

Research article

Development of a field test for evaluating aerobic fitness in middle-aged adults: Validity of a 15-m Incremental Shuttle Walk and Run Test

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Abstract

The purpose of this study was to develop a standardized and externally paced field test (15-m Incremental Shuttle Walk and Run Test [15mISWRT]), incorporating an incremental and progressive structure, to assess aerobic fitness in middle-aged adults. 68 middle-aged men performed three tests in random order between one to two week intervals: 15-m ISWRT, cardiopulmonary exercise test (CPX), and 1500-m fast walk. Variables evaluated were 15-m ISWRT performance (distance completed), VO_{2max} measured by CPX, 1500-m fast walk performance (walking time), and HR response in 15-m ISWRT and 1500-m fast walk. Validity of the 15-m ISWRT was tested by comparing the associations among the 15-m ISWRT performance, VO_{2max} and the 1500-m fast walk performance. Changes in HR response during the 15-m ISWRT and the 1500-m fast walk were also compared. Correlations between each variable were as follows: the correlation between 15-m ISWRT performance and VO_{2max} was very high, $r = 0.86$ ($p < 0.01$), the correlation between the 1500-m fast walk and VO_{2max} was $r = -0.51$ ($p < 0.01$). HR response during the 15-m ISWRT gently increased initially, whereas HR response during the 1500-m fast walk rapidly increased from the start. In conclusion, our findings indicate that the 15-m ISWRT is valid and safe for evaluating VO_{2max} in middle-aged adults.

Key words: Maximal oxygen uptake, heart rate, 20m shuttle run test, shuttle walking test, cardiopulmonary exercise test.

Introduction

Lifestyle diseases and metabolic syndrome due to overeating and insufficient exercise are currently a problem (Ford, 2005; Takeuchi et al., 2005) facing many middle-aged people in developed countries and there is growing concern over the aerobic fitness of this age group.

It is clear that aerobic fitness in middle-aged adults correlates negatively with risk factors for high blood pressure and coronary artery disease (LaCroix et al., 1993; Slatter, 1988; Twisk et al., 2000), and it contributes to prevention of lifestyle diseases and reduced mortality if maintained at a high level (Blair et al., 1984; 1989; Tallot et al., 2002). Maximal oxygen uptake (VO_{2max}) and anaerobic threshold (AT) are recognized as objective and valid standards for aerobic fitness (Farrell et al., 1979; McArdle et al., 1981; Taylor et al., 1955) and the proper evaluation of VO_{2max} and AT is, therefore, important in assessing the health and healthcare needs of middle-aged adults.

VO_{2max} can be evaluated using a cardiopulmonary exercise test (CPX) or field tests (Leger and Lambert,

1982; Singh et al., 1992). CPX provides an accurate measure of VO_{2max} , but it is not widely used in clinical settings because it requires expensive, complicated equipment and trained staff, whereas field tests are a widely used alternative because they are simple, inexpensive, and do not require specialized equipment.

The 1500-m fast walk (Japan's Ministry of Education, Culture, Sports, Science and Technology, 2000) and 20-m shuttle run test (20-m SRT) (Leger and Lambert, 1982) are currently used as field tests for middle-aged adults and they are recommended in Japan by the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

However, the 1500-m fast walk has certain drawbacks. The exercise workload is not quantified since the subjects walk at their own pace, producing test results influenced by the subjects' own inclinations and comfort zones. The test is therefore not standardized and its reliability and validity has not been sufficiently studied. This test is also restricted by weather and location since it requires a track and is usually performed outside.

The 20-m SRT has been well studied in young people showing good reproducibility and strong correlations between test performance and VO_{2max} (Leger and Lambert, 1982; McNaughton, 1988; Ramsbottom, 1988; Boreham, 1990) but it has not been tested in middle-aged adults. Because the 20-m SRT was originally developed to evaluate the aerobic fitness of athletes, the estimated VO_{2max} at the first stage was set at $27.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, a high level of exercise intensity. This field test cannot therefore be used to evaluate aerobic fitness below a VO_{2max} of $27.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, and it would impose an excessive, high-risk workload on middle-aged subjects.

