Article published online: 2023-12-19

The 6-minute Run Test: Validation and Reference Equations for Adults

Authors

Malte Leuschner[1], Martin Grauduszus[1], David Friesen[1], Nina Ferrari[1, 2], Marlen Klaudius[1], Christine Joisten[1]

Affiliations

1 Institute of Movement and Neurosciences, Department for physical activity in public health, Deutsche Sporthochschule Köln, Köln, Germany

2 Cologne Centre for Prevention in Childhood and Youth/Heart Centre Cologne, Uniklinik Köln, Köln, Germany

Key words

exercise, shuttle run test, cardiorespiratory fitness, 6 minute run test, endurance

accepted 11.10.2023

published online 19.12.2023

Bibliography

Int J Sports Med 2024; 45: 222–230

DOI 10.1055/a-2206-5291

ISSN 0172-4622

Georg Thieme Verlag, Rüdigerstraße 14, 70469 Stuttgart, Germany

Correspondence

Malte Leuschner
German Sport University Cologne
Institute for Movement and Neuroscience
Am Sportpark Müngersdorf 6
50933 Köln
Germany
Tel.: + 49 221 4982–6113
leuschner.malte@gmail.com

Additional material is available at https://doi.org/10.1055/ a-2206-5291

ABSTRACT

Endurance performance tests directly measuring cardiorespiratory fitness are complex, but field tests indirectly assessing maximum oxygen uptake (VO_{2max}) are an alternative. This study aimed to validate the 6-minute run test in adults, comparing it to the established shuttle run test, and to create reference equations. The cross-over design involved healthy adults aged 18–65 undertaking both tests, separated by a two-hour interval. The 6-minute run test required participants to run around a volleyball court for six minutes, aiming to maximize distance covered. The shuttle run involved participants covering 20 meters in defined time intervals at increasing speeds. Parameters measured included 6-minute run test distance, heart rates, calculated maximum oxygen uptake during the shuttle run, and total shuttle count. The study enrolled 250 participants (134 men and 116 women). Men averaged 1195.7 m (SD = 161.4), while women averaged 1051.2 m (SD = 148.0) in six minutes. The strongest correlation was found between the distance covered in the 6-minute run test and the total shuttle count ($r = 0.91$, $p < 0.001$). Two predictive models for 6-minute run test distance were developed and normative values for different sex-specific age clusters were established. The study showed that the 6-minute run test is valid as a practical endurance test for adults aged 18–65.

Introduction

Cardiorespiratory fitness (CRF) is strongly associated with reduced risk of obesity and the prevention of numerous non-communicable diseases. CRF is therefore considered an important predictor of morbidity and mortality [1–3]. Most commonly, aerobic capacity is expressed as maximum rate of oxygen uptake (VO_{2max}). These parameters are often measured directly by spiroergometry on a treadmill or bicycle ergometer due to their accuracy. Additional parameters, such as lactate level and blood pressure, can also be determined [4]. However, spiroergometry is an equipment-intensive and costly examination that requires specialized or trained personnel who may not be easily available [5]. Therefore, field tests to determine aerobic endurance capacity are viable alternatives. Commonly used field tests include pulse-based step tests (e. g. Harvard step test), distance running tests (e. g. 1000 or 3000 m) and timed running tests (e. g. 6 or 12 min) [1, 4, 6]. In addition, well-standardized stage-like running tests such as the Conconi-test and the 20 m shuttle run test (SRT) are widely used internationally [4, 6, 7]. The SRT has high validity for assessing VO_{2max}, which is why it is often used to assess performance and CRF in sports [1, 8].

Nonetheless, the currently used field tests usually require a certain level of physical fitness. Thus, for individuals with a lower level of fitness or chronic conditions such as COPD, pulmonary hypertension or chronic heart failure, the 6-minute walk test (6MWT) is commonly used [9].

Walking tests with shorter distances or time frames, such as the 2-minute walk test, may be sufficient for lower-performing individuals [10]. But these tests limit those with higher aerobic capacity who could have covered a greater distance by running instead of walking. Therefore, walk tests have a ceiling effect, where the endurance performance of a mediocre runner can no longer be distinguished from that of an exceptional runner [1, 11]. A compromise uniting ease of execution and athletic demand is the 6-minute run test (6MRT). However, reference values have been established only for children and adolescents so far [4]. Validity and reliability testing has just been done for the 6MWT, but not for the 6MRT [1, 5]. The aim of the present study was therefore to assess the validity of the 6MRT by comparing it with the results of the highly validated and standardized SRT and to generate 6MRT reference equations for adults aged between 18–65 years.

Materials and Methods

Sampling protocol

All tests were conducted at the german sport university cologne or institutions affiliated with the authors between May 2019 and September 2022. Due to the coronavirus pandemic, testing had to be temporarily paused from March 2020 to February 2022.

