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Reliability and validity of the 21-m shuttle-run test and its application to youth soccer players during the preseason training

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[Purpose] This study has two purposes: first to assess the reliability and validity of the 21-m shuttle-run test (21-m SRT) and, second, to evaluate the practicality of the 21-m SRT for youth soccer players during preseason training.

[Methods] Twenty-seven youth soccer players (15.9 ± 0.7 yrs., males) participated in the present study. To assess the reliability of the test, each player performed the 21-m SRT twice, on separate days. Criterion validity of the 21-m SRT was determined by examining the relationship between directly measured $\dot{V}O_{2max}$ and 21-m SRT performance. To test the practicality of the 21-m SRT, three 21-m SRTs and two graded exercise tests on a treadmill were performed by each youth soccer player during preseason training.

[Results] Results revealed that the 21-m SRT has high correlation coefficients (r = 0.87) between test and retest and has moderate correlation coefficients (r = 0.465) between $\dot{V}O_{2max}$ and SRT performance. As $\dot{V}O_{2max}$ significantly increased after the training period, SRT performance (distance and heart rate immediately after the 67th shuttle run) also positively changed during the preseason training period.

[Conclusion] The 21-m SRT has high reliability with moderate validity, and it is an effective tool for coaches to examine aerobic capacity and the efficacy of a training program for youth soccer players during the preseason training period.

[Keywords] soccer, shuttle-run test, reliability, validity, practicality, fitness test, performance indicator

INTRODUCTION

To improve athletic performance in soccer, coaches first evaluate each player's physical capacity to determine personal strengths and weaknesses. They also need to assess the efficacy of various training methods performed in the field by adopting an appropriate testing method that is reliable, valid, and sensitively measures soccer-specific physical capacity[1-3]. To date, although a number of laboratory and field tests have been developed to assess the physical capacity[4,5] of soccer players, who, during a match, intermittently travel a total of approximately 10–12 km while moving at different speeds and executing various technical actions that require muscular strength and power[6], many of such tests are seldom used in South Korea due to practical limitations, such as a lack of time, or to a lack of awareness of the importance of such evaluation processes.

Lee and Yoon developed the 21-m shuttle-run test (21-m SRT) to evaluate soccer-specific aerobic fitness levels in 2005 and widely provided it to numerous soccer teams from youth to professional players[7]. The 21-m SRT was designed to evaluate the various levels of a soccer player's capability to perform high-intensity, intermittent aerobic exercise with a large anaerobic component. Unlikely to the Yo-Yo intermittent recovery test Level 2, which is mostly used by professional teams, the 21-m SRT, which begins at 11 km/hour, is more suitable for evaluating youth or recreational soccer players who have a relatively lower fitness capacity. In addition, it has an unpredictable (irregularly placed) 8-meter recovery zone where players are required to walk back and forth before increasing their speed for the next stage. From a practical standpoint, a submaximal version of the 21-m SRT (67th shuttle run) is expected to efficiently capture improvements in aerobic capacity by monitoring each player's heart rate response as a performance indicator during the training period.

Despite the numerous practical advantages of the 21-m SRT, to date there has been no research performed on topics such as its reliability or validity. Therefore, the present study aims to (1) examine the reliability and validity of the 21-m SRT for youth soccer players and (2) test the practicality of using the 21-m SRT to evaluate the performance of youth soccer players during preseason training, focusing on fitness improvement.

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METHODS

Participants

Twenty-seven high school male soccer players who were registered in the Korean Football Association participated in this study. A researcher who received prior approval from the head coach visited the training ground, explained the purpose of the reseach to the participants as well as their parents, and obtained their voluntary informed consent to participate in the study. Characteristics of the participants are shown in Table 1.

Table 1. Characteristics of participants.

