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ORIGINAL ARTICLE

Updated Reference Standards for Cardiorespiratory Fitness Measured with Cardiopulmonary Exercise Testing: Data from the Fitness Registry and the Importance of Exercise National Database (FRIEND)

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Abstract

Objective: To provide updated reference standards for cardiorespiratory fitness (CRF) for the United States derived from cardiopulmonary exercise (CPX) testing when using a treadmill or cycle ergometer.

Patients and Methods: Thirty-four laboratories in the United States contributed data to the Fitness Registry and the Importance of Exercise National Database. Analysis included 22,379 tests (16,278 treadmill and 6101 cycle ergometer) conducted between January 1, 1968, through March 31, 2021, from apparently healthy adults (aged 20 to 89 years). Percentiles of peak oxygen consumption for men and women were determined for each decade from 20 through 89 years of age for treadmill and cycle exercise modes, as well as when defining maximal effort as respiratory exchange ratio (RER) greater than or equal to 1.0 or RER greater than or equal to 1.1.

Results: For both men and women, the 50th percentile scores for each exercise mode decreased with age and were higher in men across all age groups and higher for treadmill compared with cycle CPX. The average rate of decline per decade over a 6-decade period was 13.5%, 4.0 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ for treadmill CPX and 16.4%, 4.3 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ for cycle CPX. Observationally, the mean peak oxygen consumption was similar whether using an RER criterion of greater than or equal to 1.0 or greater than or equal to 1.1 across the different test modes, ages, and for both sexes. The updated reference standards for treadmill CPX were 1.5 − 4.6 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ lower compared with the previous 2015 standards whereas the updated cycling standards were generally comparable to the original 2017 standards.

Conclusion: These updated cardiorespiratory fitness reference standards improve the representativeness of the US population compared with the original standards.

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Since the seminal report by Blair et al[1] in 1989, evidence has clearly established that cardiorespiratory fitness (CRF) is a powerful predictor of outcomes across the spectrum of health and disease.[2-4] Indeed, a number of reports have suggested that CRF is a powerful predictor of risk for numerous health outcomes.[5-8] In particular, CRF appears to be a more powerful predictor of cardiovascular disease risk than other traditional risk factors.[9] Because of the wealth of evidence demonstrating the importance of CRF, in 2016 the American Heart Association (AHA) published a Scientific Statement suggesting that CRF be considered a clinical vital sign.[6]

Cardiorespiratory fitness can be directly measured as peak oxygen uptake (VO_{2peak})

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from cardiopulmonary exercise (CPX) testing, estimated as the exercise or functional capacity (peak work rate) from an exercise test, or predicted from nonexercise descriptive characteristics.[6,10,11] However, unlike other cardiovascular disease (CVD) risk factors that have standardized reference values, the interpretation of CRF was typically defined specific to the research cohort for each study, making it difficult to generalize interpretations to populations that were different from those studied in the research cohorts. Additionally, many studies investigating CRF as a key outcome measure have used estimates of CRF, with a range of different methods for deriving the estimate. As there is known error when estimating CRF, and the error varies depending on the method, this provided further challenges to interpreting CRF values.[12-14]

In response to an AHA Scientific Statement, an initiative was undertaken to develop reference standards for the United States for directly measured CRF determined from CPX.[15] The initial reference standards for CRF were developed by the Fitness Registry and the Importance of Exercise National Database (FRIEND) for treadmill tests in 2015[16] and for cycle tests in 2017.[17] Data from the FRIEND database have also been useful for developing reference standards for other variables, including peak exercise minute ventilation,[18] ventilatory threshold,[19] ventilatory efficiency (ie, minute ventilation/carbon dioxide production slope),[20] peak exercise oxygen pulse,[21] maximal heart rate,[22] and peak exercise blood pressure[23] as well as several age- and gender-related standards for VO_{2peak}. Additionally, data from the FRIEND database have been useful for developing equations to estimate VO_{2peak} in both healthy and diseased populations.[24-28]