A total of 250 individuals (116 women and 134 men) aged 18 to 65 years participated in the validation study. Previous studies validating the 6MWT or SRT have employed sample sizes ranging from 40 to 350 participants [9, 12–16]. Other authors recommended including 10 to 100 participants per age group [17, 18]. In 6MRT studies involving children, sample sizes have varied between 30 and 125 [4]. Recruitment sources included large companies, organizations, personal contacts, and social media, considering inclusion and exclusion criteria. Inclusion criteria were age 18–65, good overall physical health, absence of diseases listed in the exclusion criteria. Exclusion criteria comprised cardiovascular diseases (e. g. acute coronary syndrome, high-grade valvular defects), pulmonary and other acute diseases. Individuals with other severe general diseases or competitive athletes were also excluded. A medical certificate to participate in sports was required.

Study design

Each participant completed the 6MRT and the SRT in a cross-over design. Both tests were performed on the same day. The participants were randomly assigned to the respective tests. Metabolites such as lactate produced during the first run were completely broken down by the body after at most 65 minutes during passive recovery [19]. Therefore, a two-hour break between the two tests was implemented to minimize the influence of lactate. The group of participants was divided into two equal groups of up to 10 runners before the tests began.

Anthropometric data

Height and body mass were measured barefoot and in light clothing (Seca 761 scale, Seca 213 stadiometer; Seca, Hamburg, Germany). BMI was then calculated using the formula: BMI (kg/m^2) = weight (kg)/height $(m)^2$ [20] and classified into the World Health Organization (WHO) categories: underweight (< 18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), pre-obesity (25.0–29.9 kg/m^2), obesity class 1 (30.0–34.9 kg/m^2), obesity class 2 (35.0–39.9 kg/m^2) and obesity class 3 (≥ 40.0 kg/m^2) [20]. Waist circumference was measured using a flexible tape measuring midway between the lowest rib and the pelvic bone [21]. Waist-to-height ratio (WHtR) was then calculated using the formula: WHtR = waist circumference (cm)/height (cm) [22].

Heart rate

Heart rate was recorded using chest straps and heart rate monitors (Polar model M400; Polar, Kempele, Finland) before the start of the tests (resting heart rate), during the tests, and up to three minutes after the end of the tests to determine the average and maximum heart rate.

6-minute run test

The 6MRT took place on a 54-meter track encircling a volleyball court in a sports hall, which had to be run as many times as possible in six minutes. To avoid competition and accidents, the field of runners was spread out and evenly distributed at the four corners

▶ **Table 1** Demographics of study population.

Variable	n	Total	n	Women	n	Men	p-value
Age (years)	250	42.2 (12.6)	116	41.8 (12.6)	134	42.5 (12.6)	0.668[a]
Height (cm)	250	175.7 (9.4)	116	168.4 (6.3)	134	182.0 (6.6)	<0.001[a]
Weight (kg)	250	75.6 (13.4)	116	66.1 (8.7)	134	83.8 (11.2)	<0.001[a]
Waist circumference (cm)	250	85.9 (10.8)	116	80.1 (8.6)	134	90.9 (10.0)	<0.001[a]
WHtR	250	0.49 (0.06)	116	0.48 (0.05)	134	0.50 (0.06)	<0.001[a]
BMI (kg/m^2)	250	24.4 (3.2)	116	23.2 (2.9)	134	25.3 (3.2)	<0.001[a]
Underweight	1	0.4 %	1	0.9 %	0	0	0.003[b]
Normal	153	61.2 %	85	73.3 %	68	50.7 %	
Overweight	83	33.2 %	27	23.3 %	56	41.8 %	
Obese	13	5.2 %	3	2.6 %	10	7.4 %	

Abbreviations: n, number; BMI, body mass index; WHtR, waist-to-height ratio; Explanations: Data are presented as mean (standard deviation); p-values between men and women were calculated using [a]t-test or [b]χ^2 test; $p < 0.05$ = significant.

of the volleyball court [23]. Participants could run or walk as needed. The remaining time was announced after three and five minutes, concluding with a final 10-second countdown. Afterwards each runner had to stop on the spot. Total distance was calculated from laps completed plus the distance covered in the final lap. After the test, the participants were instructed to walk slowly for three minutes. The tests were conducted in accordance with the American Thoracic Society guidelines for the 6MWT [24].

20-m shuttle run test

The SRT was performed on a 20-meter track between two baselines as described by Léger and Lambert (1982) [25]. This distance had to be run as many times as possible at a speed indicated by audio signals. The track included two tolerance zones every two meters in front of the baselines. Each completed distance represented one shuttle. The number of shuttles per level increased with the level, as each level lasted one minute. The initial speed was 8.0 km/h. In the second level the speed increased to 9.0 km/h and then by 0.5 km/h per level. The first audio signal indicated the time at which the runners had to commence to run and the following one to reach the baseline. If a participant failed to reach the tolerance zone three times when the audio signal sounded, the participant's run was terminated. In addition, runners could stop the test themselves due to exertion or pain. After the run, participants were instructed to walk slowly for three minutes. Castro-Piñero et al. (2021) recommended using the formula for adults determining the relative VO_{2max} standardized by Léger et al. (1988), based on the last speed of the SRT level: $VO_{2max} = -27.4 + 6.0 * \text{last speed}$ [1, 26]. In addition, the total number of shuttles accomplished was recorded as total shuttle count (TSC).

