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**Research article**

# Effect of Different Seat Heights during an Incremental Sit-To-Stand Exercise Test on Peak Oxygen Uptake in Young, Healthy Women

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**Abstract**

'Sit-to-stand' exercise uses the repetitive motion of standing up and sitting down in a chair, a common activity of daily living. A new assessment using an incremental sit-to-stand exercise test employs an external sound to control the speed of standing-up and allows increases in work rate. The aims of the study were to examine the effect of different seat heights on peak oxygen uptake (peak $VO_2$) during an incremental sit-to-stand exercise and to assess any difference between peak $VO_2$ values during incremental sit-to-stand exercise compared with a cycle ergometer test. Thirteen healthy young women (age: 23.1 ± 2.6 years, height: 1.61 ± 0.06 m, body mass: 51.9 ± 7.4 kg·m$^{-2}$) participated in four incremental sit-to-stand tests with different seat heights and cycle tests in random order. The seat heights were adjusted to 100%, 80%, 120%, and 140% of knee height distance (100%, 80%, 120%, and 140% incremental sit-to-stand exercise, respectively). The peak $VO_2$ and completion time were measured during incremental sit-to-stand and cycle ergometer tests, and repeated-measures analysis of variance and Student's paired t-test with Holm's method were used to evaluate differences between these variables. The peak $VO_2$ values increased by about 10-12 mL·min$^{-1}$·kg$^{-1}$ as the seat height on the ISTS decreased over a 60% range of lower leg lengths. The peak $VO_2$ values on the 80%, 100%, 120%, and 140% incremental sit-to-stand tests were about 11%, 25%, 40%, and 50% lower than that on the cycle ergometer test, respectively. The peak $VO_2$ on the incremental sit-to-stand test increased as seat height decreased. These findings are useful to determine which seat height on the incremental sit-to-stand tests test is suitable for different populations.

**Key words:** Sit-to-stand test, oxygen cost, seat height.

## Introduction

Aerobic fitness measurements, such as peak $VO_2$ and anaerobic threshold (AT), may be important to understand the effects of the exercise interventions (Myers et al., 2002; Wasserman et al., 2012). Aerobic fitness can be assessed by cardiopulmonary exercise testing (CPX) using either gas exchange analysis or determination of blood lactate concentration. Common types of ergometry assessments include cycle (CE) or treadmill testing which are regarded as the "gold standard" in clinical practice (Wasserman et al., 2012). However, "gold standard" measures are not widely available for use in the clinical setting because they require specially trained staff together with expensive and specialized equipment (Goto et al., 2007). Furthermore, traditional modes of testing may not be suitable for elderly and/or frail patients who cannot cycle or walk safely (Siconolfi et al., 1982; Wasserman et al., 2012).

Conversely, field tests, which are simpler, inexpensive, and do not require complicated instrumentation are commonly used in clinical settings e.g. the incremental shuttle walking test (ISWT) (Singh et al., 1994). Furthermore, most studies observed strong correlations between distance walked and peak $VO_2$ ($r \geq 0.70$) during the ISWT, thus the ISWT can be considered a valid test to assess aerobic fitness in individuals with chronic respiratory and cardiac diseases (Parreira et al., 2014). However, Macsween et al. (2001) found no relationship between $VO_2$ max and number of shuttles completed during the ISWT in patients with cardiac disease or rheumatoid arthritis, due to limitations in musculoskeletal and locomotor ability in 50% of patients, which supports the earlier findings of Arnott (1997). Therefore, field tests such as the ISWT may not be suitable for patients with locomotor disability who cannot walk safely.

Sit-to-stand (STS) exercise uses the repetitive motion of standing up and sitting down on a chair, a common activity of daily living (Dall and Kerr, 2010). STS exercise can be performed by a large number of patients. In addition, it only requires a small space and a chair, and the exercise intensity can be easily adjusted by changing the patients' STS speed or seat height (Kamimura and Akiyama, 2011; Nakamura et al., 2014). An STS test has been used to measure lower body strength in older adults and stroke patients in previous studies (Bohannon, 2011; Jones et al., 1999). However, few studies have used an STS test to assess aerobic fitness. If a simple test using STS exercise to evaluate aerobic fitness were established, similar to the ISWT, then the aerobic fitness of a greater number of subjects could be evaluated in clinical practice.

