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ORIGINAL ARTICLE

One-minute sit-to-stand test reference values in people living at high altitudes

Valores de referencia de la prueba de levantarse y sentarse en un minuto en personas que viven a gran altitud

Mauricio Morales-Satan,[1,2,3] *Sofía Dávila-Oña,[4] *Rodrigo Torres-Castro,[5] Cristhel Hidrovo-Moreno,[6] Matías Otto-Yáñez,[7] Wilmer Esparza,[8] Camila Madera,[4] Carlos Moreta Nuñez,[9] Pamela Serón,[10,11] Lilian Solis-Navarro[5]

1 Hospital General Docente de Calderon, Quito, Ecuador. **2** Universidad Tecnológica Equinoccial, Quito, Ecuador, **3** Pontificia Universidad Católica del Ecuador, Quito, Ecuador , **4** Pontificia Universidad Católica del Ecuador, Manabí, Ecuador; **5** Universidad de Chile, Facultad de Medicina, Departamento de Kinesiología, Santiago, Chile. **6** Pontificia Universidad Católica Del Ecuador, Facultad de Enfermería, Quito, Ecuador . **7** Universidad Autónoma de Chile, Facultad de Ciencias de la Salud, Grupo de Investigación en Salud, Funcionalidad y Actividad Física (GISFAF), Kinesiología, Santiago, Chile, **8** Universidad Tecnológica Indoamérica, Carrera de Medicina, Facultad de Ciencias de la Salud y Bienestar Humano, Ambato, Ecuador. **9** Universidad Central del Ecuador, Carrera de Fisioterapia, Quito, Ecuador. **10** Universidad de La Frontera, Facultad de Medicina, Departamento de Ciencias de la Rehabilitación, Temuco, Chile. **11** Universidad de La Frontera, Centro de Excelencia CIGES, Temuco, Chile.

Abstract

Introduction:

The one-minute sit-to-stand test (1min-STST) is a practical assessment tool for measuring functional ability. Reference values are currently unavailable for populations residing at high altitudes.

Objetive:

This study aims to establish reference values for the 1min-STST in people living at high altitudes by sex and age range. Additionally, we correlate the variables analyzed with the number of repetitions obtained in the tests.

Methods:

Multicenter cross-sectional research was conducted, collecting data from two cities at high altitudes. Healthy adults between 18 and 80 years old were recruited. Anthropometric measurements, physical activity levels, smoking habits, and the number of repetitions during the 1min-STST were recorded. A multiple linear regression was performed to determine the predictive equations by sex. The stepwise method was used to generate the predictive model.

Results:

As many as 400 healthy subjects (58% women) were included. Participants had a median (P25-P75) height of 1.62 (1.56-1.68) cm, a weight of 63.0 (57.8-70.1) kg, and a BMI of 24.2 (22.5-26.0) kg/m2. The predictive equations were: 1minSTSTMen=19.833 - (age* 0.168) + (height * 0.204) - (weight * 0.122); 1minSTSTWomen= 27.845 - (age * 0.198) + (height * 0.145) - (weight* 0.094).

Conflict of interest: None

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Corresponding author

Rodrigo Torres-Castro. Department of Physical Therapy, Faculty of Medicine,University of Chile. Avenida Independencia #1027, Independencia, Santiago, Chile. Phone: +56229786513. **E-mail:** rodritorres@uchile.cl

Conclusion:

The reference values for 1min-STST were determined for the healthy population aged 18-80 years living at high altitudes.

Resumen

Introducción

La prueba de levantarse y sentarse en un minuto (1min-STST) es una herramienta práctica para evaluar la capacidad funcional. Actualmente, no existen valores de referencia para poblaciones que residen en ciudades de gran altitud.

Objetivo

Establecer valores de referencia del 1min-STST en personas que viven a gran altitud, según sexo y rango etario. Además, se analizaron las correlaciones entre las variables evaluadas y el número de repeticiones obtenidas en la prueba.

Métodos

Se realizó un estudio multicéntrico de tipo transversal en dos ciudades ubicadas a gran altitud. Se reclutaron adultos sanos entre 18 y 80 años. Se registraron medidas antropométricas, niveles de actividad física, hábito tabáquico y el número de repeticiones alcanzadas en el 1min-STST. Se aplicó un análisis de regresión lineal múltiple para determinar ecuaciones predictivas diferenciadas por sexo, utilizando el método por pasos (stepwise) para seleccionar el modelo final.

Resultados

Se incluyeron 400 sujetos sanos (58% mujeres). Los participantes presentaron una mediana (P25-P75) de estatura de 1.62 (1.56-1.68) m, peso de 63.0 (57.8-70.1) kg y un IMC de 24.2 (22.5-26.0) kg/m². Las ecuaciones predictivas obtenidas fueron:

1minSTSTHombres = 19.833 - (edad × 0.168) + (estatura × 0.204) - (peso × 0.122);
1minSTSTMujeres = 27.845 - (edad × 0.198) + (estatura × 0.145) - (peso × 0.094).

Conclusiones

Se establecieron valores de referencia para el 1min-STST en población sana de 18 a 80 años que reside en ciudades de gran altitud.

Remark

1) Why was this study conducted?

To establish sex- and age-specific reference values for the one-minute sit-to-stand test (1min-STST) in healthy adults living at high altitudes, where no normative data currently exist.

2) What were the most relevant results of the study?

In 400 adults living above 2,500 meters, sex-specific predictive equations were developed. Performance was lower compared to sea-level populations, confirming the influence of altitude on functional capacity.

3) What do these results contribute?

They provide altitude-specific normative values for the 1min-STST, improving clinical interpretation and supporting functional assessment and rehabilitation planning in high-altitude population.