Variables	Participants (27 males)	95% confidence intervals
Age (yrs.)	15.9 ± 0.7	15.6 to 16.1
Height (cm)	176.1 ± 5.9	173.8 to 178.5
Weight (kg)	67.1 ± 6.3	64.6 to 69.6
Muscle mass (kg)	32.3 ± 3.6	30.9 to 33.7
Body fat (%)	15.5 ± 2.2	14.6 to 16.4

Experimental procedures

All data collection was performed at a laboratory setting or on a training ground with an artificial grass surface. Among the twenty-seven players, those without injuries performed two graded exercise tests (GXT) on a treadmill (20 of 27 players participated) before and after preseason training and the 21-m SRT on four separate occasions at the same time of day during preseason training. To determine the reliability of the 21-m SRT, it was conducted twice, a test and a retest, at a one-week interval (weeks 1 and 2) immediately after the start of preseason training (27 players participated). To evaluate its validity and practicality, it was also conducted three times at four-week intervals (weeks 2, 6, and 10) during the last eight weeks of preseason training (16 of 27 players participated). The maximal oxygen consumption of each participant was measured in the laboratory before and after preseason training to examine the validity of the 21-SRT as a tool for soccer players' fitness development. Each procedure was configured as shown in Figure 1. Participants were instructed not to consume food or caffeine at least 4 hours prior to each test.

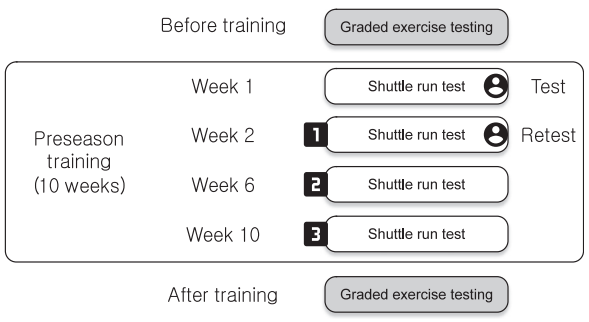

Figure 1. Experimental procedures.

21-m shuttle-run test (SRT)

The reliability, validity, and practicality of the SRT with an irregular recovery period, which was developed by Lee and Yun (2005), for evaluating the aerobic capacity of soccer players in a field setting was examined.

Before the SRT, participants performed 10 minutes of light-intensity warming up with stretching. The SRT was performed on artificial turf. The SRT requires participants to run twenty-one meters back and forth across a marked track keeping time with prerecorded beep signals. If a participant reaches the relevant marker in time, 15 seconds of active recovery time, during which the participant walks within an eight-meter area, is given, then the next level commences: participants must run faster in order to keep time with faster beeps (Figure 2). If a participant fails to reach the relevant marker in time, they are warned. A second warning terminates the test for that participant. The number of shuttle runs completed successfully and the total distance traversed are recorded to represent the performance of that player. The heart rate of participants during the SRT were obtained using the AIRBEAT system[8].

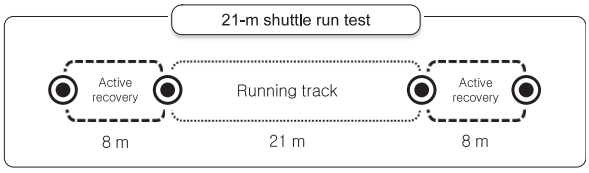

Figure 2. The 21-m shuttle run test.

Measurement of maximal oxygen consumption

Participants were taken to an air-conditioned laboratory which had a relative humidity of 50-60% at a temperature of 20-22℃. The GXT was performed on a treadmill with a modified Bruce protocol, which is highly correlated to directed measured maximal oxygen consumption[9]. Individual maximal oxygen consumption was obtained using open-circuit spirometer techniques (Quark metabolic cart, COSMED, Italy), and heart rate was measured with a Polar heartrate monitor. During the GXT, gas exchange data were collected continuously using an automated breath-by-breath method and were manipulated to calculate $\dot{V}_E$, $\dot{V}O_2$ consumption, and $\dot{V}CO_2$ production; Borg's rating of perceived exertion (RPE) was measured at the end of every minute[10]. All participants were encouraged to exercise to volitional exhaustion during the GXT. $\dot{V}O_{2max}$ was reached when at least two of the following criteria were satisfied: a leveling off of the $\dot{V}O_2$, a RPE > 17 using Borg's scale, voluntary exhaustion, and achievement of 90% the age-predicted maximal heart rate[11,12].