In a previous study, we developed the incremental (I) STS exercise protocol for assessing aerobic fitness (Table 1) (Nakamura et al., 2014; 2015). The ISTS test uses an external sound to control the speed of standing-up and allows an increase in work rate. Another study showed a strong correlation between ATs during the ISTS test with arm support and CE test, and the ISTS with arm support is a potentially valid, reproducible, and safe test for evaluating the AT in healthy young adults (Nakamura

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et al., 2015). In these previous studies, the seat height setting on the ISTS was adjusted on the basis of the standing knee height (Nakamura et al., 2014; 2015). Chair seat height is one of the important factors of an STS task, because it affects joint moments during an STS task (Yoshioka et al., 2014). Yoshioka et al. (2014) reported that during STS movement, the peak hip and knee joint moments decrease inversely, relative to the seat height within the range of normal to high seat height. Furthermore, lowering the height of the seat makes the STS movement difficult for the elderly (Schurr et al., 2012; Weiner et al., 1993). For example, the minimum height for successful seat rising for community-dwelling elderly people (64–105 years of age) with chair rise difficulties appears to be less than 120% of the knee height, when standing up from the chair without arm support (Weiner et al., 1993). In other words, many elderly people may be able to stand up from a chair seat at 120% or more of the knee height without arm support.

**Table 1. Protocol for the incremental sit-to-stand exercise.**

| Level | Time (seconds) | Standing up frequency (times/min) | Sum standing up (repetitions) * |
|---|---|---|---|
| 1 | 45 | 6 | 4 |
| 2 | 90 | 8 | 10 |
| 3 | 135 | 10 | 17 |
| 4 | 180 | 12 | 26 |
| 5 | 225 | 14 | 36 |
| 6 | 270 | 16 | 48 |
| 7 | 315 | 18 | 61 |
| 8 | 360 | 20 | 76 |
| 9 | 405 | 22 | 92 |
| 10 | 450 | 24 | 110 |
| 11 | 495 | 26 | 129 |
| 12 | 540 | 28 | 150 |
| 13 | 585 | 30 | 172 |
| 14 | 630 | 32 | 196 |
| 15 | 675 | 34 | 221 |
| 16 | 720 | 36 | 248 |

* Sum standing up was number of cumulative stand-up repetitions completed during the ISTS

A greater understanding of the impact of the seat height during STS exercise on aerobic fitness is critical to developing valid methods for the evaluation of aerobic fitness. However, the effect of seat height on oxygen uptake during the ISTS exercise remains unclear. Furthermore, leg strength is an important component of being able to do STS tasks. However, the relationships between leg strength and ISTS performance remain unclear.

Therefore, the aims of the present study were to 1) investigate the effect of seat height during the ISTS test on $VO_2$; 2) examine any difference between peak $VO_2$ during the ISTS and CE tests; and 3) examine the relationship between leg strength and ISTS performance. We hypothesized that the highest $VO_2$ during the ISTS test would increase as the seat height decreased.

## Methods

The present study had a within-subject design to examine any difference between the values of peak $VO_2$, peak heart rate (HR), and completion time during the ISTS tests using four different seat heights compared with a CE test.

### Participants

Thirteen healthy young women were recruited for the present study. The selection criteria were as follows: 1) aged 20–29 years, 2) subjects were healthy, but not endurance trained, 3) no history of bone, joint, or cardiorespiratory disease that would impede exercise, and 4) willing to provide voluntarily consent to participate. Table 2 shows the subjects' physical characteristics.

**Table 2. Physical characteristics of all subjects included in the study. Values are means (± standard deviation).**

| | All (n = 13) |
|---|---|
| Age (years) | 23.1 (2.6) |
| Height (m) | 1.61 (.06) |
| Weight (kg) | 51.9 (7.4) |
| Body mass index ($kg\cdot m^{-2}$) | 20.2 (2.7) |
| Knee extensor muscle strength ($Nm\cdot kg^{-1}$) | 3.0 (.4) |

This cross-sectional study was conducted at Shinshu University, and was approved by the Shinshu University School of Medicine's Ethics Committee and Matsumoto City Hospital's Ethics Committee. Volunteers were treated in accordance with the principles laid down in the Declaration of Helsinki. All volunteers were familiarized with the experimental procedures prior to testing, and written informed consent was obtained.