Introduction

Physical capacity is defined as the ability of muscle systems to generate energy for mechanical work through aerobic and anaerobic metabolism [1]. Its evaluation is essential for healthy individuals and patients, as it supports developing personalized rehabilitation programs and progress monitoring [2]. Physical capacity can be assessed in clinical or everyday environments [3]. The most dominant measures of physical capacity are muscular strength or gait speed [4]. Standard methods for measuring physical capacity include laboratory-based physical tests, where cardiovascular, respiratory, and muscular interaction can be evaluated with complex physiological parameters [3]. Usually, field tests are used to measure physical capacity and, in some cases, assess functional capacity in more realistic situations. These tests may include walking, running, lifting objects, bending, sitting, and standing [5].

The six-minute walk test (6MWT) is a commonly used sub-maximal exercise test that assesses the maximum distance an individual can cover within a six-minute timeframe by walking as quickly as feasible [5]. However, it requires specific infrastructure, such as a 30-meter corridor, which may not always be feasible. Notably, the one-minute sit-to-stand test (1min-STST) has emerged because it can be used in a reduced space and has shown a good psychometric property compared with the 6MWT in metabolic, cardiovascular, and respiratory diseases [6]. Recently, the 1min-STST has gained much popularity after the COVID-19 pandemic as an alternative to the 6MWT [7,8]. Its minimal space requirements and ability to detect exercise-induced desaturation made it suitable for outpatient and inpatient settings [9,10]. Unlike the 6MWT, the 1min-STST primarily assesses lower-limb muscle strength and endurance [11]. When utilizing field tests such as the 1min-STST, reference values are crucial for interpreting the acquired outcomes within the relevant frameworks [5]. The reference values must consider ethnic, anthropometric, and other variables that can influence the specific population studied [5]. Moreover, some geographic characteristics that affect oxygenation could be incorporated, such as altitude [12].

At high altitudes, there is limited information on the behavior of the field tests. High-altitude environments (2,500-3,500 m) [13] are characterized by reduced atmospheric pressure and the partial pressure of inspired oxygen (PiO_2) [14], leading to chronic hypoxemia and decreased oxygen transport. These physiological changes can significantly impact functional performance, emphasizing the need for altitude-specific reference values [15].

Unacclimatized individuals at high altitudes experience exercise-related effects such as dyspnea or fatigue and may also experience gas exchange alterations, even when they are acclimatized and at rest [13]. The literature has shown the diminution of physical capacity in subjects living or are exposed at higher altitudes, assessed with 6MWT and cardiopulmonary exercise test (CPET) [13,16-18]. Attitude's physiological and functional effects on physical performance have been widely described in permanent and temporary residents [19]. These adaptations include metabolic changes, such as increased muscle myoglobin content and enhanced oxidative metabolic efficiency [20], which may influence performance on functional tests such as the 1min-STST. However, there is a notable lack of specific normative values to assess functional capacity in these populations, limiting their clinical applicability.

Studies have shown that altitude significantly influences the results of functional capacity tests such as the 6MWT, affecting both the distance walked and the level of dyspnea, so it is relevant to investigate whether these physiological adaptations also affect performance in the 1min-STST [21].

However, there is no information regarding the 1min-STST. This evaluation would allow the establishment of specific reference values for populations living at high altitudes, thus improving the clinical interpretation of results in this context. The impact of high altitude on health is well-documented, with studies highlighting its association with congenital heart defects and other physiological adaptations due to chronic hypoxia [22]. Environmental factors at high altitudes impact disease prevalence and functional capacity. Despite recognizing altitude as a health determinant, data on its effects on functional test performance, such as the 1min-STST, remain scarce. Establishing altitude-specific reference values enhances clinical assessments and guides targeted health interventions. For this reason, our objective was to establish reference values for the 1min-STST in people living at high altitudes by sex and age range**.** Additionally, we correlate the variables analyzed with the number of repetitions obtained in the tests.

Materials and Methods

Study design and participants

This cross-sectional study was conducted simultaneously in two cities in Ecuador, Quito (2,850 m) and Latacunga (2,860), from January to March 2024. This study was approved by the Ethics Committee of Ecuador, Quito (MSP-CZ9HGDC-2023-6096-M). All subjects gave written consent. This study was performed following the "Strengthening the Reporting of Observational Studies in Epidemiology" (STROBE) Guidelines [23].

Participants were recruited from the general population using non-probability snowball sampling. Initial participants were identified through public and private institutions, social media, and virtual posters and were then encouraged to refer to others who met the inclusion criteria. This approach was chosen to facilitate recruitment in high-altitude cities and ensure diverse socio-demographic groups' participation. The inclusion criteria were as follows: Adults between 18 and 80 self-reported as healthy [24], declared the absence of chronic diseases or acute medical conditions in the last 30 days and confirmed their ability to stand up and sit down from a chair. The exclusion criteria were: BMI $\geq$35 kg/m^2, having a chronic or acute respiratory illness in the last 30 days, having a musculoskeletal injury (acute or chronic) that directly affects mobility or the ability to perform the sit-to-stand movement, concomitant heart, brain, or neuromuscular disease that prevents performing the tests or having an inability to understand the instructions for the 1min-STST.

The University of Granada software was used to estimate the sample size based on the formula for cross-sectional studies with proportions, assuming a 95% confidence level (Z= 1.96), a 5% margin of error (d= 0.05), and a population proportion of 0.5 to ensure a conservative estimate. As a result, the final estimate determined a minimum of 385 participants.