The FRIEND registry has continued to acquire data from more laboratories and clinics as well as from more locations within the United States, which has led to larger sample sizes across the age spectrum for both men and women. Thus, the purpose of this report was to provide updated CRF reference values derived from CPX testing in the United States for apparently healthy men and women performing treadmill or cycle tests. These updated standards have been expanded to include reference values for men and women from 80 to 89 years of age. Additionally, the original reference standards were developed using a respiratory exchange ratio (RER) value of greater than or equal to 1.0 for maximal effort for treadmill tests and an RER value of greater than or equal to 1.1 for cycle tests. This updated report provides reference standards for both treadmill and cycle tests using an RER value of greater than or equal to 1.0 and provides a comparative analysis when using an RER of greater than or equal to 1.1 for maximal effort.

PATIENTS AND METHODS

The procedures detailing data acquisition and management of the FRIEND registry have been previously reported.[16] Briefly, the FRIEND registry is composed of data from high-quality laboratories performing CPX testing administered by experienced personnel. Although laboratories varied in terms of equipment, protocols, and definitions of CRF (eg, VO_{2peak} determined from time averages between 15 and 60 seconds), all laboratories conducted testing in accordance with published guidelines.[10] Each contributing laboratory obtained local research ethics board approval before submitting deidentified, coded data to the data coordinating center at Ball State University, which has institutional review board approval for maintaining the database as a core laboratory. Data from each contributing laboratory were reviewed to ensure CRF values were within expected normal ranges before being added to the FRIEND database.

Cohort

The present analysis includes 22,379 tests (16,278 treadmill and 6101 cycle ergometer) from 34 participating laboratories in the United States (see Acknowledgments) that were performed from January 1, 1968, through March 31, 2021. Geographical representation included one or more tests from all 50 states apart from Alaska,

TABLE 1. Descriptive Characteristics of the FRIEND Cohort for the Treadmill and Cycling Ergometer Analysis Using an Inclusion Criterion of RER ≥ 1.0[a]

	Age Group (years)							
	20-29	30-39	40-49	50-59	60-69	70-79	80-89	All
Treadmill								
Men	n=1278	n=1473	n=2119	n=2082	n=1663	n=776	n=173	n=9564
Age (years)	23.6±3.0	35.0±2.9	44.8±2.9	54.6±2.9	64.5±2.9	73.9±2.6	82.9±2.3	49.0±15.7
Height (cm)	179.6±7.4	178.9±6.9	178.8±6.8	177.9±7.1	176.9±7.0	175.8±6.8	174.9±6.9	178.1±7.1
Weight (kg)	83.2±16.6	88.1±18.5	88.7±17.1	90.9±17.7	89.7±16.1	87.7±15.0	84.4±13.0	88.4±17.2
BMI (kg m^{-2})	25.7±4.6	27.5±5.4	27.7±4.9	28.7±5.2	28.6±4.7	28.4±4.4	27.6±4.0	27.8±5.0
Women	n=1142	n=1043	n=1372	n=1457	n=1045	n=549	n=106	n=6714
Age (years)	23.8± 3.0	34.8±2.8	44.7±2.9	54.5±2.9	64.3±2.9	74.0±2.7	83.2±2.3	47.8±16.2
Height (cm)	165.7±6.9	165.4±6.5	164.7±6.5	164.1±6.4	162.7±6.3	161.7±6.0	158.0±5.2	164.2±6.6
Weight (kg)	66.6±14.9	72.3±18.7	75.2±19.1	76.1±18.1	76.7±18.4	73.6±15.0	63.9±12.2	73.4±18.0
BMI (kg m^{-2})	24.2±5.1	26.4±6.6	27.7±6.8	28.2±6.4	28.8±6.3	28.1±5.4	25.6±4.9	27.2±6.4
Cycle Ergometer								
Men	n=367	n=251	n=446	n=601	n = 465	n=257	n=52	n=2439
Age (years)	23.1±2.7	35.3±3.0	45.1±2.8	54.2±3.0	64.5±2.7	74.4±2.8	82.4±2.5	50.6±16.5
Height (cm)	179.5±7.2	178.7±7.2	177.9±7.4	178.5±7.2	177.1±7.4	175.8±6.7	174.8±7.4	177.9±7.3
Weight (kg)	80.8±15.6	92.6±20.3	94.4±18.2	94.0±16.9	91.1±16.1	88.8±16.5	88.7±16.3	90.7±17.7
BMI (kg m^{-2})	25.1±4.4	28.9±5.7	29.8±5.3	29.5±5.0	29.0±4.7	28.7±4.9	29.0±4.6	28.6±5.2
Women	n=411	n=377	n=674	n=1115	n=750	n=308	n=27	n=3662
Age (years)	23.3±2.9	35.0±2.8	45.1±2.9	54.8±2.8	64.0±2.8	73.5±2.7	83.3±2.6	51.1±14.7
Height (cm)	166.0±6.6	164.7±6.9	163.9±6.8	162.0±6.7	161.6 ± 6.4	160.9±6.5	161.2±6.4	162.9±6.9
Weight (kg)	68.8±17.3	78.7±19.3	81.5±18.1	81.4±15.8	78.3±14.7	74.1±14.2	70.5±11.3	78.4±16.9
BMI (kg m^{-2})	24.9±5.9	29.1±7.3	30.3±6.5	31.0±5.9	30.0±5.5	28.7±5.6	27.1±3.9	29.6±6.3