### Measures

The main outcome measures of the present study were the peak $VO_2$, peak HR during the ISTS and CE tests, and completion time during the ISTS tests. The peak $VO_2$ and HR were defined as the average value obtained during the last 30 s of testing (Ito et al., 2013). All $VO_2$ measures were relative to body mass ($mL\cdot min^{-1}\cdot kg^{-1}$) (Ito et al., 2013). If a subject completed the test but met the general discontinuation criteria for exercise tests (procedures, below), the data were not included in the subsequent statistical analysis.

### Procedures

All subjects performed four ISTS tests with different seat heights (according to a protocol developed from a previous study) and a CE test in a random sequence with a minimum of 3 and a maximum of 14 days separating the tests (Nakamura et al., 2015). The subjects were asked to fast for 2 h prior to each exercise test.

During the ISTS test, subjects were instructed to use both hands on the pole to push off; however, we did not limit how much force they used. The pole was adjusted to a specific height such that the elbows of the subjects were at 30 degrees in the standing position (Nakamura et al., 2015). Accordingly, subjects had to touch each "target" in the upright and seated position in order to define the STS motion (Figure 1). Participants' feet were placed in a comfortable position and were set shoulder width apart. The seat height settings were adjusted on the basis of the standing knee height (KH), defined as the distance

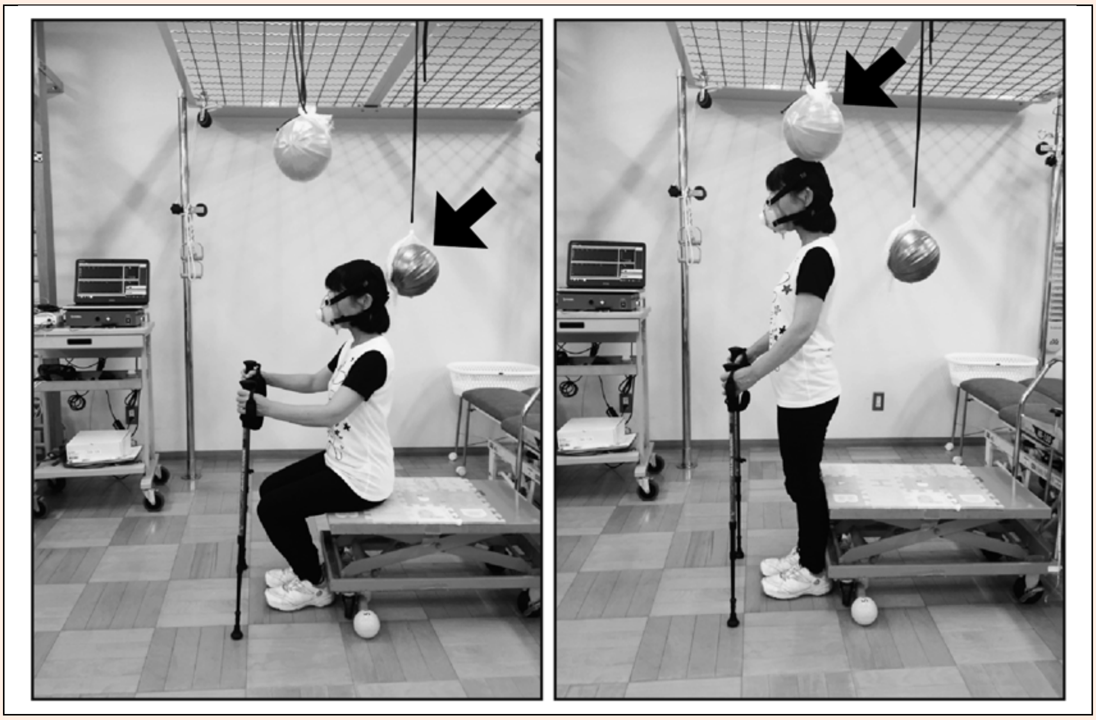

**Figure 1. The position of the subject during the incremental sit-to-stand exercise. The subjects had to touch each target (arrows) in the upright and sitting positions.**

from the floor to the level of the upper end of the fibular head when the tibia was perpendicular to the floor. The four seat heights were set at 80%, 100%, 120%, and 140% of the KH distance (100%, 80%, 120%, and 140% ISTS, respectively) (Kamimura and Akiyama, 2011; Nakamura et al., 2014). The ISTS protocol consisted of 3 min of rest, followed by 3 min of warm-up, and then 12 min of exercise. The frequency during the ISTS was 6 times/min during the warm-up period and was 6–36 times/min during the 12-min exercise period (Table 1) (Nakamura et al., 2014; 2015). The frequency of standing up was controlled by audio signals via a metronome.