Measurements

The 1min-STST test consisted of a simple movement: standing up from a chair and adopting the bipedal position with their knees in maximum extension [25]. A standard 46 cm chair was used, with thoracolumbar support [26,27]. Participants sit in a chair against the wall, keeping their back straight, their knees and hips flexed, and their feet shoulder-width apart, resting on the floor [28,29]. The movement required participants to rise to a full standing position with their knees extended and then return to a sitting position as often as possible within one minute [28]. Per the pre-test instructions, participants were instructed to perform as many repetitions as possible within one minute [28,30] (Figure 1). Before the test, trained personnel demonstrated to ensure participants understood the procedure. Participants then performed two repetitions of the sit-to-stand movement as practice to minimize errors during the test. After this practice, participants proceeded to the full 1min-STST. Pauses were allowed during the test, and participants were encouraged to resume without additional coaching. The main variable measured was the number of repetitions everyone fully stood up from and then sat back in a chair during this one minute [6,30]. A single measurement of the 1min-STST lasting was carried out [29]. It's worth noting that after the test, participants perceived exertion was assessed using the modified Borg Scale [31]. Additionally, a pulse oximeter was used to measure the oxygen saturation (SpO_2) and heart rate baseline at the end of the test (G1B, General Meditech, China).

The tests were conducted during daylight hours in controlled indoor environments, such as laboratories or university classrooms where participants were recruited. These settings ensured

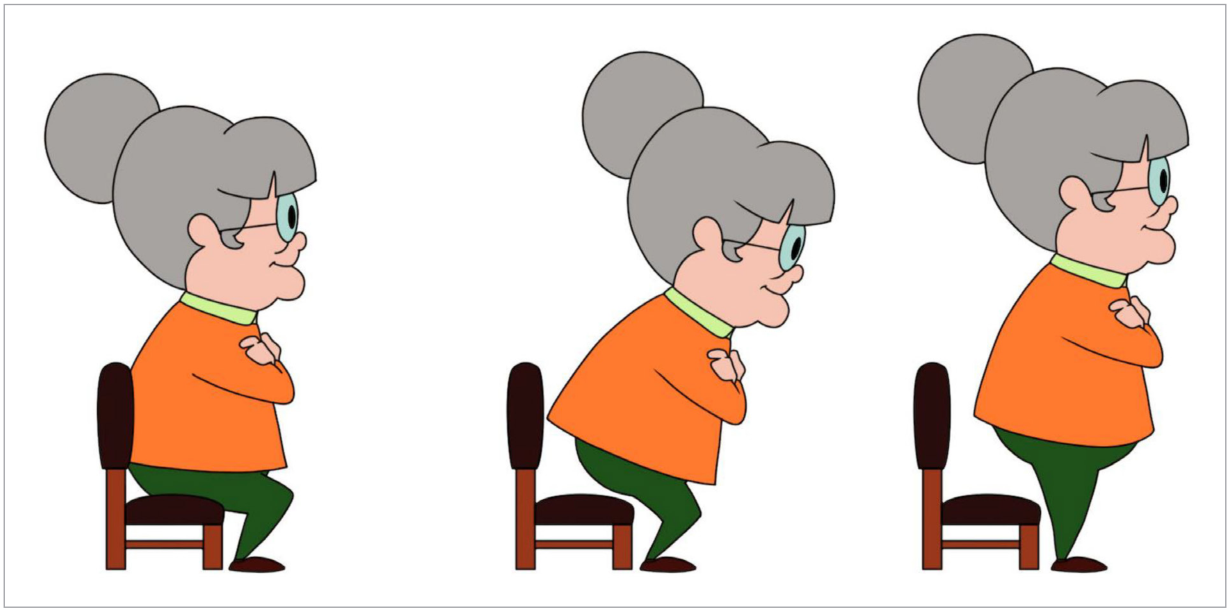

Figure 1. Illustration of the 1-minute sit-to-stand maneuver.

minimal distraction and consistent conditions for all participants. Verbal encouragement was provided 15 seconds before the end of the test, with the evaluators informing participants, "You have 15 seconds left". All assessments were performed by the same physiotherapist at each recruitment center, who was trained to ensure consistency in test administration and adherence to the standardized protocol.

Personnel training was carried out to standardize the measurements before performing the 1min-STST, using a designated pilot test user [11]. The objective was to verify that the staff understood the test's instructions and preserve the reliability of measurements [11]. After indicating the samples and doing it as practice, authorization was granted to start the measurements.

Each participant was assessed following a standardized evaluation protocol. Before the 1min-STST, data on participants' physical and demographic characteristics were collected. For smoking status, participants indicated whether they were "Active smokers," "Never smokers," or "ex-smokers." The short version of the International Physical Activity Questionnaire (IPAQ-SF) [32] was used to indicate the level of physical activity. Participants were categorized according to their activity level as low, moderate, and high [32].

Statistical analysis

Data was analyzed using statistical IBM SPSS version 25.0 (IBM Corporation, Armonk, NY, USA). Continuous variables were presented as median (percentile 25^{th} - 75^{th}), and categorical variables were presented as frequency and percentage. Data distribution was analyzed using the Kolmogorov-Smirnov test. A correlation analysis was also performed using Spearman's test for the quantitative variables (age, weight, height, BMI, initial Borg, and final Borg) with the 1min-STST results.

To examine the relationship between individual performances in the 1min-STST and age, we constructed dispersion graphs depicting the performance distribution concerning age and sex (Figure 2A y 2B). To assess the impact of physical activity on 1min-STST performance, we compared the number of repetitions at different levels of physical activity, as measured by IPAQ-SF. This comparison was conducted using ANOVA or Kruskal-Wallis tests.