Statistical analyses

To test its reliability, participants performed the 21-m SRT on two separate occasions, exactly 1 week apart, and at the same time of day. Pearson's correlation coefficients and paired sample *t*-tests were used to examine the relationship

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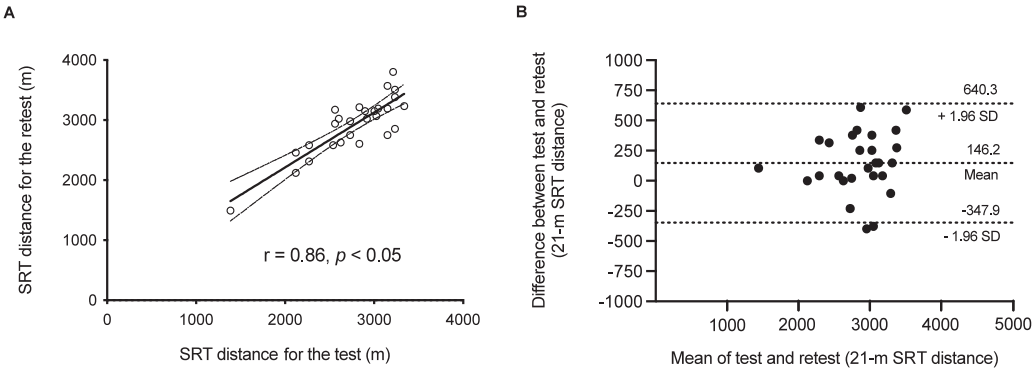

Figure 3. The relationship of shuttle-run test performance between test and retest (A) and the Bland-Altman plot for test and retest (B).

and systemic bias between the test and retest. The criterion-related validity of 21-m SRT performance was investigated using Pearson's correlation coefficients between directly measured $\dot{V}O_{2max}$ and 21-m SRT performance, which is the total distance covered during the test. To evaluate the practicality of the 21-m SRT for soccer players during preseason training, paired sample *t*-tests were performed for the level of $\dot{V}O_{2max}$ before and after 8 weeks of preseason training. Moreover, 21-m SRT performance, which is represented by heartrate immediately after the 67th repetition (SRT_{HR67}) and by the total distance covered ($SRT_{Distance}$), during the preseason training was measured on three separate occasions with two 4-week intervals. Statistical comparisons were performed using a repeated one-way ANOVA design with a within-subject factor of time [baseline (2nd week), 6th week, and 10th week] for 21-m SRT performance during preseason training. When a significant *F* value was obtained, a post-hoc test using the Bonferroni method was applied. Statistical analyses were performed using GraphPad Prism 9.5.1 packages.

RESULTS

Test-retest reliability

The test and retest of the 21-m SRT were performed by 27 participants exactly 1 week apart at the beginning of preseason training. The mean of $SRT_{Distance}$ for the test was 2770 ± 451.2 m (95% confidence interval (CI) 2591 – 2948 m) and that for the retest was 2916 ± 482.2 m (95% CI 2725 – 3107 m). A strong correlation existed between the test and retest for $SRT_{Distance}$ (Figure 3A). The paired *t*-test conducted to test the hypothesis for the equality of mean between the SRT test and retest revealed a statistically significant bias ($p = 0.0057$). The absolute mean difference ± 95% Limit of Agreement was 146.2 ± 494.1 m. The Bland-Altman plot for mean test and retest is depicted in Figure 3B.

Validity of 21-m SRT

Twenty players performed a GXT on a treadmill to examine the criterion-related validity of the 21-m SRT using Pearson's correlation coefficients between directly measured $\dot{V}O_{2max}$ in the laboratory and $SRT_{Distance}$ performed in the second week. The mean $\dot{V}O_{2max}$ of the twenty players was 58.6 ± 4.6 ml · min · kg^{-1} (95% CI, 56.4 – 60.7 ml · min · kg^{-1}). There was a significant correlation between directly measured $\dot{V}O_{2max}$ and $SRT_{Distance}$ ($r = 0.465$, $p = 0.039$). The equation for estimated $\dot{V}O_{2max}$ from the 21-m SRT is depicted in Figure 4.

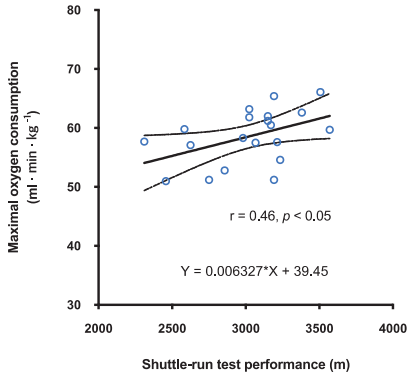

Figure 4. The relationship between 21-m shuttle run test performance (m) and maximal oxygen consumption (ml · min · kg^{-1}). Note: X is shuttle-run test performance (m) and Y is estimated $\dot{V}O_{2max}$.