Lifestyle parameters

Sociodemographic factors such as marital status, profession, and information on physical activity in daily life were collected using a standardized questionnaire [27]. Individuals were categorized as either active, defined as more than 150 min/week of physical activity or inactive, defined as having less than 150 min/week of physical activity, according to WHO recommendations [28]. Dietary intake over the previous 24 hours was recorded using a food diary [29, 30].

Statistics and data analysis

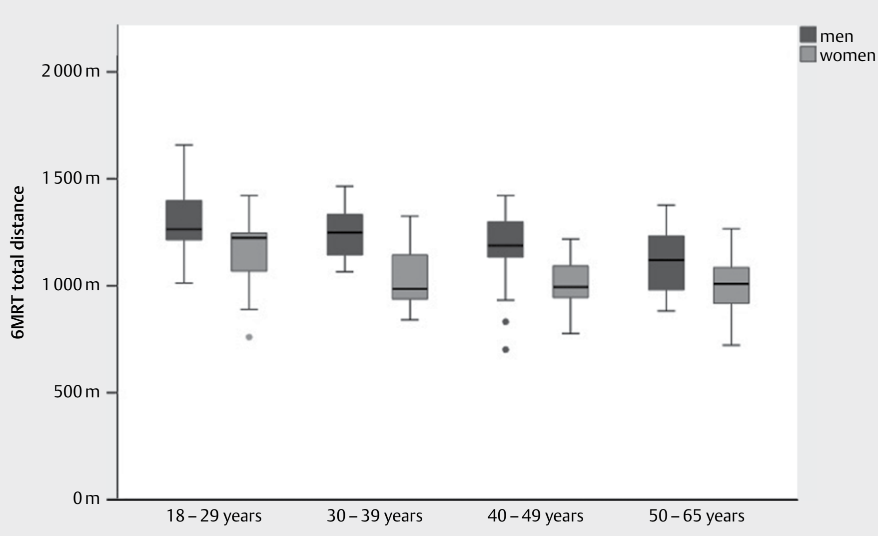
Data analysis was performed using IBM SPSS 28.0 software (IBM Corp., Armonk, NY, USA). Descriptive statistics, including mean (M), quantiles, standard deviation (SD), and minimum/maximum values for anthropometric data and the endurance test results, were calculated. Normal distribution was assessed using the Kolmogorov–Smirnov test and Shapiro–Wilk test along with histograms. Significance testing was conducted at a predetermined significance level, set at α-values of 5 %. Sex-specific differences were analyzed using the t-test for independent samples. Pearson's correlation coefficient was used to determine relationships between 6MRT performance and anthropometric variables.

To validate the 6MRT, linear regression analysis with calculation of the coefficient of determination (R^2) was performed. The dependent variable was 6MRT distance; independent variables included TSC achieved during SRT, along with demographic variables such as age, body mass, and height. Normative values in the respective age clusters were divided into percentiles ($p = 0.1; 0.33; 0.5; 0.66; 0.9$). Multiple regression models were designed using anthropometric variables to establish reference equations for predicting 6MRT performance. Unrealistic heart rate data was excluded from anthropometric data. Two female participants unable to perform in the 6MRT were not considered for the calculation of linear regressions.

Results

Anthropometric data

The mean age of the runners was 42.2 years (SD = 12.6). There was no significant difference in age between the sexes ($t(248) = 0.43$; $p = 0.668$). The average height of women and men was 168.4 cm



▶ **Fig. 1** Boxplot showing the 6-minute run (6MRT) total distance in men and women divided into age groups. Dots mark outliers.

(SD = 6.2) and 182.0 cm (SD = 6.6), respectively. Women were significantly shorter, lighter, had a lower BMI, WHtR, and smaller waist circumference than men (▶ **Table 1**).

6MRT results

The mean distance run by men and women was 1195.7 m (SD = 161.4) and 1051.2 m (SD = 148.0), respectively (t(246) = 7.30; p < 0.001; ▶ **Fig. 1**). With increasing age, the average distance continuously decreased in both sexes (men: M = 1286.9–1110.9 m; women: M = 1168.6–1000.9 m). The pre-run heart rate was 88 bpm (SD = 16.6) for men and 87 bpm (SD = 15.5) for women. The mean heart rate during the run was 150 bpm (SD = 22.1) for men and also 150 bpm (SD = 22.5) for women (t(245) = 0.25; p = 0.801). The maximum heart rate was 176 bpm (SD = 18.9) for men and 169 bpm (SD = 18.0) for women (t(246) = 2.77; p = 0.06; ▶ **Table 2**). The physically active participants (> 150 min/week of activity) ran an average distance of 1158.30 m (SD = 172.8). In comparison, the less active participants (< 150 min/week of activity) ran a mean distance of 1060.92 m (SD = 146.4).