Multiple linear regression was performed for men and women to facilitate the calculation of reference values, with performance in the 1min-STST. The stepwise method was used to generate the predictive model. To evaluate the generalizability of the prediction equations

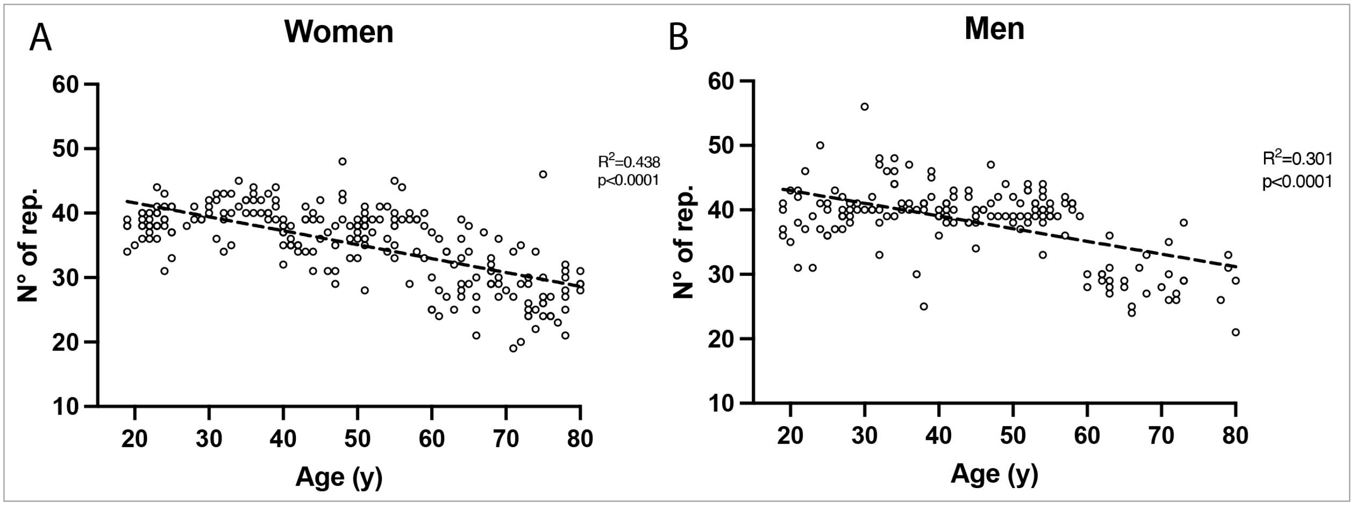

Figure 2. Association between the number of repetitions of the 1min-STST and age in women (A) and men (B). N° of rep: Number of repetitions.

generated by linear regression, a K-fold cross-validation (k= 5) was performed. In addition, sensitivity analysis was implemented to examine how variations in key predictor variables (age, height, and weight) affect the model's predictions. These methods ensure the robustness and consistency of the proposed models.

Sex- and age-specific normative percentiles (2.5rd, 25th, 50th, 75th, and 97.5th) were used to establish the reference values [33].

Results

Four hundred people were included in the study: 233 women (58.3%) and 167 men (41.8%). Regarding physical activity levels, 36.8% of participants reported a low level, 47.8% moderate, and 15.6% high. In terms of smoking history, 32.5% of participants identified as current smokers, 47.8% as non-smokers, and 19.8% as former smokers. More detailed information on the characteristics of the population can be found in Table 1.

Data has been presented as median (percentile 25th- percentile 75th) or frequency (percentage), as appropriate. BMI: body mass index; IPAQ-SF: International Physical Activity Questionnaire-Short Form; SpO_2: Oxygen saturation.

The correlations between the values of 1min-STST and age revealed a moderated inverse relationship (r= -0.555; *p* <0.001), a weak correlation with BMI (r= -0.215; *p* <0.001), with Borg post (r= -0.226 *p* <0.001), and with the height (r= 0.378; *p* <0.001). The correlation between the 1min-STST with the initial SpO_2 was very weak (r=0.129; *p*= 0.01), and with the final SpO_2, it was r= 0.171 *p*= 0.001; it can be said that there is a very weak correlation. Figures 2A and B illustrate the inverse association between age and 1min-STST performance in men and women, respectively (R^2 = 0.301 for men and R^2 = 0.438 for women; *p* <0.0001 for both).

The median number (p25-p75) of repetitions according to physical activity was 38 (36-40), 39 (33-41), and 38 (30-41) for low, medium, and high levels of physical activity, respectively, without statistically significant differences between groups (*p*= 0.705). The specific reference values by sex and age range are presented in Table 2 and Figure S1.

Percentile distribution of 1min-STST repetitions by sex and age group. Percentiles (p2.5, p25, p50, p75, and p97.5) are provided for both women and men across different age ranges (18-29, 30-39, 40-49, 50-59, 60-69, and 70-80 years). The values represent the number of repetitions completed during the 1min-STST.

Table 1. Characteristics of the population

Variable	All (n=400)	Women (n=233)	Men (n=167)
Age range, n (%)			
18-29	77	42 (54.5%)	45.5%)
30-39	65	32 (49.2%)	50.8%)
40-49	71	39 (54.9%)	(45.1%)
50-59	82	46 (56.9%)	(43.9%)
60-69	54	37 (68.51%)	(31.48%)
70-80	51	37 (72.5%)	14 (27.5%)
Height (m)	1.62 (1.56-1.68)	1.58 (1.53-1.61)	1.69 (1.64-1.74)
Weight (Kg)	63.0 (57.8-70.1)	60.0 (55.5-64.1)	70.2 (62.8-76.4)
BMI (kg/m2)	24.2 (22.5-26.0)	24.0 (22.2-25.8)	24.4 (23.1-26.5)
BMI, n (%)			
Underweight	5 (1.3%)	3 (0.12%)	2 (12%)
Normal	254 (63.5%)	155 (61%)	99 (59.2%)
Overweight	122 (30.5%)	62 (50.8%)	60 (35.9%)
Obese	19 (4.8%)	13 (0.04%)	6 (0.3%)
IPAQ-SF n (%)			
Low	147(36.8%)	95 (40.8%)	52 (31.1%)
Moderate	191 (47.8%)	107 (45.9%)	84 (50.3%)
High	62 (15.6%)	31(13.3%)	31 (18.6%)
Tobacco use, n (%)			
Smoker	130 (32.5%)	65 (27.9%)	65 (38.9%)
Non-smoker	262 (65.5%)	161 (69.1%)	101 (60.5%)
Former smoker	8 (2.0%)	7 (3.0%)	1 (0.6%)
SpO2 pre, median (p25-p75)	94(93-95)	94 (93-95)	94 (93-95)
SpO2 post, median (p25-p75)	94(93-95)	94 (93-95)	94 (93-95)
Basal Borg, median (p25-p75)	0 (0-1)	0 (0-1)	0 (0-1)
Final Borg, median (p25-p75)	3 (2-4)	3 (2-4)	3 (2-4)