During the CE test, a ramp exercise protocol was used (Aerobike 75XLII; Combi, Tokyo, Japan). Following 3 min of seated rest, the subject commenced a 3 min warm-up at 10 watts. After the warm-up period, the power output increased by 15 watts/min (Ito et al., 2013; Wasserman et al., 2012) subjects maintained a cadence of 60 rpm throughout the test.

The criteria for the termination of the test were as follows: 1) when the general discontinuation criteria for exercise tests were met (American College of Sports Medicine, 2013); 2) when a subject missed the pacing given by the metronome for the third time in a row (Kamimura and Akiyama, 2011; Nakamura et al., 2014; 2015); and 3) when a subject became unable to maintain a cadence of 60 pedal revolutions/min.

Measurements included expired gases, HR, Borg's 6–20 scale of rating of perceived exertion (RPE) which reflects ventilatory effort (RPE-V) and leg fatigue (RPE-L) (Borg et al., 1970; Green et al., 2003), and knee extensor muscle strength (Andrews et al., 1996; Izawa et al., 2014). Before testing during the participants' first visit, maximum voluntary isometric contraction of the knee extensor muscle was measured by using a hand-held dynamometer (μ Tas F-100; Anima, Tokyo, Japan). All participants sat on a bench with the dynamometer fixed to a rigid bar. Testing was performed on both legs for a maximum of three times the maximal isometric voluntary contraction of the knee extensor muscle. After measurement, the average of the highest value of the right plus left side knee extensor muscle strength was calculated (Andrews et al., 1996; Izawa et al., 2014). The knee extensor muscle strength ($Nm \cdot kg^{-1}$) was calculated using body mass and lower leg length according to the following formula: strength (N) × lower leg length (m) / body mass (kg). During testing, expired gases, such as oxygen uptake ($VO_2$), carbon dioxide output ($VCO_2$), and HR were continuously monitored. Heart rate was measured using a belt HR monitor (H2 Heart Rate Sensor; Polar, Kempele, Finland). Expired gases were measured using a breath-by-breath analyzer (AT1100; Anima). The gas analyzer was calibrated prior to and following each test using precision reference gases. The breath-by-breath expired gas data were converted into time series data. The data sets were calculated using the gas analysis software for the AT1100, in which the variable moving average was assessed. A nine-point moving average of the data was applied to the calculation for the respiratory gas parameters. The RPE scales immediately after completion of the exercise were measured to ensure the safety of the exercise. The temperature in the exercise room was maintained between 21ºC and 24ºC.

## Statistical analysis

Statistical analysis was performed using SPSS software for Windows (SPSS package, version 18.0J, SPSS Inc., Chicago, IL, USA). The values are presented as means ± standard deviations (SDs) and medians (interquartile ranges). The Shapiro-Wilk test was used to determine normality of values. Repeated-measures analyses of variance were applied for peak $VO_2$ and peak HR across the exercise conditions. If an F value was significant, pairwise comparisons were made for all pairs in the exercise conditions by using Student's paired t-test. To control the family-wise error rate in each multiple comparison, Holm's method was used to adjust the p-value of each t-test (Holm, 1979; Yoshioka et al., 2014). A statistical significance level was set at $p < 0.05$. The Friedman test and the post hoc Steel-Dwass test were used to compare the RPE scores obtained during the ISTS and CE tests.

## Results

The seat heights (mean ± SD) of 80%, 100%, 120%, and 140% ISTS were 32.2 ± 1.0, 41.5 ± 1.2, 49.8 ± 1.4, and 58.2 ± 1.7 cm, respectively. Significant differences were found in the comparisons between 80%, 100%, 120%, and 140% ISTS ($p < 0.01$). No subjects met the general discontinuation criteria for exercise tests, and knee pain was not provoked in any exercise. All the subjects completed the 100%, 120%, and 140% ISTS tests at 12 minutes. Four of 13 subjects completed the 80% ISTS test at 12 minutes, and the rest of the subjects finished the 80% ISTS when they were not able to keep up the pacing given by the metronome for the third time in a row.