20-m SRT results

On average, men achieved an SRT level of 7.8 (SD = 2.2) and a TSC of 66.5 (SD = 22.8) and women an SRT level of 5.6 (SD = 2.0) and a TSC of 44.1 (SD = 19.7; ▶ **Table 2**). The difference in TSC of 22.4 shuttles between men and women was significant (t(248) = 8.23; p < 0.001; **supplementary Appendix 1**). From the TSC we also calculated the total SRT distance. Men covered an average distance of 1329.0 m (SD = 456.6), while women ran an average of 881.6 m (■SD = 393,1; (t(248) = 8.20; p < 0.001). Mean pre-run heart rate was 87 bpm (SD = 17.7) among men and 86 bpm (SD = 14.3) among women. The average heart rate was 145 bpm (SD = 21.6) for men and 141 bpm (SD = 24.7) for women (▶ **Table 2**). Only the maximum heart rate during the SRT differed significantly comparing the sexes, averaging 178 bpm (SD = 19.7) among male runners and 167 bpm (SD = 24.6) among female runners (t(247) = 4.00; p < 0.001; **supplementary Appendix 1**).

Correlations between 6MRT distance and 20-m SRT performance

The strongest correlations were found between the 6MRT distance and TSC (r(248) = 0.91; p < 0.001), between the 6MRT distance and VO_{2max}, respectively (r(248) = 0.90; p < 0.001; ▶ **Table 3**). Linear regression analysis of the total sample showed that the TSC had the highest explanation of variance of all variables (F(1,246) = 1206.54; p < 0.001; R^2 = 0.83; ▶ **Fig. 2**). When analyzed by sex, the regression was also significant showing an R^2 value of 0.76 for women and 0.82 for men.

The regressions were repeatedly calculated in all age groups and were always significant throughout (p < 0.001 each). Explanation of variance was between R^2 values of 0.75 and 0.91 (▶ **Fig. 3**). When the age groups were considered separately according to sex, the regression analysis also showed only significant correlations (p < 0.001 each), with R^2 between 0.34 and 0.88. Logically, the calculations with the SRT distance yielded identical results. But when the total distances run in each test were compared, there was no significant difference (t(247) = 0.08; p = 0.94)

The average heart rates measured in both tests were significantly correlated (F(1,245) = 51.77; p < 0.001; R^2 = 0.18). Significantly

▶ **Table 2** Results of the 6MRT and SRT.

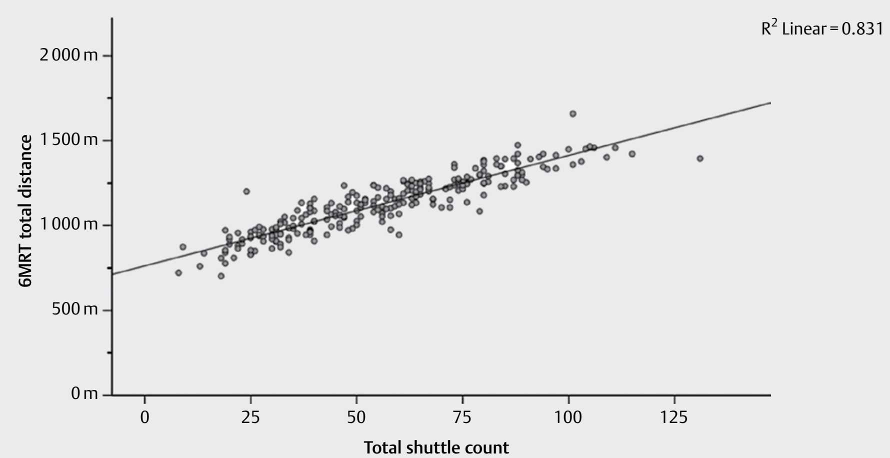
	Total					Women					Men				
Variable	**n**	**SRT**	**n**	**6MRT**	**p-value**	**n**	**SRT**	**n**	**6MRT**	**p-value**	**n**	**SRT**	**n**	**6MRT**	**p-value**
HR before run (bpm)	250	86.7 (16.2)	248	87.2 (16.1)	0.506	116	86.1 (14.3)	114	86.7 (15.5)	0.553	134	87.1 (17.7)	134	87.7 (16.6)	0.711
HR average (bpm)	249	143.0 (23.1)	247	150.0 (22.2)	<0.001	115	140.9 (24.7)	114	149.7 (22.5)	<0.001	134	144.8 (21.6)	133	150.4 (22.1)	0.010
HR max (bpm)	249	172.9 (22.8)	248	172.7 (18.8)	0.840	115	166.7 (24.6)	114	169.2 (18.0)	0.312	134	178.1 (19.7)	134	175.7 (18.9)	0.222
HR 3 min after run (bpm)	249	110.3 (19.5)	247	107.7 (15.7)	0.042	116	107.5 (17.4)	114	105.3 (13.9)	0.291	133	112.7 (21.0)	133	109.7 (16.9)	0.074
SRT total shuttle count (TSC)	250	56.1 (24.1)		x		116	44.1 (19.7)		x		134	66.5 (22.8)		x	
SRT level	250	6.78 (2.38)		x		116	5.60 (2.00)		x		134	7.81 (2.22)		x	
6MRT total distance (m)		x	248	1129.2 (171.0)			x	114	1051.2 (148.0)			x	134	1195.7 (161.4)	

Abbreviations: n, number; SRT, shuttle run test; 6MRT, 6-min run test; HR, heart rate; Explanations: Data are presented as mean (standard deviation); p-values between SRT and 6MRT results were calculated using t-test; p < 0.05 = significant.