Data has been presented as median (percentile 25th- percentile 75th) or frequency (percentage), as appropriate. BMI: body mass index; IPAQ-SF: International Physical Activity Questionnaire-Short Form; SpO2: Oxygen saturation.

Figure 3 presents the distribution of 1min-STST repetitions by sex. A statistically significant difference was observed between groups (p <0.0001).

The predictive equations for the 1min-STST were: Men: 1min-STST= 19.833 − 0.168 × Age (SE= 0.03) + 0.204 × Height (SE= 0.08) − 0.122 × Weight (SE= 0.04). R^2= 0.34; RMSE= 4.63; p <0.001. Corresponding t-values: Age= −5.60; Height= 2.55; Weight= −3.05. Women: 1min-STST= 27.845 − 0.198 × Age (SE= 0.03) + 0.145 × Height (SE= 0.07) − 0.094 × Weight (SE= 0.03). R^2= 0.46; RMSE= 4.29; p <0.001. Corresponding t-values: Age= −6.60; Height= 2.07; Weight= −3.13.

Cross-validation (k = 5) showed a stable average R^2 of 0.44 (SD= 0.05). Although a combined model revealed that sex did not reach statistical significance (p = 0.054), we retained sex-specific models due to their improved explanatory power and consistency with previously published reference equations (Figure 4).

Figure 5 shows the residuals of the prediction models plotted against age, separately for men and women. The residuals were more dispersed in older participants, suggesting reduced prediction accuracy in the upper age ranges.

The mean number of 1min-STST repetitions for the entire sample was 36.7 ±5.3. When analyzing by physical activity level, participants with low physical activity performed 36.7 ±5.3 repetitions, those with moderate activity performed 36.4 ±6.0 repetitions, and those with high physical activity performed 36.1 ±7.1 repetitions.

When considering sex differences, females with low physical activity performed 35.7 ±5.4 repetitions, those with moderate activity performed 35.0 ±6.0 repetitions, and those with high activity performed 35.4 ±6.4 repetitions. In males, repetitions were 38.7 ±4.4 for low activity, 38.3 ±5.4 for moderate activity, and 36.8 ±7.8 for high activity. Comparisons between different physical activity levels showed no statistically significant differences (p = 0.8).

Table 2. Number of 1min-STST by sex and age range

Age group (years)	Number of STS repetitions									
	Women					Men				
	p2.5	p25	p50	p75	p97.5	p2.5	p25	p50	P75	p97.5
18-29	31	37	38	40	44	31	37	39	41	46
30-39	34	40	41	43	44	25	40	41	45	48
40-49	29	35	37	39	43	34	39	40	41	44
50-59	28	36	38	39	45	33	39	40	41	44
60-69	21	27	30	34	38	24	28	29	31	33
70-80	19	24	27	30	35	21	26	29	32	35

Percentile distribution of 1min-STST repetitions by sex and age group. Percentiles (p2.5, p25, p50, p75, and p97.5) are provided for both women and men across different age ranges (18-29, 30-39, 40-49, 50-59, 60-69, and 70-80 years). The values represent the number of repetitions completed during the 1min-STST.

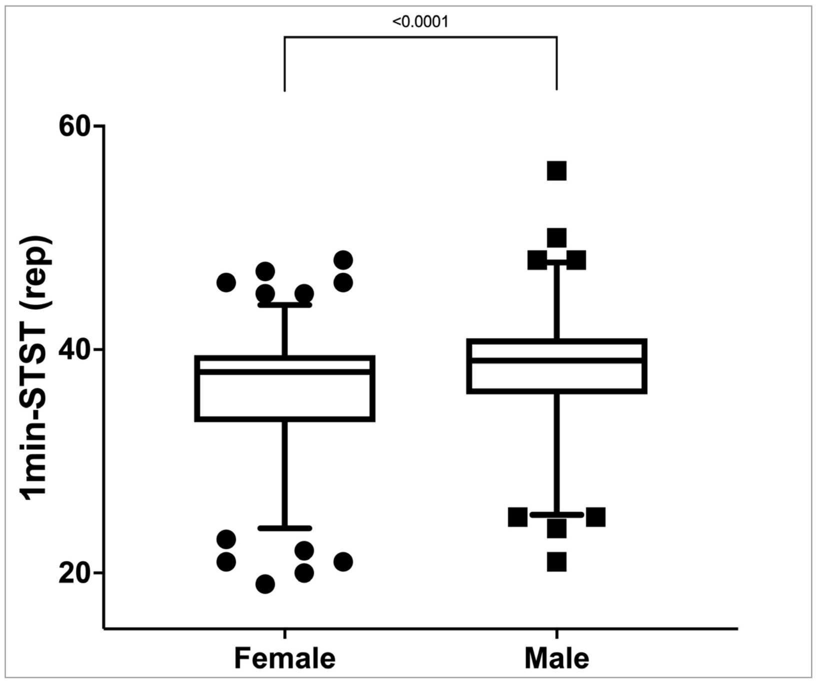

Figure 3. Distribution of 1min-STST repetitions by sex. The boxplots show the median, interquartile range, and total data range, with individual outliers represented as circles (females) and squares (males). A statistically significant difference was found between groups ($p < 0.0001$).