The peak $VO_2$ values of 80%, 100%, 120%, and 140% ISTS were 26.7 ± 1.6, 23.1 ± 1.8, 18.4 ± 1.7, and 15.4 ± 1.7 $mL \cdot min^{-1} \cdot kg^{-1}$, respectively (Table 3). The peak $VO_2$ value of the 80% ISTS was significantly higher than that of the other ISTS tests ($p < 0.01$). The peak $VO_2$ value of the 100% ISTS was significantly higher than that of the 120% and 140% ISTS ($p < 0.01$). The peak $VO_2$ value of the 120% ISTS was significantly higher than that of the 140% ISTS ($p < 0.01$). The peak $VO_2$ value of the 80% ISTS was 11% lower than that of the CE test ($p < 0.01$) (Table 3). The peak HR values on the 80% ISTS and CE test were significantly higher than those on the other ISTS tests ($p < 0.01$). The mean ± SD for the completed time (s) in the 80%, 100%, 120%, and 140% ISTS were 643.4 ± 56.0, 720 ± 0, 720 ± 0, and 720 ± 0, respectively.

The correlation between the completed time on the 80% ISTS and knee extensor strength was $r = 0.33$ ($p = 0.27$).

The median (interquartile range) RPE-V of the 80%, 100%, 120%, and 140% ISTS and CE test were 15 (15), 13 (13–15), 12 (12–14), 12 (11.5–12), and 15 (14.5–15), respectively. The median (interquartile range) RPE-L of the 80%, 100%, 120%, and 140% ISTS and CE test were 16 (14–18), 13 (11–15), 12 (11–13), 11 (10.5–12), and 15 (14.5–17), respectively. The factor of test conditions significantly affected the RPE-V and RPE-L. The RPE-V and RPE-L on the 80% ISTS were significantly higher than those on the 100%, 120%, and 140% ISTS ($p < 0.05$). The RPE-V and RPE-L on the CE test were significantly higher than those on the 120% and 140% ISTS ($p < 0.05$). There was no significant difference in the RPE-V and RPE-L between the 80% ISTS and the CE test.

## Discussion

This is the first study to investigate the effect of the seat height setting on an ISTS test on peak $VO_2$ values in healthy young women. Ito et al. (2013) reported standard values of peak $VO_2$ in a normal Japanese population, and showed that the peak $VO_2$ during a CE test was 30.0 ± 4.2 $mL \cdot min^{-1} \cdot kg^{-1}$ in women. The peak $VO_2$ during the CE test in the present study was similar to that previously reported by Ito et al. (2013). Furthermore, the knee extensor muscle strength in participants was also similar to that reported by Lindle et al. (1997). Therefore, participants in the present study have a normal level of physical abilities.

The results of this study indicate that the peak $VO_2$ during the ISTS test increases as seat height decreases. Our data showed that peak $VO_2$ values increased by 10-12 $mL \cdot min^{-1} \cdot kg^{-1}$ as the seat height on the ISTS decreased over a 60% range of lower leg length. Many previous studies investigated the effect of seat height when standing up from a chair on lower-limb joint load and muscular activity, while little is available on the effect of the seat height on $O_2$ uptake during STS exercise. A lower seat brings down the centre of gravity and increases the degree of trunk flexion and angular displacement of the trunk, hip, knee, and ankle when standing up from sitting (Janssen et al., 2002). Standing up from a lower seat height would be more demanding due to the increase in the floor reaction force and the maximum moment generated by the hip and knee joint (Arborelius et al., 1992; Janssen et al., 2002; Rodosky et al., 1989). Demura and Yamada (2007) also reported that when the seat height was 20% lower than the lower leg length, the peak floor reaction force increased. Furthermore, Yoshioka et al. (2014) proposed that the peak mechanical load and the peak hip and knee joint moments increase as seat height decreases. With regard to the muscular activity when standing up from different seat heights, previous studies reported that the vastus lateralis, rectus femoris, and tibialis anterior muscles showed a tendency towards higher activity levels with decreasing seat height (Arborelius et al., 1992; Yamada and Demura, 2004). Based on such

**Table 3. Comparison of peak oxygen uptake ($mL \cdot min^{-1} \cdot kg^{-1}$) and peak heart rate (bpm) between the incremental sit-to-stand exercises and cycle-ergometer test. Values are presented as mean s (± standard deviation) (n = 13).**

| | 80% ISTS | 100% ISTS | 120% ISTS | 140% ISTS | CE | F-value | Post-hoc |
|---|---|---|---|---|---|---|---|
| **Peak $VO_2$** | 26.7 (1.6) | 23.1 (1.8) | 18.4 (1.7) | 15.4 (1.7) | 31.0 (3.7) | 149.6* | CE > 80% > 100% > 120% > 140% |
| **Peak HR** | 173 (7) | 155 (13) | 132 (13) | 119 (8) | 176 (6) | 150.7* | 80%, CE > 100% > 120% > 140% |
| **Compl. time** | 643 (56) | 720 (0) | 720 (0) | 720 (0) | 472 (70) | 126.7* | 100%, 120%, 140% > 80% >CE |