Practicality of 21-m SRT for soccer players during preseason training

Twenty players performed a GXT on a treadmill before and after 10 weeks of preseason training to examine the effect of preseason training on maximal oxygen consumption. The $\dot{V}O_{2max}$ of the twenty players [61.6 ± 5.3 ml · min · kg^{-1} (95% CI, 59.2 – 64.1 ml · min · kg^{-1})] was significantly higher after the preseason training ($t(19) = 2.36$, 95% CI of difference 0.3403 to 5.780, $p < 0.05$). To determine the manner of the changes in players' aerobic capacity after preseason training, whether 21-m SRT performance ($SRT_{Distance}$ and SRT_{HR67}) differed between training periods, which were separated by 4 weeks, was examined. Among the twenty-seven participants, only sixteen successfully completed all three 21-m SRTs during preseason training without injury. There were statistically significant differences in 21-m SRT performance (F (2, 15) = 13.59, p = 0.0002, Figure 5A for $SRT_{Distance}$; F (2, 15) = 10.83, p = 0.0003, Figure 5B for SRT_{HR67}). A post hoc test using Bonferroni correction demonstrated that

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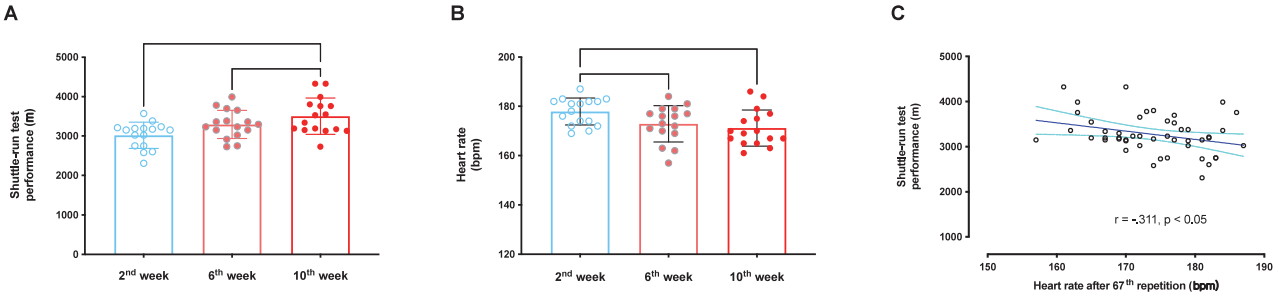

Figure 5. Shuttle-run test performance during the preseason training period for distance (A) and heart rate (B) immediately after 67th repetition; relationship between distance covered (m) and heart rate immediately after 67th repetition during preseason training (C).

$SRT_{Distance}$ at the 10th week (3504 ± 458 m) was significantly higher than that of the 2nd week (mean difference = 485.6 m, 95% CI of difference 222.6 m to 748.7 m, $p = 0.0005$) and than that of the 6th week (mean difference = 485.6 m, 95% CI of difference 222.6 m to 748.7 m, $p = 0.0005$). Moreover, SRT_{HR67th} had significantly decreased at the 6th week (mean difference -5.0 bpm, 95% CI -9.1 bpm to -0.93 bpm, $p = 0.0143$) and at the 10th week (mean difference -6.7 bpm, 95% CI -10.8 bpm to -2.6 bpm, $p = 0.0014$) compared to that of the 2nd week (177.9 ± 5.48 bpm). Moreover, there was a significant negative correlation between SRT_{HR67} and $SRT_{Distance}$ during the preseason training period ($r = -0.311$, $p < 0.05$, Figure 5C).

DISCUSSION

The aim of the present study was to examine the reliability and the validity of the 21-m SRT, which is widely used by various soccer teams from youth to professional in South Korea, and to evaluate the practicality of 21-m SRT performance measured during the preseason training period in a youth male soccer team. The present findings reveal that the 21-m SRT test yields highly consistent results for test-retest bias and that the maximal distance covered during a 21-m SRT is highly correlated to soccer players' maximal oxygen consumption, which is a representative indicator of aerobic capacity. As for its practicality, 21-m SRT performance ($SRT_{Distance}$ and SRT_{HR67}) had a high sensitivity, which would allow coaches to efficiently identify longitudinal changes in physical capacity during the preseason training camp.