[a]BMI, body mass index; FRIEND, Friend Registry and the Importance of Exercise: A National Database; RER, respiratory exchange ratio.

Nebraska, and Wyoming. Inclusion criteria used to create the present cohort were: (1) no known pre-existing diagnosis of CVD (coronary artery disease, myocardial infarction, heart failure, peripheral arterial disease, or stroke); (2) no known pre-existing diagnosis of chronic obstructive pulmonary disease; (3) maximal CPX testing performed on a treadmill or cycle ergometer; (4) men and women aged 20 to 89 years; and (5) peak RER of greater than or equal to 1.0 to indicate a maximal effort.

Statistical Analysis

Analyses were performed in Python version 3.8.5. Reference standards for CRF in men and women were created for treadmill and cycle ergometer CPX testing separately. Additionally, box plots were created to compare changes in CRF across age deciles. Means and percentiles for CRF were first created using the inclusion criterion of RER greater than or equal to 1.0 and then repeated with an inclusion criterion of RER greater than or equal to 1.1. Continuous data are reported as mean ± standard deviation, whereas categorical data are reported as frequencies (percentages).

RESULTS

The FRIEND cohort included 12,003 tests in men (9564 from treadmill and 2439 from cycle ergometer) and 10,376 tests in women (6714 from treadmill and 3662 from cycle ergometer). Descriptive characteristics of the cohort, by test mode, sex, and in 10-year age groups, are provided in Table 1. Peak responses during treadmill and cycle ergometer CPX testing, including RER for objective indications of sufficient effort, are provided in Table 2. Overall, men had a CRF that was 26%, 6.6 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ higher than women for treadmill CPX and a CRF that was 37.9%, 7.6 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ higher

than women for cycle ergometer CPX. The treadmill-determined CRF was an average of 22%, 4.5 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ higher than the CRF determined from a cycle ergometer CPX.

The change in CRF with each decade of age in men and women for treadmill and cycle ergometer CPX is shown in the Figure. Further, percentiles by age group for CRF using an inclusion criterion of RER greater than or equal to 1.0 are presented for treadmill and cycle ergometer CPX testing in Table 3. For both men and women, the 50th percentile scores decreased with age and were higher in men across all age groups.

The mean CRF across age groups when using an inclusion criterion of RER greater than or equal to 1.0 compared to a criterion of RER greater than or equal to 1.1 are presented in Table 4. Observationally, the means were similar between the two RER criteria with differences of less than or equal to 1.0 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ across the different test modes, ages, and for both sexes. The percentiles by age group for CRF when using an inclusion criterion of RER greater than or equal to 1.1 are presented in Supplemental Table 1 (available online at http://www.mayoclinicproceedings.org) for treadmill and cycle ergometer CPX.