CE, cycle ergometer; HR, heart rate; ISTS, incremental sit-to-stand; peak VO2, peak oxygen uptake; Compl. Time: Completion time (sec). F-values were determined by the one-way analysis of variance with repeated measures. * $p < 0.05$.

previous studies, the 80% ISTS using a lower seat height may require a larger muscle mass to be activated (the legs and trunk) to create a larger extending moment on the knee and hip joint than ISTSs which use a higher seat. The amount of the muscle mass used in the exercise may be the reason for the differences observed between the different exercise modes (Hill and Vingren, 2014; Nagle et al., 1984; Orr et al., 2013). The 80% ISTS, in which a larger muscle mass is used compared with the 100% to 140% ISTS, is potentially more stressful to the cardiopulmonary system than the latter. However, the peak $VO_2$ on the 80% ISTS was about 10% lower than that measured during the CE test. However, there is no definite explanation for the observed differences in the peak $VO_2$ value between the 80% ISTS and the CE test. In the present study, the frequency of STS movements was up to 36 times/min during the ISTS test, while subjects maintained a cadence of 60 rpm throughout the CE test. Thus, ISTS has lower muscular activity, and that may result in a lower peak $VO_2$ compared with the CE test.

Given that there are differences in peak $VO_2$ between a young and elderly population, a suitable seat height for the elderly may differ from that for the young. Ito et al. (2013) reported on the standard values of peak $VO_2$ in a normal Japanese population and showed that peak $VO_2$ values during the CE test were 23.25 $mL \cdot min^{-1} \cdot kg^{-1}$ in men and 21.66 $mL \cdot min^{-1} \cdot kg^{-1}$ in women in their 70s, and 20.53 mL/min/kg in men and 19.7 $mL \cdot min^{-1} \cdot kg^{-1}$ in women in their 80s. Based on the present study, 100% to 120% ISTS may be suitable to estimate aerobic fitness in the elderly. On the other hand, many elderly people experience difficulty when standing up from a low chair (Schurr et al., 2012; Weiner et al., 1993). For example, Schurr et al. (2012) reported that the lowest possible height from which 23 elderly participants (58–92 years of age) can rise from siting-to-standing without the use of the upper limb was 42.3 ± 12.5 cm. Weiner et al. (1993) also reported that about 73–86% of elderly participants were able to stand up from a chair set at 120% of the knee height without arm support. Based on these previous studies, 120% ISTS may be used to evaluate aerobic fitness in the elderly. Furthermore, because knee pain may be provoked when the elderly perform the ISTS, the height of the chair and frequency of the STS speed would need to be adjusted.

We have shown that the relationship between the completed time on the 80% ISTS and lower muscular strength is weak (r = 0.33). This result differs from previous studies that used an STS test to measure leg strength (Bohannon, 2011; Jones et al., 1999). A possible reason for this difference is that the ISTS protocol consisted of 12 min of exercise, which was longer than that in Jones's test (Jones et al., 1999), and the performance in the ISTS may have been affected by cardiopulmonary function rather than lower leg strength.

Because no subjects met the discontinuation criteria, the present protocol was considered to have a safe physical workload for healthy young individuals. In the present study, the RPE after exercise in the 80% ISTS was similar to that in the CE test, while that in the 100%, 120%, and 140% ISTS was lower than that in the CE test. This finding suggests that the ISTS test is useful in the clinical setting, generating similar responses to a CE test.

The present study has some limitations. First, only healthy young women were recruited; therefore, further studies including men and an older population are needed to develop the ISTS test as an aerobic fitness measure suitable for elderly and frail patients. Second, a further study investigating the reproducibility of the ISTS test is needed to develop the ISTS as an aerobic fitness measurement. In addition, in order to be functionally useful for elderly and frail patients, arm position and arm use during the test need to be further studied.

## Conclusion

In conclusion, this is the first study to evaluate any difference between peak $VO_2$ values using the ISTS exercise tests with different seat heights versus a CE test. The peak $VO_2$ on the ISTS test increased as seat height decreased. Comparing the effect of different seat heights during the ISTS test on the peak $VO_2$ is beneficial to determine which seat height on the ISTS test is suitable for different populations. Future studies using the ISTS test on other populations that would benefit from the ISTS test for exercise testing are warranted.