Singh and colleagues modified the 20-m SRT to produce the 10-m Incremental Shuttle Walking Test (10-m ISWT) (Singh et al., 1992) for evaluating the aerobic fitness of patients with chronic obstructive pulmonary disease (COPD). Because the 10-m ISWT uses an external sound to control walking speed, it can increase the exercise load to the limits of the subject's fitness in the same way as CPX. The test also has high reproducibility over repeated measurements (Singh et al., 1992) and shows good correlation between test performance and peak oxygen intake (VO_{2peak}) (Singh et al., 1994). This test is now widely used throughout the world as a field test for evaluating the aerobic fitness of patients with respiratory and cardiovascular disease. However, because the 10-m ISWT was developed for COPD patients, the maximum estimated VO_{2max} calculated from 10-m ISWT

Table 1. Reference values and ranges of maximal oxygen uptake ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) for health promotion by gender and age.

		20-29years	30-39years	40-49years	50-59years	60-69years
Males	Reference values	40	38	37	34	33
	Range	33-47	31-45	30-45	26-45	25-41
Females	Reference values	33	32	31	29	28
	Range	27-38	27-36	26-33	26-32	26-30

Exercise and physical activity reference for health promotion 2006 (Japan's Ministry of Health, Labour and Welfare, 2006).

test performance is $30.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, making it unsuitable for evaluating aerobic fitness when $\text{VO}_{2\text{max}}$ is above $30.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.

Based on the $\text{VO}_{2\text{max}}$ reference values and ranges for health promotion in people aged 50-59 years (Table 1) (Japan's Ministry of Health, Labour and Welfare, 2006), published by Japan's Ministry of Health, Labour and Welfare, it is clear that the exercise intensity of the 20-m SRT and 10-m ISWT tests is unsuitable for middle-aged adults.

It is apparent from this brief survey of methods for evaluating aerobic fitness in middle-aged adults that none of the existing field tests satisfy the expected conditions of standardization, validity, safety and simplicity. In view of this, we extended the 10-m course of the 10-m ISWT to create a 15-m incremental shuttle walk and run test (15-m ISWRT). A pilot study (Mikawa et al., 2005) of the 15-m ISWRT demonstrated that the $\text{VO}_{2\text{max}}$ range measurable from this test was $7\text{-}52 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, and that 15-m ISWRT performance correlated very closely with $\text{VO}_{2\text{mean}}$ ($r = 0.95$, $p < 0.01$) at each level. However, the test was not validated for older subjects because the pilot study used healthy adults in their twenties.

Therefore, the aim of the present research was to investigate the validity of the 15-m ISWRT based on the relationships among 15-m ISWRT performance, 1500-m fast walk performance, and $\text{VO}_{2\text{max}}$ from CPX in middle-aged adults.

Methods

Subjects

Initially, 107 potential subjects responded to recruitment announcements distributed to participants at local health workshops, hospital employees, university staff, and members of private sports clubs. Of the 77 who were accepted as meeting the study selection criteria, 68 took part in the study. The reason why nine subjects dropped out from the study was that they were busy working and not able to attend throughout the entire three weeks. Table 2 shows the subjects' physical characteristics.

Table 2. Physical characteristics of the subjects (n = 68).

Variable	Mean (\pm SD)	Range
Age (yr)	50.4 (6.4)	40 - 59
Height (m)	1.67 (.07)	155.2 - 176.7
Weight (kg)	65.2 (8.9)	55.5 - 79.3
BMI ($\text{kg}\cdot\text{m}^{-2}$)	23.7 (4.9)	16.3 - 30.7

BMI = body mass index

Subject selection criteria were: 1) 40-59 years old, 2) male, 3) capable of running, 4) no history of bone and joint disease or cardiorespiratory disease that would impede the exercise, and 5) gave consent to take part in the research. This research was conducted with the approval of the Nagasaki University Graduate School Ethics

Committee.