DISCUSSION

This report provides updated reference standards for CRF for the apparently healthy US population. Since the original reference standards were published 4 to 6 years ago,[16,17] the FRIEND registry now has more than 22,000 CPX testing assessments in apparently healthy individuals across the United States. The representative sample for each age group has increased and the updated standards now include values for individuals from 80 to 89 years old. Additionally, this report provides standards with maximal CPX test criteria of both RER greater than or equal to 1.0 and RER greater than or equal to 1.1, which indicates that peak VO_{2peak} values are similar between the two effort criteria.

In the updated CRF reference standards for treadmill tests with an effort criterion of RER greater than or equal to 1.0, the values for men are notably lower across all age groups versus the effort criterion of greater than or equal to 1.1. The mean and 50th percentile values for each decade ranged from 2.4 to 4.6 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ and 1.5-3.8 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ lower, respectively. For women, the updated values were also lower; however, the differences across all age groups were much smaller with mean and 50th percentile declines ranging from 0.4-1.4 and 0.4-1.9 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$, respectively. These lower values are unlikely to be due to decreases in CRF over the years. Rather, the updated values may more accurately represent the CRF of individuals across the United States as more data have been collected.

The updated CRF reference standards for cycle tests with an effort criterion of RER greater than or equal to 1.1, which was used in the original publication, were generally similar to the values in the original standards with most mean and 50th percentile values being within 1.2 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$. One exception is for the 20- to 29-year-old age group for men, as the mean for the updated standards and the 50th percentile values are 3.1 and 2.1 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ higher, respectively. This is likely attributable to a contribution from one site, which included a group of professional and elite cyclists.

The original reference standards used effort criteria of RER greater than or equal to 1.0 for treadmill tests and RER greater than or equal to 1.1 for cycle tests.[16,17] The present update provides reference standards for both RER greater than or equal to 1.0 and RER greater than or equal to 1.1 for both treadmill and cycle CPX testing. The mean VO_{2peak} between the two effort criteria were similar. For treadmill tests, the greatest difference between the mean and 50th percentile values was 1.1 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$, with all values for age groups 40 years and older within 0.5 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$. Likewise, for cycle tests, there was little difference between the mean and 50th percentile values with all values less than 1.0 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$. Because of differences between labs for data averaging and testing protocols, it would be inappropriate to

TABLE 2. CPX Responses at Peak Effort for the Treadmill and Cycling Ergometer Analysis Using an Inclusion Criterion of RER ≥ 1.0[a]