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## References

American College of Sports Medicine. (2013) Interpretation of results. In: *ACSM's guidelines for exercise testing and prescription*. Eds: Pescatello, L.S., Arena, R., Riebe, D. and Thompson, P.D. Philadelphia: Lippincott Williams & Wilkins. 87.

Andrews, A.W., Thomas, M.W. and Bohannon, R.W. (1996) Normative values for isometric muscle force measurements obtained with hand-held dynamometers. *Physical Therapy* **76**, 248-259.

Arborelius, U.P., Wretenberg, P. and Lindberg, F. (1992) The effects of armrests and high seat heights on lower-limb joint load and muscular activity during sitting and rising. *Ergonomics* **35**, 1377-1391.

Arnott, A.S. (1997) Assessment of functional capacity in cardiac rehabilitation: reproducibility of a 10-m shuttle walk test. *Coronary Health Care* **1**, 30-36.

Bohannon, R.W. (2011) Test-retest reliability of the five-repetition sit-to-stand test: a systematic review of the literature involving adults. *Journal of Strength and Conditioning Research* **25**, 3205-3207.

Borg, G. (1970) Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitative Medicine* **2**, 92-98.

Dall, P.M. and Kerr, A. (2010) Frequency of the sit to stand task: an observational study of free-living adults. *Applied Ergonomics* **41**, 58-61.

Demura, S. and Yamada, T. (2007) Height of chair seat and movement characteristics in sit-to-stand by young and elderly adults. *Perceptual and Motor Skills* **104**, 21-31.

Goto, Y., Saito, M., Iwasaka, T., Daida, H., Kohzuki, M., Ueshima, K., Makita, S., Adachi, H., Yokoi, H., Omiya, K., Mikouchi, H. and Yokoyama, H.; Japanese Cardiac Rehabilitation Survey Investigators. (2007) Poor implementation of cardiac rehabilitation despite broad dissemination of coronary interventions for acute myocardial infarction in Japan: a nationwide survey. *Circulation Journal* **71**, 173-179.

Green, J.M., Crews, T.R., Bosak, A.M. and Peveler, W.W. (2003) Overall and differentiated ratings of perceived exertion at the respiratory compensation threshold: effects of gender and mode. *European Journal of Applied Physiology* **89**, 445-450.

Hill, D.W. and Vingren, J.L. (2014) Effects of exercise mode and participant sex on measures of anaerobic capacity. *Journal of Sports Medicine and Physical Fitness* **54**, 255-263.

Holm, S. (1979) A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics* **6**, 65-70.

Hulley, S.B., Cummings, S.R., Browner, W.S., Grady, D.G. and Newman, T.B. (2013) *Designing clinical research*. 4th edition. Philadelphia: Lippincott Williams & Wilkins.

Ito, H., Ajisaka, R., Koike, A., Makita, S., Omiya, K., Kato, Y., Adachi, H., Nagayama, M., Maeda, T., Tajima, A., Harada, N. and Taniguchi, K.; Committee on Exercise Prescription for Patients (CEPP) Members. (2013) Heart rate and blood pressure response to ramp exercise and exercise capacity in relation to age, gender, and mode of exercise in a healthy population. *Journal of Cardiology* **61,** 71-78.

Izawa, K.P., Watanabe, S. and Oka, K. (2014) Muscle strength of male inpatients with heart failure with reduced versus preserved ejection fraction. *International Journal of Cardiology* **172**, e228-229.

Janssen, W.G., Bussmann, H.B. and Stam, H.J. (2002) Determinants of the sit-to-stand movement: a review. *Physical Therapy* **82**, 866-879.

Jones, C.J., Rikli, R.E. and Beam, W.C. (1999) A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Research Quarterly for Exercise and Sport* **70**, 113-119.

Kamimura, S. and Akiyama, S. (2011) The relationship between sit-to-stand frequency and anaerobic threshold determined by cycle ergometer. *Journal of Physical Therapy Science* **23**, 53-55.

Lindle, R.S., Metter, E.J., Lynch, N.A., Fleg, J.L., Fozard, J.L., Tobin, J., Roy, T.A. and Hurley, B.F. (1997) Age and gender comparisons of muscle strength in 654 women and men aged 20-93 yr. *Journal of Applied Physiology* **83**, 1581-1587.