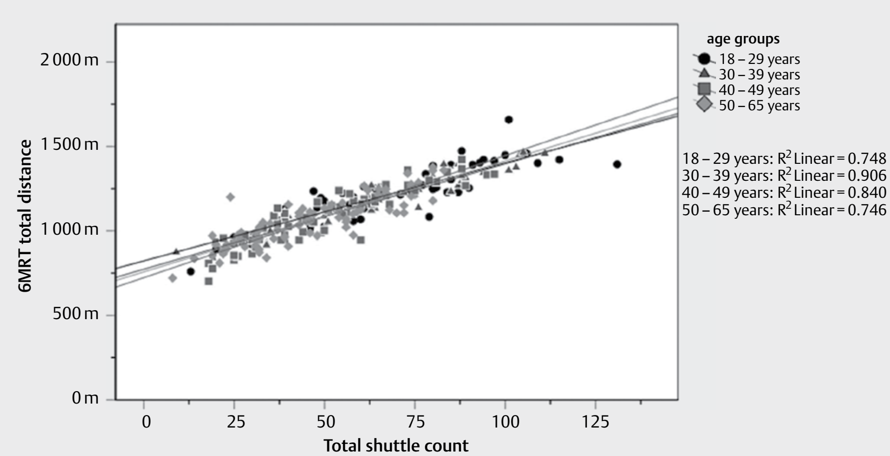
▶ **Table 3** Univariate correlation analysis of 6MRT distance.

	Total		Women		Men	
Variable	**r-value**	**p-value**	**r-value**	**p-value**	**r-value**	**p-value**
SRT total shuttle count	0.911	<0.001	0.903	<0.001	0.874	<0.001
SRT level/VO_{2max}	0.903	<0.001	0.865	<0.001	0.892	<0.001
Age	−0.392	<0.001	−0.425	<0.001	−0.470	<0.001
Height	0.414	<0.001	0.137	0.145	0.197	0.023
Weight	0.061	0.343	−0.308	<0.001	−0.325	<0.001
Waist circumference	−0.216	<0.001	−0.528	<0.001	−0.554	<0.001
WHtR	−0.247	<0.001	−0.415	<0.001	−0.451	<0.001
BMI	−0.417	<0.001	−0.553	<0.001	−0.581	<0.001
HR before 6MRT	0.058	0.365	0.063	0.505	0.040	0.648
Average HR 6MRT	0.111	0.082	0.055	0.564	0.163	0.060
Max HR 6MRT	0.273	<0.001	0.242	0.009	0.209	0.015
HR 3 min after 6MRT	0.003	0.967	−0.059	0.533 (NS)	−0.067	0.443

Abbreviations: BMI, body mass index; WHtR, waist-to-height ratio; HR, heart rate; Explanations: r-value, Pearson's correlation coefficient; $p<0.05$ = significant.



▶ **Fig. 2** Linear regression showing the relationship between the 6-minute run test (6MRT) distance and the total shuttle count (TSC) in the total study population. R^2-value (coefficient of determination) indicates explanation of variance.



▶ **Fig. 3** Linear regression showing the relationship between the 6-minute run test (6MRT) distance and the total shuttle count (TSC) per age group. R^2-value (coefficient of determination) indicates explanation of variance in each age group.

Leuschner M et al. The 6-minute run test: … Int J Sports Med 2024; 45: 222–230 |

▶ **Table 4** Age- and sex-specific percentile values for 6MRT distance.

Age group	n	p10	p33	p50	p66	p90
Men						
18–29 years	28	1044.0	1221.0	1264.5	1386.8	1459.6
30–39 years	32	1090.3	1205.6	1249.0	1296.0	1434.2
40–49 years	30	933.5	1158.7	1188.0	1272.8	1359.9
50–65 years	44	909.0	1019.9	1121.0	1175.1	1314.0
Women						
18–29 years	29	920.8	1137.1	1224.0	1236.8	1392.0
30–39 years	19	874.5	962.8	986.0	1096.4	1296.0
40–49 years	33	836.8	945.9	994.5	1064.9	1167.4
50–65 years	33	839.0	948.7	1009.0	1058.6	1144.2

Abbreviations: n, number; p, percentile; Explanations: Data are presented as percentiles in meters. Percentiles indicate how many values in a ranked order are set below in each age group. They were calculated for both sexes. p50 = Median.

▶ **Table 5** Model 1 – Reference equation for 6MRT distance.

Sex category	Model		Non-standardised coeff icient		Standardised coefficient	t	Sig.
			B	Std. error	Beta		
Male	1	Constant	541.014	307.472		1.760	0.081
		Age	−5.629	0.872	−0.438	−6.454	<0.001
		Height	7.737	1.770	0.317	4.372	<0.001
		Weight	−6.141	1.042	−0.426	−5.896	<0.001
Female	1	Constant	587.265	322.769		1.819	0.072
		Age	−4.599	0.926	−0.391	−4.968	<0.001
		Height	6.523	2.040	0.273	3.198	0.002
		Weight	−6.707	1.454	−0.394	−4.613	<0.001

Dependent variable: Total 6MRT distance.

▶ **Table 6** Model 2 – Reference equation for 6MRT distance.