	Age group, years							
	20–29	30–39	40–49	50–59	60–69	70–79	80–89	All
Treadmill								
Men	n=1278	n=1473	n=2119	n=2082	n=1663	n=776	n=173	n=9564
VO_{2peak}, $mLO_2 \cdot kg^{-1} \cdot min^{-1}$	45.2±11.8	40.0±11.8	35.8±10.8	30.2±9.7	25.4±8.3	21.2±6.5	17.9±3.9	33.2±12.6
Peak HR, $beat \cdot min^{-1}$	185.8±17.7	178.9±18.2	169.3±20.7	158.1±22.3	144.2±24.7	132.4±25.2	130.9±21.5	162.1±27.2
Peak RER	1.19±0.11	1.19±0.10	1.18±0.10	1.18±0.10	1.17±0.10	1.15±0.09	1.13±0.08	1.18±0.10
Women	n=1142	n=1043	n=1372	n=1457	n=1045	n=549	n=106	n=6714
VO_{2peak}, $mLO_2 \cdot kg^{-1} \cdot min^{-1}$	36.3±10.2	29.5±9.0	26.6±8.1	23.8±6.6	20.0±5.5	17.5±4.2	15.9±4.8	26.2±9.7
Peak HR, $beat \cdot min^{-1}$	183.2±18.9	174.6±20.6	168.0±20.0	159.9±20.9	146.8±23.4	135.3±24.2	123.9±26.6	162.9±25.9
Peak RER	1.16±0.10	1.18±0.10	1.17±0.10	1.17±0.10	1.14±0.09	1.13±0.09	1.12±0.08	1.16±0.10
Cycle ergometer								
Men	n=367	n=251	n=446	n=601	n=465	n=257	n=52	n=2439
VO_{2peak}, $mLO_2 \cdot kg^{-1} \cdot min^{-1}$	45.1±13.3	32.4±12.8	28.9±9.0	26.2±8.8	22.7±7.3	18.9±6.4	13.8±5.1	28.5±12.5
VO_{2peak}, $LO_2 \cdot min^{-1}$	3.61±1.00	2.92±0.86	2.65±0.67	2.42±0.67	2.04±0.58	1.63±0.46	1.19±0.38	2.51±0.93
Peak workload, W	285±70	236±73	220±64	197±64	162±54	129±42	86±34	197±77
Peak HR, $beat \cdot min^{-1}$	180.9±16.7	165.5±18.8	158.6±18.2	149.3±20.2	139.4±19.8	127.8±22.4	108.4±25.9	151.9±25.7
Peak RER	1.20±0.10	1.17±0.08	1.16±0.08	1.16±0.08	1.16±0.07	1.16±0.09	1.13±0.11	1.17±0.09
Women	n=411	n=377	n=674	n=1115	n=750	n=308	n=27	n=3662
VO_{2peak}, $mLO_2 \cdot kg^{-1} \cdot min^{-1}$	32.0±10.6	23.0±8.5	20.0±6.0	17.6±4.5	16.1±3.6	14.4±3.0	11.7±4.2	19.6±7.8
VO_{2peak}, $LO_2 \cdot min^{-1}$	2.11±0.62	1.74±0.48	1.57±0.38	1.40±0.30	1.23±0.24	1.05±0.23	0.82±0.27	1.48±0.47
Peak workload, W	168±50	135±37	121±33	105±27	91±21	76±20	57±21	110±39
Peak HR, $beat \cdot min^{-1}$	178.0±16.5	166.5±16.7	157.5±17.5	150.3±17.8	141.6±17.3	129.7±17.4	102.9±26.0	152.2±22.0
Peak RER	1.18±0.10	1.16±0.09	1.15±0.08	1.15±0.07	1.15±0.08	1.15±0.07	1.11±0.09	1.15±0.08

[a]CPX, cardiopulmonary exercise test; HR, heart rate; RER, respiratory exchange ratio; VO_{2peak}, peak oxygen uptake.

suggest whether one RER criterion should be used over the other. Nonetheless, the present study provides reference standards that can be used by laboratories or clinics with different test criteria.

Since the release of the AHA Scientific Statement suggesting that CRF be considered a clinical vital sign,[6] the importance of CRF assessment has grown both within the United States and globally.[29-35] With the increase in