Measurements

Procedures

The 68 subjects performed three tests in random order between one to two week intervals: 15-m ISWRT, CPX, and 1500-m fast walk. Variables evaluated were 15-m ISWRT performance (distance completed), $\text{VO}_{2\text{max}}$ measured by CPX, 1500-m fast walk performance (walking time), and HR in 15-m ISWRT and 1500-m fast walk. Validity of the 15-m ISWRT was tested by comparing the associations among the 15-m ISWRT result, $\text{VO}_{2\text{max}}$, and the 1500-m fast walk result. Changes in HR response during the 15-m ISWRT and the 1500-m fast walk were also compared.

15-m Incremental Shuttle Walk and Run Test (15-m ISWRT)

The 15-m ISWRT was performed on a straight, 15-m course on level ground. The subjects moved back and forth over the 15-m course which had a guide pole placed 0.5 m from each end to prevent sharp changes of direction. Subjects had to walk or run at the prompting of a sound played at regular intervals from the 10-m ISWT CD, reaching the guide pole at the opposite side before the next sound was heard. Travel speed ranged from level 1 to level 12, increasing by increments of $15 \text{ m}\cdot\text{min}^{-1}$. Level 1 speed was set at $2.7 \text{ km}\cdot\text{h}^{-1}$ so that three lengths of the 15 m course were covered in 1 minute (1.5 return trips). With each increase in level, the number of lengths travelled was increased by one so that level 2 was four lengths (2 return trips) per minute and so on until the final level 12 required 14 lengths per minute (7 return trips). Table 3 shows the protocols for the 15-m ISWRT.

Table 3. The protocols of 15m Incremental Shuttle Walk and Run Test (15m ISWRT).

Level	Speed ($\text{km}\cdot\text{h}^{-1}$)	No of shuttles per level	Distance per level (m)	Sum (m)
1	2.7	3	45	45
2	3.6	4	60	105
3	4.5	5	75	180
4	5.4	6	90	270
5	6.3	7	105	375
6	7.2	8	120	495
7	8.1	9	135	630
8	9.0	10	150	780
9	9.9	11	165	945
10	10.8	12	180	1125
11	11.7	13	195	1320
12	12.6	14	210	1530

Stopping criteria conformed to the American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (American College of Sports Medicine,

1995). Inability to cover the 15-m course within the set time was an additional stopping criterion.

Cardiopulmonary exercise test (CPX)

VO_{2max} was measured by CPX using a symptom-limited ramp exercise test. The ramp exercise protocol was performed using a bicycle ergometer (75XL II, Combi Corp. Tokyo, Japan) and consisted of 2 minutes of rest, followed by 3 minutes of warming up at $10 \text{ watt}\cdot\text{min}^{-1}$ and then exercise at $15 \text{ watt}/\text{min}$. During the test, HR and ECG were monitored with an ECG monitor, and blood pressure was taken once per minute with an automatic sphygmomanometer (EBP-300, Minato Medical Science, Tokyo, Japan). Expired gas indicators were measured breath-by-breath using an Aeromonitor (AE-300S, Minato Medical Science). Moreover, the rating of perceived exertion (RPE) was evaluated during exercise. VO_{2max} and HR_{max} during the test were defined as a series of maximum values of VO_2 and HR observed during exercise, providing that the subject exercised to that subject's symptomatic limit. Stopping criteria followed the American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (American College of Sports Medicine, 1995).

VO_{2max} was confirmed when at least two of the following criteria were met: 1) HR at termination greater than 90% age-predicted HR_{max} ; 2) respiratory quotient greater than 1.05; 3) detection of plateau in VO_2 curve; and 4) RPE greater than 9. The test was also stopped as soon as the subject became unable to maintain pedal rotation of 50 rotations per minute in time with a metronome.

1500-m fast walk

The 1500-m fast walk was performed in accordance with MEXT's New Physical Test Guidelines (Japan's Ministry of Education, Culture, Sports, Science and Technology, 2000). Subjects were timed over a distance of 1500 m (7.5 times around a level 200-m track), having been instructed to walk as quickly as possible. The mean speed was $6.8 \text{ km}\cdot\text{h}^{-1}$ in the 1500-m fast walk.

Statistical analysis

The validity of the 15-m ISWRT was tested using Pearson product-moment correlation analysis among the measured variables (15-m ISWRT distance completed, VO_{2max} , and 1500-m fast walk time). HR changes during the 15-m ISWRT and the 1500-m fast walk were analyzed using a paired *t*-test to compare HR across tests in 60-second segments.