Discussion

This study established normative values for the 1min-STST in high-altitude populations to support clinical interpretation of test performance in these settings. These values were derived from a diverse sample of healthy individuals aged 18-80 living in cities above 2,500 meters. Using reference values from other populations may lead to misinterpretation due to individual and regional variability [34]. The ATS/ERS Statement recommends using population-specific reference values [35].

The values most used are the Strassman et al. [27], model from a Swiss population, which may not be universally applicable due to anthropometric and ethnic differences observed in populations residing in high-altitude environments. The Swiss population is also more physically active; according to IPAQ data, about 85% of our participants reported moderate or low physical activity.

Zürich, where Strassmann's data were collected, is located approximately 400 meters above sea level, contrasting with our sample's >2,500 meters altitude. At the 50th percentile, our participants showed consistently a lower performance. For example, women aged 20-24

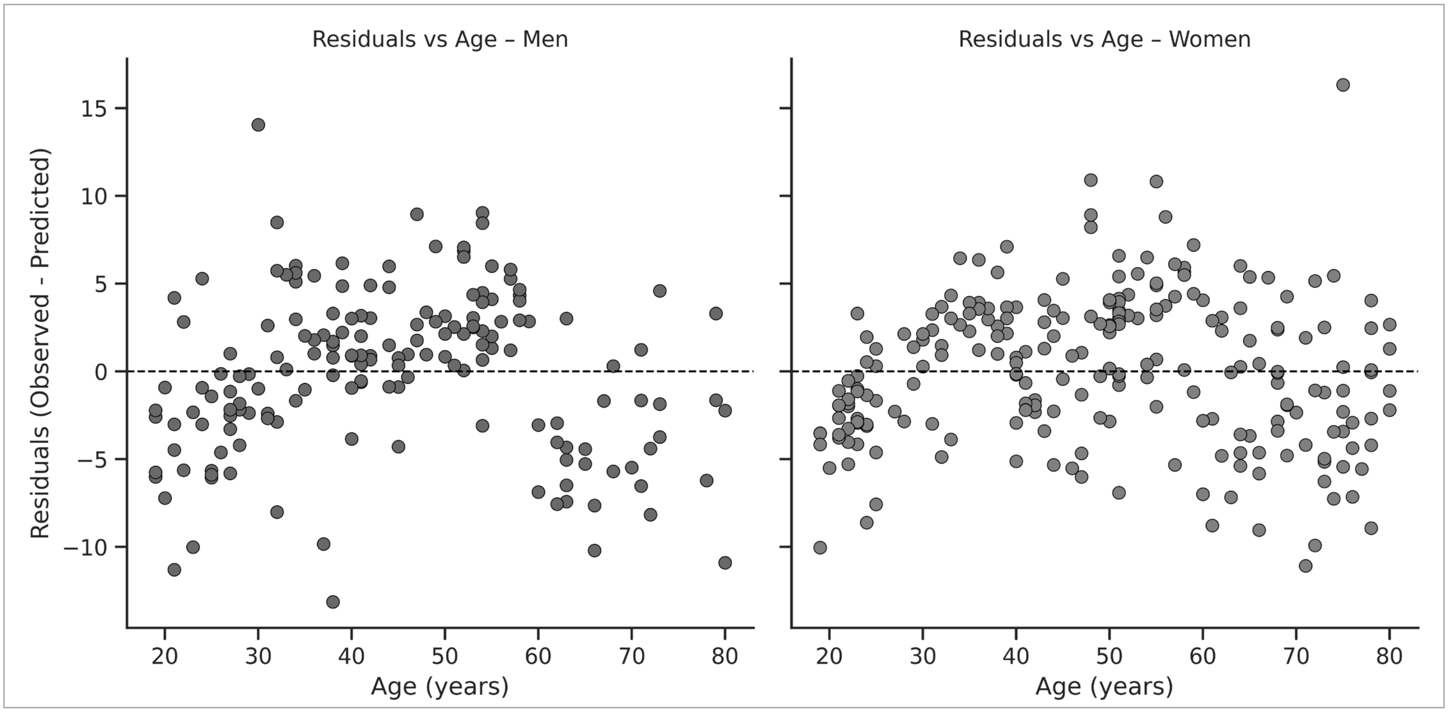

Figure 4. Residuals of the 1min-STST model (Observed - Predicted values) plotted against age, shown separately for men and women. The horizontal dashed line represents perfect agreement. Increased residual dispersion is visible in older participants, especially among men.

completed 38 repetitions versus 47 in Strassmann et al., and men completed 39 versus 50. In the 60-64 age group, women performed 30 versus 34, and men 29 versus 37 [27]. These differences, ranging from 12% to 22%, highlight the need for region-specific reference values (Table S1). In contrast, our values were comparable to those reported by Furlanetto *et al.* [36], with differences under 15% across most age groups. Their data were collected from Brazilian cities below 760 meters of altitude.

Several studies have shown an inverse relationship between BMI and 1min-STST performance [26,36]. In our sample, which had an average BMI slightly under 25, 35% of participants were classified as overweight or obese and performed approximately two fewer repetitions than those with normal weight. These findings align with previous reports, although the general Ecuadorian population has a higher prevalence of overweight and obesity [37].