Sex category	Model		Non-standardised coefficient		Standardised coefficient	t	Sig
			B	Std. error	Beta		
Male	2	Constant	2037.259	91.491		22.267	<0.001
		Age	−4.177	0.887	−0.325	−4.709	<0.001
		Waist-to-height ratio	−1328.026	189.640	−0.483	−7.003	<0.001
Female	2	Constant	1802.154	99.046		18.195	<0.001
		Age	−3.326	0.925	−0.283	−3.597	<0.001
		Waist-to-height ratio	−1286.967	216.590	−0.467	−5.942	<0.001

Dependent variable: Total 6MRT distance.

higher average heart rates were recorded during the 6MRT (150 bpm (SD = 22.2)) compared to the SRT (143 bpm (SD = 23.1)), regardless of sex ($t(245) = 4.36$; $p < 0.001$; ▶ **Table 2**). In addition, the post-exercise heart rate was significantly different between the 6MRT and SRT ($t(245) = -2.05$; $p = 0.042$; ▶ **Table 2**).

Associations of anthropometric data with 6MRT distance

There was a significant positive correlation between 6MRT distance and height ($r(250) = 0.67$; $p < 0.001$). Also, there was a weak positive relationship linking 6MRT distance and maximum heart rate. In contrast, weak negative correlations were found regarding 6MRT distance and age, BMI, waist circumference, and WHtR. No correlation was detected for 6MRT distance and body mass ($r(250) = 0.06$; $p = 0.343$; ▶ **Table 3**).

Normative values

The 6MRT distance was divided into percentiles (10, 33, 50, 66 and 90) and clustered by age groups and sex (▶ **Table 4**).

Reference equations

Several multiple regression models for predicting 6MRT distance were tested and two were selected. Model 1 included age, height, and body mass and gave an explanation of variance of 33 % for women and 41 % for men (▶ **Table 5**). Model 2 included age and

WHtR and explained 38 % of variance for women and 43 % for men (▶ **Table 6**).

For model 1, including age, height and body mass, the following reference equations were calculated:

Men: 6MRT distance = 541.014 − [*age* (*years*) × 5.629] + [*height* (*cm*) × 7.737] − [body mass (kg) × 6.141]; $r^2 = 0.41$

Women: 6MRT distance = 587.265 − [*age* (*years*) × 4.599] + [*height* (*cm*) × 6.523] − [body mass (kg) × 6.707]; $r^2 = 0.33$

For model 2, including WHtR instead of body mass, the following reference equations were calculated:

Men: 6MRT distance = 2037.259 − [*age* (*years*) × 4.177] − [*WHtR* × 1328.026]; $r^2 = 0.43$

Women: 6MRT distance = 1802.154 − [*age* (*years*) × 3.326] − [*W HtR* × 1286.967]; $r^2 = 0.38$

Discussion

To our knowledge, this is the first study to validate the 6MRT in adults and to develop age- and sex-specific reference equations. The 6MRT demonstrated a high level of validity as a field test, with the TSC and calculated VO_{2max} showing strong correlations with the 6MRT distance. Among the predictors, TSC proved to be the most accurate for assessing 6MRT performance across all age groups and both sexes.

Reference equations were derived from anthropometric data, with model 1 utilizing age, height, and body mass to predict 6MRT distance without complex measurements. Model 2 required measurement of waist circumference to calculate WHtR in addition to age, resulting in a 5 % increase in coefficient of determination for women and a 2 % increase for men compared to model 1.

Consistent with previous 6MWT studies, men also outperformed women in the 6MRT [9, 16]. This is mostly due to factors like greater muscle mass and taller stature resulting in longer stride length [9]. Therefore, height had a positive influence on 6MRT distance, while body mass and waist circumference correlated negatively with running performance (▶ **Table 3**). Naturally, individuals with higher body mass, particularly fat mass, and the often-associated lack of physical activity tend to perform worse [9]. Age also correlated negatively with the 6MRT performance (▶ **Table 3**). This association is likely to be due to the decline in muscle mass, muscle strength and oxygen uptake with advanced age [9].

On average, participants achieved slightly higher total distances in the SRT. However, when compared statistically, there was no significant difference. Therefore, the 6MRT should be considered for more frequent testing because it is easier to administer than the SRT.

Apart from maximum heart rate, no other cardiac parameters correlated significantly with total 6MRT distance. Maximum heart rate indicates maximal exertion and effort, with greater increases during heavy exertion compared to moderate or light exertion [31]. An individual who ambitiously pushes to their maximal potential tends to cover more distance in six minutes. The overall average heart rate was higher during the 6MRT than during the SRT. This difference may be attributed to the continuous high cardiovascular load during the 6MRT compared to an intermittent load with a slow start in the SRT. The 6MRT allows individuals to choose their own pace, whereas the SRT imposes a strict pattern [32]. This disparity therefore may arise from variations in exercise protocols, characterized by distinct physiological demands and corresponding effort levels. Such discrepancies in heart rate responses should be considered when employing and interpreting diverse exercise regimens.