SPSS (18.0J for Windows) was the statistical software used with the significance was set a priori at < 0.05 .

Results

Validity of 15-m ISWRT

Means \pm SD for the 15-m ISWRT (distance completed), VO_{2max} measured by CPX, and 1500-m fast walk (walking time) were $1086.8 \pm 107.1 \text{ m}$, $34.2 \pm 6.3 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, and $812 \pm 64.2 \text{ s}$, respectively.

Correlations between each variable (15-m ISWRT performance, VO_{2max} , 1500-m fast walk performance)

were as follows: the correlation between 15-m ISWRT performance and VO_{2max} was very high at $r = 0.86$ ($p < 0.01$) (Figure 1), and it was represented by the regression equation: $VO_{2max} = 14.56 \pm 0.02 \text{ distance}$ where VO_{2max} is in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and distance is in meters. The correlation between the 1500-m fast walk and VO_{2max} was $r = -0.51$ ($p < 0.01$) (Figure 2), and between the 15-m ISWRT and the 1500-m fast walk the correlation was $r = -0.52$ ($p < 0.01$).

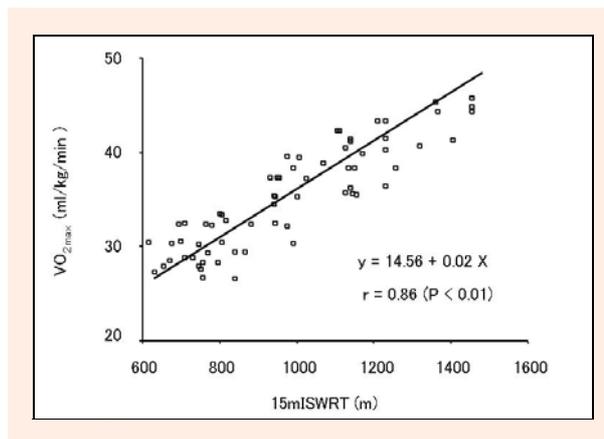


Figure 1. Regression line for the relationship between VO_{2max} and performance distance on the 15mISWRT. 15mISWRT = 15m Incremental Shuttle Walk and Run Test, VO_{2max} = Maximal oxygen uptake

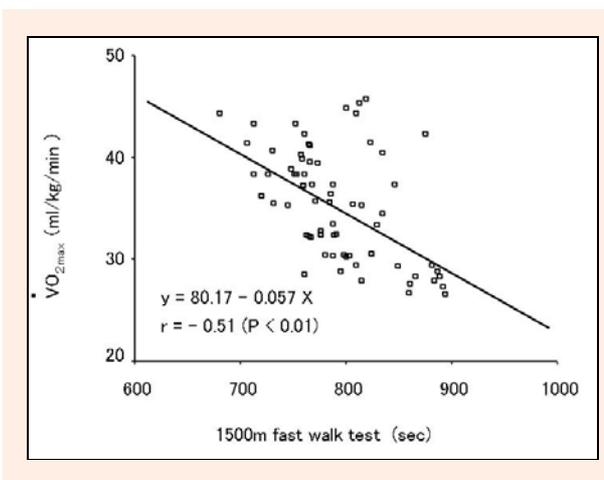


Figure 2. Regression line for the relationship between VO_{2max} and performance time on the 1500m fast walk test. VO_{2max} = Maximal oxygen uptake

HR response during 15-m ISWRT and 1500-m fast walk

Figure 3 shows the HR response during the 15-m ISWRT and the 1500-m fast walk. Mean test times were $575 \pm 48 \text{ s}$ in the 15-m ISWRT and $812 \pm 64 \text{ s}$ in the 1500-m fast walk. HR_{max} was significantly higher in the 15-m ISWRT than in the 1500-m fast walk ($p < 0.01$); mean values were $160.2 \pm 5.6 \text{ bpm}$ and $142.4 \pm 11.4 \text{ bpm}$, respectively. In addition, HR during the 15-m ISWRT gently increased initially, then increased in stages from 4 minutes onwards, whereas HR during the 1500-m fast walk increased rapidly at the start. HR was significantly higher in the 1500-m walk than in the 15-m ISWRT ($p < 0.05$) from 1 to 5

minutes after the start of the test, and it was significantly higher in the 15-m ISWRT than in the 1500-m walk from 9 to 10 minutes ($p < 0.05$).