Physical capacity is reduced at high altitudes due to lower atmospheric pressure and PiO_2 [15]. While our study did not include a sea-level comparison group, the average SpO_2 was 94%, slightly below values reported at sea level. Only 1.75% of participants experienced a desaturation of ≥4 points during the test, and just three ended with SpO_2 <90%. These results suggest good tolerance to the 1min-STST at altitude, with minimal risk of exertional desaturation.

Evaluating exercise tolerance requires objective indicators (e.g., oxygen saturation) and subjective perceptions of effort. The relatively low proportion of participants who experienced significant desaturation (≥4%) during the test suggests that most individuals exhibited good tolerance to the 1min-STST at high altitudes. However, the perception of exertion also supports this observation. Integrating the SpO_2 and Borg values provides a comprehensive understanding of exercise tolerance rather than just safety. This distinction is important when interpreting the applicability of the test in diverse clinical settings.

Functional capacity is influenced by environmental and physiological factors specific to high-altitude settings, including chronic exposure to hypobaric hypoxia [19,38]. Our data contributes to interpreting functional performance in these populations, where oxygen delivery and

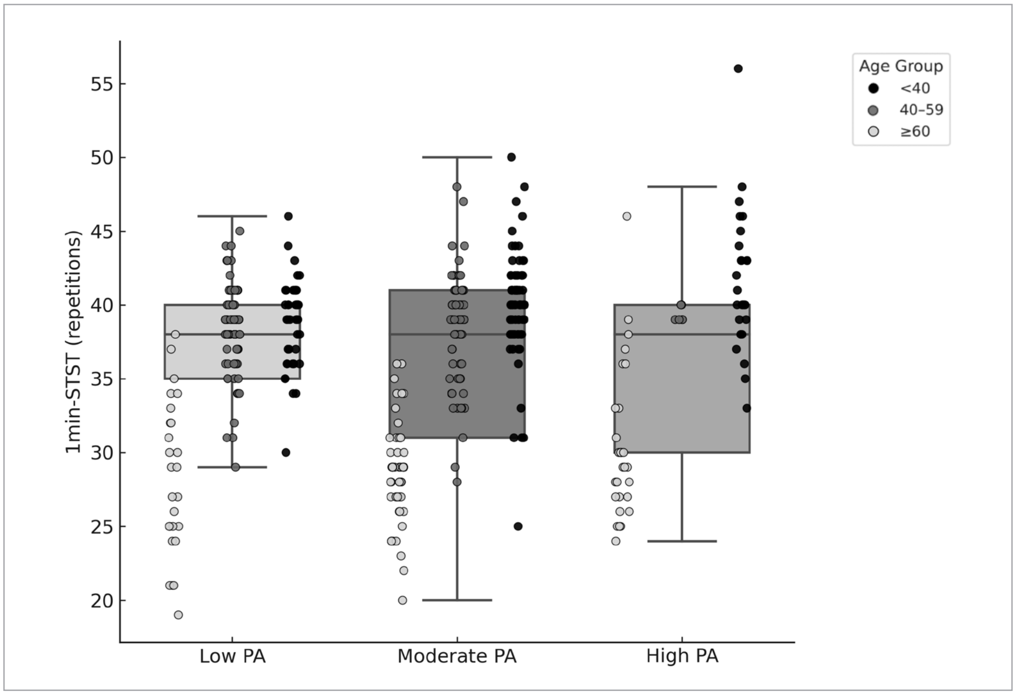

Figure 5. Boxplot of 1min-STST repetitions by physical activity level (IPAQ-SF). Individual data points are overlaid and color-coded by age group (<40, 40-59, ≥60 years). No statistically significant differences were observed across groups (p= 0.8).

muscular endurance may differ from sea-level conditions. Establishing localized reference values is essential for accurate clinical assessment and rehabilitation planning at altitude.

Previous studies have shown that functional performance, such as in the 6MWT, decreases with altitude due to hypoxia-induced limitations in oxygen transport and aerobic capacity [39-41]. These findings highlight the need for altitude-specific reference values for functional tests like the 1min-STST.

Exercise capacity is known to decrease at high altitudes because of hypobaric hypoxia on oxygen availability and aerobic performance [17,18,42]. VO_2 max may decline by 20-30% at altitude, reinforcing the need for context-specific reference values for functional tests. Future studies should compare populations at different altitudes to further validate the applicability of the 1min-STST across diverse environments.

The present study provides normative data for the 1min-STST in high-altitude populations, offering practical benchmarks for assessing functional capacity. These values are particularly relevant for identifying potential impairments in individuals living in chronically hypoxic environments, allowing clinicians to detect deviations from typical performance better and plan appropriate rehabilitation strategies.

One of the key findings of this study was the need to develop sex-specific prediction equations for the 1min-STST, as the relationships between predictors and outcomes differed between men and women. The equations differed in age, height, and weight coefficients, with greater predictive power in the female model. These results underscore the importance of considering sex as a determinant of functional performance, reflecting physiological differences such as body composition and muscular strength.

Age was the strongest predictor of 1min-STST performance, consistent with previous normative studies reporting progressive age-related test performance declines, particularly after midlife [26-28,36]. However, its association with test outcomes was not uniform across the age spectrum. As shown in Figure 2, performance remained relatively stable until around 40-50 years, after which a steeper decline was observed. Residual analysis also revealed greater dispersion in older adults, particularly among men, which may reflect increased physiological heterogeneity and the smaller sample size in this subgroup. These patterns may explain the moderate R^2 values obtained, suggesting that a single linear model may not fully capture age-related variation. Future studies with a broader representation of older individuals should explore segmented or non-linear models to improve predictive accuracy.