Mayorga-Vega et al. (2016) advocate SRT for adult aerobic capacity assessment, with minor sex and age influence for validity in their study. For time/distance running, the 1.5 mile run test and the 12-minute run test showed high validity for estimating cardiorespiratory fitness. The authors did not recommend shorter times or distances [32]. Nevertheless, our results show that the 6MRT is also a valid alternative for adults. As there have been no reference equations used for the 6MRT in adults yet, we cannot compare these results with those of similar-designed studies. In 2017, Batista et al. lamented the lack of literature regarding validation and reference values for the 6MRT [5]. As of 2023, only our study addresses this gap, emphasizing the need for further research, including diverse populations and ethnicities, to establish reference values.

This study's strength lies in its broad participant age range from 18–65 years and inclusion of both sexes, enhancing representativeness, diversity, and external validity. Strict exclusion criteria and medical fitness certificates for sport ensured that the participants were healthy, so that normative values can be applied to healthy populations. A cross-over design with a clearly structured test procedure, adherence to recovery breaks, along with well-trained administrators minimized potential biases that could result from differences in participant characteristics or environmental factors.

Our study has certain limitations. Ideally, we would have compared 6MRT results to directly measured VO_{2max} during the run or from a treadmill spiroergometry. However, this was not a realistic feasible option. Instead, we chose the SRT as the best validated instrument for indirect measurement of CRF for comparison. Volunteers in our study were more likely sports enthusiasts and amateur athletes than in a random sample of healthy adults, potentially biasing normative values. The largest possible sample is expected to provide greater validity and a normal distribution of test results. While we originally aimed for 500 participants, the coronavirus pandemic forced a testing paused, resulting in 250 participants, still sufficient for norm establishment and validity testing. Age group boundaries were set post-testing to ensure adequate representation in each age cluster. The sample was diverse in age and sex, but recruitment was limited to a local healthy population as in most comparable studies on the 6MWT. The extent to which the reference equations can be applied to other populations is therefore not yet foreseeable. Also reference equations for the 6MWT vary widely by location, population and health status [16]. The pandemic also prevented the possibility of re-testing. Reliability testing is recommended for future studies.

Preventing and reducing cardiovascular diseases through a healthy lifestyle is increasingly important in healthcare systems and societies. The value of validated and standardized, easy-to-perform field tests in amateur sports is steadily increasing. Comparing performance against corresponding age groups can provide information about individual fitness and motivation for training. The use of the 6MRT, like the Cooper test or the SRT, can assess training capacity in sports. For this reason, an app for smartphones has been developed to record distance covered in six minutes. Results can then be classified and evaluated using anthropometric data and then be shared with physicians or coaches. Further, with additional training and test repetitions, a change in fitness over time may be observed. Fitness tracking is useful in the digital age, where smartphones are prevalent and self-optimization plays a big role in motivation. Smartphone programs for the 6MWT have shown validity when used in the park or in domestic environment, making self-administration using an application a valid option [33, 34].

Conclusions

This study shows that the 6MRT total distance is strongly related to the TSC obtained from the SRT. Individuals achieving greater distance in six minutes also reached a higher TSC. The 6MRT can therefore be considered a valid test for the assessment of cardiorespiratory fitness in adults. This field test is a simple and inexpensive alternative to directly measuring VO_{2max}. The calculation of reference values can lead to a broader adaptation of the 6MRT and allow the classification of individual's current fitness level within their corresponding age cohorts. Reference equations can be used to calculate the expected distance.

Fundings

Sportärztebund Nordrhein e.V.

Acknowledgements

We would like thank Ms Frank for the statistical advice and all participants for their attendance in this study.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] Castro-Piñero J, Marin-Jimenez N, Fernandez-Santos JR et al. Criterion-related validity of field-based fitness tests in adults: A systematic review. J Clin Med 2021; 10: 3743

[2] Ezzatvar Y, Izquierdo M, Núñez J et al. Cardiorespiratory fitness measured with cardiopulmonary exercise testing and mortality in patients with cardiovascular disease: A systematic review and meta-analysis. J Sport Health Sci 2021; 10: 609–619

[3] Strasser B, Burtscher M. Survival of the fittest: VO(2)max, a key predictor of longevity? Front Biosci (Landmark Ed) 2018; 23: 1505–1516

[4] von Haaren B, Härtel S, Seidel I et al. Die Validität des 6-Minuten-Laufs und 20m Shuttle Runs bei 9- bis 11-jährigen Kindern. Deutsche Zeitschrift für Sportmedizin 2011; 62: 351–355

[5] Batista MB, Romanzini CLP, Castro-Piñero J et al. Validity of field tests to estimate cardiorespiratory fitness in children and adolescents: A systematic review. Rev Paul Pediatr 2017; 35: 222–233

[6] Bös K. Handbuch motorische Tests: sportmotorische Tests, motorische Funktionstests, Fragebögen zur körperlich-sportlichen Aktivität und sportpsychologische Diagnoseverfahren. Goettingen: Hogrefe Verlag: 2017

[7] Adam C. Eurofit: handbook for the Eurofit tests of physical fitness. Rome: Italian National Olympic Committee. Central Direction for Sport's Technical Activities Documentation and Information Division: 1988