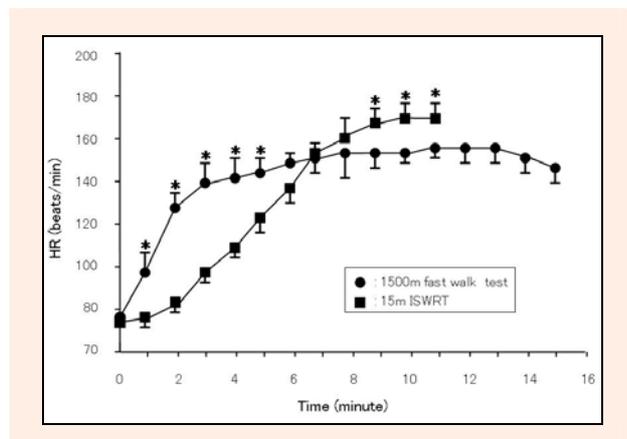


Figure 3. Response of the HR during 15m Incremental Shuttle Walk and Run Test and 1500m fast walk test. HR = heart rate, 15mISWRT = 15m Incremental Shuttle Walk and Run Test. * $p < 0.05$.

Discussion

This study is the first trial of an incremental and progressive field test for evaluating aerobic fitness in middle-aged adults. We have shown that the 15-m ISWRT is valid and safe for evaluating VO_{2max} in this group.

Validity of 15-m ISWRT

As seen in Figure 1, there was a very high correlation of $r = 0.86$ ($p < 0.01$) between 15-m ISWRT performance and VO_{2max} . Leger and colleagues have reported a correlation of $r = 0.84$ between 20-m SRT performance and VO_{2max} (Leger and Lambert, 1982). Similarly, Singh and colleagues reported a correlation of $r = 0.88$ between 10-m ISWRT performance and VO_{2peak} (Singh et al., 1994). The correlation coefficient we obtained for 15-m ISWRT and VO_{2max} was similar to these field tests. The main reason for this similarity of results and the strong correlation between 15 m ISWRT and VO_{2max} is probably that the 15-m ISWRT shares with the 20-m SRT and the 10-m ISWRT the feature that the exercise load and rate are controlled externally (by sound from CD) as with CPX, creating an incremental exercise test that can take the subjects to the limits of their fitness. These results suggest that the 15-m ISWRT has good validity as a field test for evaluating aerobic fitness in middle-aged adults.

In contrast, 1500-m fast walk performance and VO_{2max} showed a correlation of $r = -0.51$ ($p < 0.01$), as shown in Figure 2. As a correlation coefficient for a field test for measuring aerobic fitness, this is not particularly high. The main reason for this is probably that the subjects walk at a self-determined pace in the 1500-m fast walk and they may select a relatively comfortable walking speed without approaching their symptomatic limit. This is supported by the fact that some subjects with high VO_{2max} in CPX recorded poor completion times in the 1500-m fast walk. In summary, the 1500-m fast walk has poor validity as a field test for evaluating aerobic fitness in middle-aged adults since test performance correlates

poorly with VO_{2max} and the protocol is not standardized. However, in the present study, the lack of a high correlation between the results of the 1500-m fast walk and VO_{2max} may have been due to the fact that no familiarity trial for the 1500-m fast walk was conducted a few days before data collection. This was because the present study was conducted based on MEXT's New Physical Test Guidelines (Japan's Ministry of Education, Culture, Sports, Science and Technology, 2000), which did not stipulate a familiarity trial. If a familiarity trial had been held, there may have been a higher correlation between the results of the 1500-m fast walk and VO_{2max} . This issue will be investigated in the future.