This study has some limitations. The categorization of seemingly healthy individuals relied on self-reporting and the absence of diagnosed medical conditions, which may have included individuals with undiagnosed conditions-an inherent limitation in extensive population studies aimed at establishing reference parameters. Moreover, the study had a lower representation of men aged 60 and older due to the difficulty in recruiting healthy volunteers in this age group. Additionally, the distribution of subjects by age does not necessarily reflect the age pyramid of the country or region, which may limit the representativeness of the reference values. Consequently, the limited number of participants in specific age subgroups did not allow for the development of stratified models by age. Therefore, we opted to analyze the population as a single entity (aged 18-80), which, although useful for general estimations, may limit the specificity of the reference values for older adults. Percentile-based age-group values may provide useful benchmarks but should be interpreted cautiously due to smaller subgroup sizes.

Furthermore, information on pack-years for smokers and ex-smokers was not collected, restricting the assessment of smoking history on 1min-STST performance. Although differences between physical activity levels were measured, no statistically significant differences were observed, suggesting that other factors, such as socioeconomic status, diet, or habitual activity patterns, may also influence outcomes. Body composition and anatomical characteristics, key indicators of functional impairment, were not assessed. In addition, this study did not evaluate potential learning effects associated with repeated 1min-STST trials, which remain inconsistently reported in the literature [28,43,44]. Future studies should address these limitations by incorporating these variables and conducting comparative analyses with populations to refine predictive models across altitudes.

Conclusion

This study provides normative values for the 1min-STST in Ecuadorian healthy adults living at high altitudes. These values offer a practical reference to assess functional capacity in this population and may support clinical decision-making in rehabilitation and health monitoring. While specific to the studied context, these reference values can serve as a foundation for future research and comparisons across similar high-altitude settings.

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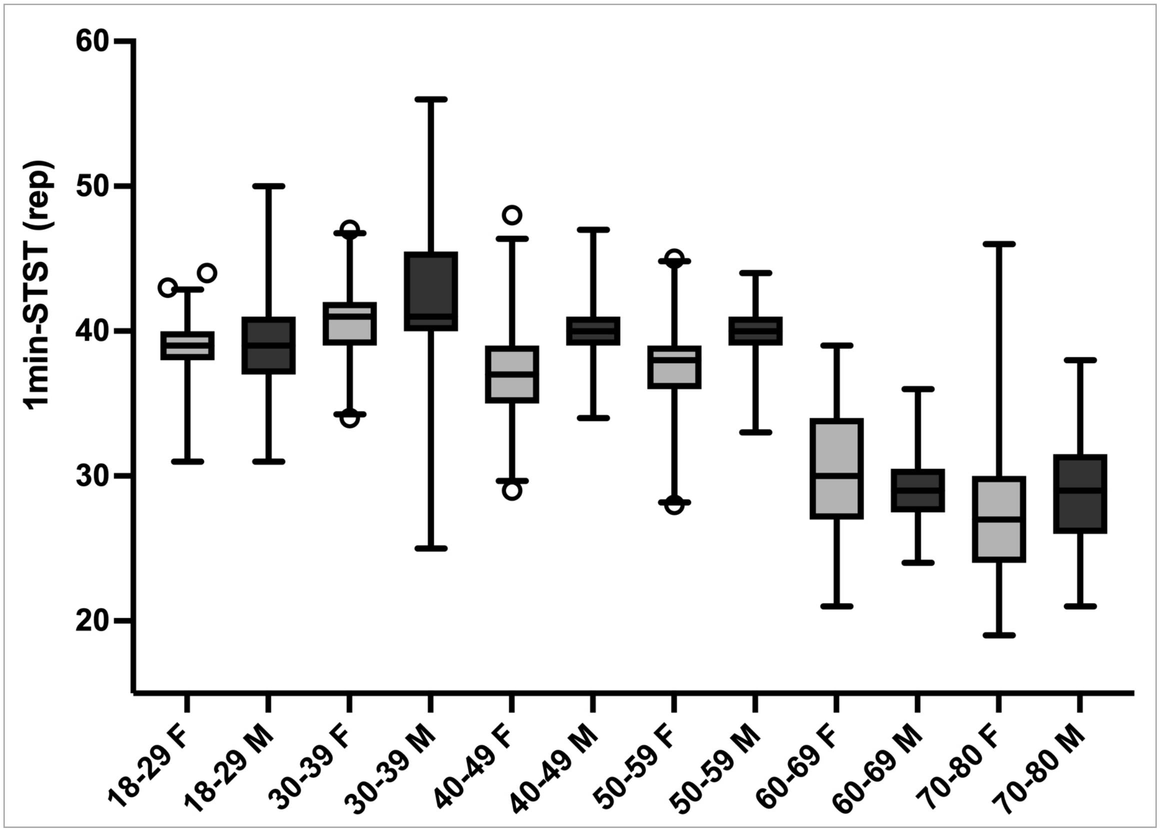
Supplementary Material

Figure S1



Distribution of 1min-STST repetitions by age and sex. Boxplots display the median, interquartile range, and full data spread for each subgroup. Although a gradual decline in performance is observed with increasing age, the pattern differs slightly between men and women. F = female; M = male.

Table S1. Comparison of p50 values with Strassmann et al. (2013).

Age Group	Women (Strassmann et al.)	Women (Morales-Satan et al.)	Men (Strassmann et al.)	Men (Morales-Satan et al.)
20-24	47	38	50	39
25-29	47	38	48	39
30-34	45	41	47	41
35-39	42	41	47	41
40-44	41	37	45	40
45-49	41	37	44	40
50-54	39	38	42	40
55-59	36	38	41	40
60-64	34	30	37	29
65-69	33	30	35	29
70-74	30	27	32	29
75-79	27	27	30	29

Table S1. Percentile 50 (p50) values for the 1min-STST with Strassmann et al. (2013), stratified by age group and sex. Age groups from the present study were broader and matched approximately to the narrower Strassmann age bands.