model	R^2	adj R^2	*SEE* (mL/kg/min)
Regression model for males	0.588	0.544	4.17
Regression model for female	0.692	0.649	3.39
Average	0.640	0.597	3.78

3.3.4 Regression equations

We developed the regression equations for the estimation of VO_2max using 10-m MST (Table 8).

Table 8. The regression equation for prediction of VO_2max using 10-m MST.

Regression model	Regression equation
Regression model for males	VO_2max = 0.231 × (shuttle count) – 1.975 × (final speed) – 0.073 × (BMI) – 23.488 × (WHR) + 60.909
Regression model for females	VO_2max = 0.272 × (shuttle count) – 1.530 × (final speed) – 0.649 × (BMI) + 15.392 × (WHR) – 0.029 × (age) + 30.345

BMI, Body Mass Index; WHR, the waist to hip ratio.

3.4 Validity test for 10-m MST

We used the 30% of the total data that had not been included in developing the regression models (males: 42, females: 42). We calculated the *SEE* using Equation 1. As a result, the *SEE*s of regression models for males and females were 4.38 mL/kg/min and 4.56 mL/kg/min. These values were like the *SEE* of the developed regression models (Table 9).

Table 9. Results of the validity test.

Regression model	*SEE* (mL/kg/min)
Regression model for males	4.38
Regression model for females	4.56

4. Discussion

4.1 Comparison of GXT and 10-m MST

In this study, we performed GXT and 10-m MST in 120 healthy volunteers, between 20 and 50 years of age. The VO_2max had a significant correlation of 0.8 or more between GXT and 10-m MST in males and females, respectively. Also, the HRmax was highly correlated of 0.8 or more between GXT and 10-m MST in males and females, respectively. Correlations between the predicted values of 10-m MST and the measured VO_2max in this study were as high as in the 20-m MST ($r = 0.84$) [16] and the revised 20-m MST versions, for example, the Anderson test ($r = 0.84$). This study can be used at various ages (20–50 years) and genders. It can be utilized to overcome the disadvantages of previous studies [16,23,26,28,37]. Also, the VO_2max and HRmax were faster in the 10-m MST than in the maximum exercise test. So, we expected our test protocol had shortened the VO_2max measurement time. At this time, a question may arise that if the measurement time is short, it will not reach VO_2max. However, according to this study's results, the VO_2max of GXT using the treadmill and the VO_2max of 10-m MST showed a high correlation of 0.8 or more. Also, HRmax showed a high correlation of 0.9 or more between GXT using the treadmill and 10-m MST. These results show that even 10-m MST, which has a relatively short measurement time, does not have any problem measuring the maximum exercise capacity. However, if the measurement time is shorter than, there is a concern that the measurement will be terminated before reaching the maximum exercise capacity because the subject's physiological change between stages appears large. To prevent this error, we set a small increase in exercise load between stages. When making the test protocol using the treadmill, we set the exercise load increase between stages to be small and calculated the shuttle speed of the 10-m MST based on this treadmill speed. As a result, the treadmill test's measurement duration was slightly longer, while the maximum exercise capacity test was possible at the 10-m MST.

4.2 Development of equations to estimate VO_2max using 10-m MST

In the present study, we used 70% of the data pertaining to 120 adult males and females based on Bernoulli's trials. We performed multiple regression analyses by selecting variables that were highly correlated without autocorrelation. Several studies validated and developed the formula for the evaluation of adults using the 20-m MST [16]. Leger *et al*. [23] studied 77 adults subjected to tests with a speed increase of 0.5 km/h/min (start speed of 8.5 km/h). As a result, we estimated the VO_2max to a high degree of correlation ($r = 0.90$) with the actual VO_2max, using the final speed and age.

In addition, Ramsbottom *et al*. [26] reported that the 20-m MST [23] strongly correlated with the maximal exercise test ($r = 0.92$) and the 5-km running record ($r = 0.94$) in 74 male adults (19–36 years). In addition, several researchers have developed a VO_2max estimation formula using the 20-m MST. But this formula has limited practical application because the subjects were predominantly male [37] or of uneven age distribution. The estimation equation developed in this study distinguished men and women and adjusted for age distribution. The coefficient of determination (R^2) of the estimation equation was meaningful (R^2 = 0.588 for males, R^2 = 0.692 for females).

4.3 Validation of 10-m MST

The validation of the estimating equation developed in this study of 120 adult males and females utilized 30% the data divided by Bernoulli's trials. As a result of the validity test, the estimated standard error (*SEE*, mL/kg/min) ratio was within 2% (male 4.38, female 4.56). Based on these results, we confirmed that the regression model was highly valid. Thus, we have developed a new 10-m MST as an alternative to the existing 20-m MST by overcoming its limitations (gender classification, application across various ages, and short measurement distance).

Lastly, our made 10-m MST has the advantage of being able to estimate VO_2max relatively accurately even if it is used as an alternative method in environments (space not enough, etc.) where it is difficult to apply the existing shuttle run test. Also, the sample size of the 10-m MST developed by us is 120, which is larger than that of the 20-m MST developed by Leger and Lambert [16]. However, we do not think that the sample size per category is sufficient when categorized by age group, gender, etc. Therefore, it is necessary to verify additional practicality while using the 10-m MST extensively.

Additionally, when considering this study's results, there was no evidence that the 10-m MST made by reducing the measurement distance overestimated the maximum exercise capacity. However, even to address these concerns, we hope that this test method will be modified-developed as it is widely used.

5. Conclusions

In this study, we developed a 10-m MST for VO_2max estimation in 60 healthy adult men and women in their 20s and 50s which has improved reliability, validity, and simplicity.

Towards this end, we collected 120 data measurements and divided them according to a 7 : 3 ratio based on Bernoulli's trials. We used the data for 70% of males and females for VO_2max estimation, and 30% of the data was used to confirm the validity of the regression equation that we had developed. As a result, the coefficient of determination (R^2) of the developed regression equation was 0.588 for males and 0.692 for females, suggesting above average performance. The average *SEE* of 4.47 mL/kg/min also confirmed the high validity of the regression model. However, since the study included general population subjects, additional studies are needed before the results can be applied to athletes and other individuals.

In summary, the 10-m MST developed by us can be used when the existing 20-m MST cannot be used due to spatial limitations and can be applied to both men and women in their 20s and 50s.

Author contributions

SSN conceived and designed this study; SSN, HYP, and HLC performed the experiment and measurement; SSN conducted the data analysis; HLC and HYP wrote the original draft preparation; SSN discussed of result and concluded. All authors have read and agreed to the published version of the manuscript.

Ethics approval and consent to participate

This study was conducted according to the Helsinki Declaration's guidelines and approved by the local ethics committee of Kyunghee University (KHU IRB 2014-G01). Also, informed consent was obtained from all subjects involved in the study.

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Conflict of interest

The authors declare no conflict of interest.

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