Changes in HR response during 15-m ISWRT and 1500-m fast walk

HR during the 15-m ISWRT increased gently for 3 minutes, then increased in steps from around 4-5 minutes with HR_{max} reaching 160.2 ± 5.6 bpm. In contrast, HR during the 1500-m fast walk increased rapidly initially, but leveled out at about 4-5 minutes with HR_{max} reaching only 142.4 ± 11.4 bpm. The relative heart rate ($\%HR_{max}$) calculated from HR_{max} during both tests was 88% for the 15-m ISWRT and 78% for the 1500-m fast walk. However, the relative heart rate exceeded 70% for longer in the 1500-m fast walk than in the 15-m ISWRT.

These results indicate that the 15-m ISWRT results in an exercise intensity approaching maximal exercise and increasing in a stepped manner. Such a stepped increase is related to safe exercise testing (Singh et al., 1992), but in the 1500-m fast walk, the exercise intensity increases rapidly at the start. Foster and colleagues have reported subclinical ischemic responses in 60-70% of healthy subjects engaged in strenuous exercise without warm up (Foster et al., 1981) which implies that a rapid HR increase at the start of the 1500-m fast walk could present a high risk for middle-aged adults. It is also interesting to note that circulatory function undergoes stress for a longer period of time during the 1500-m fast walk than during the 15-m ISWRT.

Therefore, it appears that, although the 15-m ISWRT results in maximal work, maximal effort approaches exhaustion only for a short time because the mode of work brings about exhaustion by incremental stress rather than by constant-rate stress. The 15-m ISWRT is thus a highly safe exercise stress test. It is highly probable that physical tests for middle-aged adults will be undertaken by people who typically get insufficient exercise and feel they lack physical strength. For middle-aged adults, a safe exercise stress test is desirable, and in this regard, the 15-m ISWRT can be considered a highly suitable exercise stress test for this group.

A limiting factor in this study was that the subject group consisted of volunteers rather than being randomly selected. Thus, the possibility of selection bias cannot be ruled out. Furthermore, we only studied middle-aged men; no women were included. A future study using a large group of randomly selected subjects is needed to address the limitations of this study.

In clinical applications, if it were verified that VO_{2max} in the middle-aged adults can be simply and accurately estimated from 15-m ISWRT performance, this test

could become a valid means for evaluating aerobic fitness as an alternative to CPX in institutions (general healthcare facilities, educational establishments) and situations (community health checks) where CPX is difficult to implement. It could also be offered when prescribing suitable exercise.

Conclusion

We investigated the validity of the 15-m ISWRT designed for middle-aged adults and based on the 10-m ISWT developed by Singh and colleagues (Singh et al., 1992). The reasons for studying the 15-m ISWRT were as follows. 1) As with the 10-m ISWT, the exercise load in the 15-m ISWRT protocol was controlled externally and had been standardized. Furthermore, because it was an incremental test, a near-maximal exercise load up to the symptomatic limit could be applied. 2) The procedure of the 15-m ISWRT is simple, and it does not use expensive equipment. Therefore, it can be administered indoors to many people in one session with just a straight 15-meter course and without the need for testers with specialist knowledge. 3) A pilot study (Mikawa et al., 2005) with young, healthy subjects demonstrated the utility and validity of the 15-m ISWRT.

Our findings indicate that the 15-m ISWRT is valid and safe for evaluating VO_{2max} in middle-aged adults. The 15-m ISWRT is therefore highly recommended as a field test for evaluating aerobic fitness in the middle-aged adults.

Acknowledgement

We are grateful to Sue Jenkins, PhD, Associate Professor at the School of Physiotherapy, Curtin University of Technology for help in reviewing this manuscript. In addition, we are especially thankful to the staff of the following for their assistance in data collection: rehabilitation staff of Hozenkai Tagami Hospital, Isahaya Memorial Hospital, Nagasaki Keyaki Clinic, Chubu-Gakuin University.

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Key points

- The 15-m ISWRT is valid and safe for evaluating VO_{2max} in middle-aged adults.
- In comparison with the 1500-m fast walk, the 15-m ISWRT may be a more favourable field-based assessment of aerobic fitness in the middle-aged adults.
- The 15-m ISWRT could become a valid means for evaluating aerobic fitness as an alternative to CPX in institutions and situations where CPX is difficult to implement.

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