Macsween, A., Johnson, N.J., Armstrong, G. and Bonn, J. (2001) A validation of the 10-meter incremental shuttle walk test as a measure of aerobic power in cardiac and rheumatoid arthritis patients. *Archives of Physical Medicine and Rehabilitation*, **82**, 807-810.

Myers, J., Parkash, M., Froelicher, V., Do, D., Partington, S. and Atwood, J.E. (2002) Exercise capacity and mortality among men referred for exercise testing. *New England Journal of Medicine* **346**, 793-801.

Nagle, F.J., Richie, J.P. and Giese, M.D. (1984) $VO_{2max}$ responses in separate and combined arm and leg air-braked ergometer exercise. *Medicine and Science in Sports and Exercise* **16**, 563-566.

Nakamura, K., Ohira, M. and Yokokawa, Y. (2014) The effect of different standing up frequencies in sit-to-stand exercise on oxygen uptake. *Journal of Physical Therapy Science* **26**, 1631-1633.

Nakamura, K., Ohira, M., Yokokawa, Y. and Nagasawa, Y. (2015) Validity and reproducibility of an incremental sit-to-stand exercise test for evaluating anaerobic threshold in young, healthy individuals. *Journal of Sports Science and Medicine* **14**, 708-715.

Orr, J.L., Williamson, P., Anderson, W., Ross, R., McCafferty, S. and Fettes, P. (2013) Cardiopulmonary exercise testing: arm crank vs cycle ergometry. *Anaesthesia* **68**, 497-501.

Parreira, V.F., Janaudis-Ferreira, T., Evans, R.A., Mathur, S., Goldstein, R.S. and Brooks, D. (2014) Measurement properties of the incremental shuttle walk test: a systematic review. *Chest* **145**, 1357-1369.

Rodosky, M.W., Andriacchi, T.P. and Andersson, G.B. (1989) The influence of chair height on lower limb mechanics during rising. *Journal of Orthopaedic Research* **7**, 266-271.

Schurr, K., Sherrington, C., Wallbank, G., Pamphlett, P. and Olivetti, L. (2012) The minimum sit-to-stand height test: reliability, responsiveness and relationship to leg muscle strength. *Clinical Rehabilitation* **26**, 656-663.

Siconolfi, S.F., Cullinane, E.M., Carleton, R.A. and Thompson, P.D. (1982) Assessing $VO_2$ max in epidemiologic studies: modification of the Astrand-Rhyming test. *Medicine and Science in Sports and Exercise* **14**, 335-338.

Singh, S.J., Morgan, M.D., Hardman, A.E., Rowe, C. and Bardsley, P.A. (1994) Comparison of oxygen uptake during a conventional treadmill test and the shuttle walking test in chronic airway limitation. *European Respiratory Journal* **7**, 2016-2020.

Wasserman, K., Hansen, J.E., Sue, D.Y., Stringer, W.W., Sietsema, K.E., Sun, X. and Whipp, B.J. (2012) *Principles of exercise testing and interception*. 4th edition. Philadelphia: Lippincott Williams & Wilkins.

Weiner, D.K., Long, R., Hughes, M.A., Chandler, J. and Studenski, S. (1993) When older adults face the chair-rise challenge. A study of chair height availability and height-modified chair-rise performance in the elderly. *Journal of the American Geriatrics Society* **41**, 6-10.

Yamada, T. and Demura, S. (2004) Influence of the relative difference in chair seat height according to different lower thigh length on floor reaction force and lower-limb strength during sit-to-stand movement. *Journal of Physiological Anthropology and Applied Human Science* **23**, 197-203.

Yoshioka, S., Nagano, A., Hay, D.C. and Fukashiro, S. (2014) Peak hip and knee joint moments during a sit-to-stand movement are invariant to the change of seat height within the range of low to normal seat height. *Biomedical Engineering Online* **13**, 27.

## Key points

- Researchers involved in collecting data in this study have no financial or personal interest in the outcome of results or the sponsor.
- The ISTS is a simple test that requires only a small space and a chair, and the exercise intensity can be easily adjusted by changing the patients' STS speed or the seat's height.
- The peak $VO_2$ on the ISTS test increased inversely, relative to seat height within 140% to 80% of the lower leg length.
- The effect of different seat heights during the ISTS test on the peak $VO_2$ is beneficial to determine which seat height on the ISTS test is suitable for different populations.

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