The 21-m SRT performance exhibited during preseason training could provide valuable feedback to the coach both on the efficacy of the training program and the responsiveness of each individual athlete to the training program[13]. Therefore, it is important to ensure that any changes in performance reflected in a field test following training are "real". Which is to say that such changes in performance are a reflection of altered physical capacity rather than the results of variation between or within players[14]. In addition, performance on the test should reflect the physical performance required in a real match in the sport[15]. Such issues are addressed by determining the reliability and the validity of the 21-m SRT[16,17].

As for the reliability, the findings indicating a correlation between the 21-m SRT test and retest (r = 0.86) suggest a significant linear relationship, and these results are similar to previous reports examining the 20-m multi-stage shuttle-run test[18,19]. In addition, the test and retest reliability showed that the result of 95% Limit of Agreement was 146 ± 494.1 m covered in the 21-m SRT (± 23.6 shuttle). By adopting the Bland-Altman plot for the test and retest results, it is possible to provide the absolute differences in performance. The result of 95% Limit of Agreement was slightly higher than those in previous studies examining the 20-m multi-stage shuttle-run test, but it is difficult to argue whether there is test and retest reliability based on a comparison of these results because characteristics of participants were different among studies[18,19].

The validity of a field test has been commonly determined by using correlation analysis to assess the relationship between performance on a field test and physical performance during the actual event. In the present study, the validity of the 21-m SRT was examined using a correlation coefficient between 21-m $SRT_{Distance}$ and maximal oxygen consumption levels, which are the most commonly used variables to reflect individual aerobic capacity[20]. Interestingly, a moderate correlation (r = 0.465) between 21-m $SRT_{Distance}$ and maximal oxygen consumption was found in the present study. Although the majority of energy provision is derived from the aerobic capacity during a soccer match, numerous actions, such as frequent high-intensity intermittent running or changing directions during a soccer match, require a player to increase their energy demands from anaerobic metabolism[4]. Therefore, 21-m SRT performance might be more suitable for evaluating soccer-specific fitness.

The current results reveal that 10 weeks of preseason training for the youth soccer players significantly improved their aerobic capacity (mean difference 3.1 ± 5.8 ml · min · kg^{-1}). As aerobic capacity increased, 21-m SRT performance ($SRT_{Distance}$ and SRT_{HR67}) changed at the same time. There was a significant improvement in 21-m $SRT_{Distance}$ (mean difference 485.6 m) over the course of the entire training period that was considerably larger than the reproducibility of the test-retest. From the viewpoint of practicality, SRT performance data from the monthly evaluations was sensitive to changes over the course of each month and could, therefore, provide valuable feedback to coaches. Moreover,

SRTs can be implemented for a low cost (no treadmill, no metabolic cart) and rapidly. Interestingly, there was significant decrease in SRT_{HR67} and it was significantly correlated to $SRT_{Distance}$ during the entire training period. Based on these results, it could be recommended that coaches apply the submaximal version of the SRT test (67 shuttle repetitions and the monitoring of heart rate), as it would be useful for efficiently measuring subtle changes in soccer-specific fitness.

The present study examined the test-retest reliability of the 21-m SRT using correlation coefficients and Limit of Agreement and assessed the criterion-related validity with the correlation coefficients between maximal oxygen consumption and SRT performance. In addition, a 21-m SRT for youth soccer players was applied during preseason training to examine whether it could measure changes of SRT performance in the same way that players' aerobic performance improves during the preseason training period. However, this study has several limitations. The current study reported relatively low correlation coefficients between $\dot{V}O_{2max}$ and $SRT_{Distance}$. This is probably because in addition to the aerobic fitness levels measured by $\dot{V}O_{2max}$, muscle strength and power may also improve throughout the preseason training. Therefore, future studies should examine whether SRT performance indicators such as $SRT_{Distance}$ and SRT_{HR67} are related to match-performance indices, such as number of sprints or amount of high-intensity running, that are supported by the anaerobic energy system. In addition, changes in physiological responses such as glucose, lactate, and creatine kinase levels during preseason training could be explored in future studies.

These results reveal that the 21-m SRT, which is widely used in the field, is a reliable and valid training tool. It can be applied in a practical way to examine the level of aerobic capacity of youth soccer players and the efficacy of the training program in an efficient manner using performance indicators such as $SRT_{Distance}$ and SRT_{HR67}. Further studies need to examine whether the 21-m SRT performance results predict a soccer player's key performance indicators or actual match performance by adopting an electronic performance and tracking system.

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