[8] Mayorga-Vega D, Aguilar-Soto P, Viciana J. Criterion-related validity of the 20-m shuttle run test for estimating cardiorespiratory fitness: A meta-analysis. J Sports Sci Med 2015; 14: 536–547

[9] Oliveira MJ, Marçôa R, Moutinho J et al. Reference equations for the 6-minute walk distance in healthy Portuguese subjects 18–70 years old. Pulmonology 2019; 25: 83–89

[10] Bohannon RW, Bubela D, Magasi S et al. Comparison of walking performance over the first 2 minutes and the full 6 minutes of the. BMC Res Notes 2014; 7: 269

[11] Puente-Maestu L, Stringer W, Casaburi R. Exercise testing to evaluate therapeutic interventions in chronic respiratory diseases. Barc Respir Netw 2018; 4: 274–286

[12] Bandyopadhyay A. Validity of 20 meter multi-stage shuttle run test for estimation of maximum oxygen uptake in male university students. Indian J Physiol Pharmacol 2011; 55: 221–226

[13] Bandyopadhyay A. Validity of 20 meter multi-stage shuttle run test for estimation of maximum oxygen uptake in female university students. Indian J Physiol Pharmacol 2013; 57: 77–83

[14] Kim J, Jung SH, Cho HC. Validity and reliability of shuttle-run test in Korean adults. Int J Sports Med 2011; 32: 580–585

[15] Paradisis GP, Zacharogiannis E, Mandila D et al. Multi-stage 20-m shuttle run fitness test, maximal oxygen uptake and velocity at maximal oxygen uptake. J Hum Kinet 2014; 41: 81–87

[16] Zou H, Zhu X, Zhang J et al. Reference equations for the six-minute walk distance in the healthy Chinese population aged 18–59 years. PLoS One 2017; 12: e0184669

[17] Hunziker C. Überprüfung der Gütekriterien einer Testbatterie zur Messung von koordinativen Fähigkeiten bei 5-bis 10-Jährigen. University of Freiburg: 2014

[18] Oberger J. Sportmotorische Tests im Kindes- und Jugendalter: Normwertbildung - Auswertungsstrategien – Interpretations-möglichkeiten; Überprüfung anhand der Daten des Motorik-Moduls (MoMo). Karlsruhe: KIT Scientific Publishing; 2015

[19] De Marées H. Sportphysiologie. Köln: Sport und Buch Strauß: 2002

[20] World Health Organization. Obesity: preventing and managing the global epidemic. Report of a WHO consultation. World Health Organ Tech Rep Ser 2000; 894: i-xii 1–253

[21] Ma WY, Yang CY, Shih SR et al. Measurement of waist circumference: midabdominal or iliac crest? Diabetes Care 2013; 36: 1660–1666

[22] Yoo EG. Waist-to-height ratio as a screening tool for obesity and cardiometabolic risk. Korean J Pediatr 2016; 59: 425–431

[23] Jouck S. Dordel-Koch-Test (DKT) Ein Test zur Erfassung der motorischen Leistungsfähigkeit im Kindes-und Jugendalter. Cologne: Deutsche Sporthochschule Köln; 2009

[24] American Thoracic Society. ATS statement: guidelines for the six-minute walk test. Am J Respir Crit Care Med 2002; 166: 111–117

[25] Léger LA, Lambert J. A maximal multistage 20-m shuttle run test to predict VO2 max. Eur J Appl Physiol Occup Physiol 1982; 49: 1–12

[26] Léger LA, Mercier D, Gadoury C et al. The multistage 20 metre shuttle run test for aerobic fitness. J Sports Sci 1988; 6: 93–101

[27] Graf C, Schlepper S, Bauer C et al. Feasibility and acceptance of exercise recommendations (10,000 steps a day) within routine German health check (Check-Up 35/GOÄ29)—study protocol. Pilot and Feasibility Stud 2016; 2: 52

[28] Bull FC, Al-Ansari SS, Biddle S et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med 2020; 54: 1451–1462

[29] Biró G, Hulshof KF, Ovesen L et al. Selection of methodology to assess food intake. Eur J Clin Nutr 2002; 56: S25–S32

[30] Frisch A, Toeller M, Müller-Wieland D. Ernährungserhebungsmethoden in der Ernährungsepidemiologie. Diabetologie und Stoffwechsel 2010; 5: 301–308

[31] Mongin D, Chabert C, Uribe Caparros A et al. The complex relationship between effort and heart rate: a hint from dynamic analysis. Physiol Meas 2020; 41: 105003

[32] Mayorga-Vega D, Bocanegra-Parrilla R, Ornelas M et al. Criterion-related validity of the distance- and time-based walk/run field tests for estimating cardiorespiratory fitness: A systematic review and meta-analysis. PLoS One 2016; 11: e0151671

[33] Scherrenberg M, Bonneux C, Yousif Mahmood D et al. A mobile application to perform the six-minute walk test (6MWT) at home: A random walk in the park is as accurate as a standardized 6MWT. Sensors (Basel) 2022; 22: 4277

[34] Stienen MN, Gautschi OP, Staartjes VE et al. Reliability of the 6-minute walking test smartphone application. J Neurosurg Spine 2019; 13:1–8