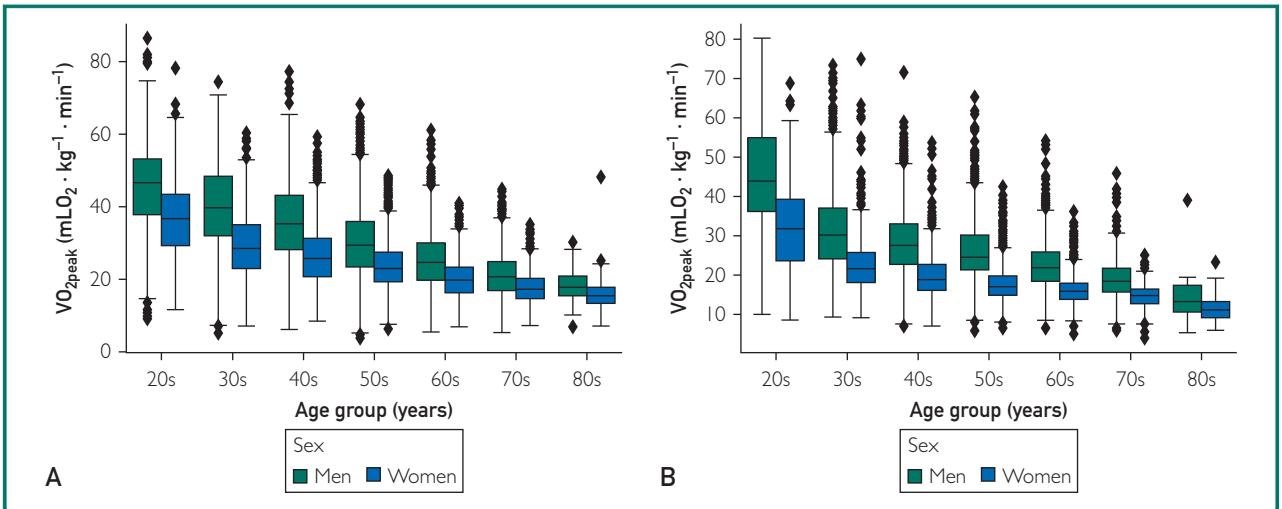

FIGURE. Box plots showing the median, interquartile range, and outliers for measured peak oxygen uptake (VO_{2peak}) from (A) treadmill CPX and (B) cycle ergometer CPX testing. Men are presented in green and women are presented in blue.

TABLE 3. CRF Percentiles for the FRIEND Cohort by Age Group for Treadmill and Cycle Ergometer CPX With Directly Measured VO_{2peak} ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$) Using an Inclusion Criterion of RER $\geq$ 1.0[a]

	Age group, years													
	Men							Women						
Percentile	20–29	30–39	40–49	50–59	60–69	70–79	80–89	20–29	30–39	40–49	50–59	60–69	70–79	80–89
Treadmill														
90	58.6	55.5	50.8	43.4	37.1	29.4	22.8	49.0	42.1	37.8	32.4	27.3	22.8	20.8
80	54.5	50.0	45.2	38.3	32.0	25.9	21.4	44.8	37.0	33.0	28.4	24.3	20.8	18.4
70	51.9	46.4	40.9	34.3	28.7	23.8	20.0	41.8	33.6	30.0	26.3	22.4	19.6	17.3
60	49.0	43.4	37.9	31.8	26.5	22.2	18.4	39.0	31.0	27.7	24.6	20.9	18.3	16.0
50	46.5	39.7	35.3	29.2	24.6	20.6	17.6	36.6	28.3	25.7	22.9	19.6	17.2	15.4
40	43.6	37.0	32.4	26.9	22.8	19.1	16.6	34.0	26.4	23.9	21.5	18.3	16.2	14.7
30	40.0	33.5	29.7	24.5	20.7	17.3	16.1	30.8	24.2	21.8	20.1	17.0	15.2	13.7
20	35.2	29.8	26.7	22.2	18.5	15.9	14.8	27.2	21.9	19.7	18.5	15.4	14.0	12.6
10	28.6	24.9	22.1	18.6	15.8	13.6	12.9	22.5	18.6	17.2	16.5	13.4	12.3	11.4
Cycle ergometer														
90	62.2	50.5	41.9	37.1	31.4	26.2	18.7	46.0	32.0	27.3	22.4	20.3	18.0	18.1
80	57.0	39.0	35.1	31.6	27.0	22.6	17.3	40.9	27.0	23.5	20.4	18.5	16.8	14.3
70	52.8	35.5	31.4	28.4	24.5	20.6	16.2	37.5	24.5	21.8	18.9	17.4	15.9	12.9
60	48.3	31.6	29.0	26.3	23.3	19.4	14.6	34.3	22.9	20.3	17.8	16.4	15.0	11.3
50	44.0	30.2	27.4	24.5	21.7	18.3	13.2	31.6	21.6	18.8	16.9	15.7	14.5	10.9
40	40.8	27.9	25.4	23.1	20.7	17.1	12.2	28.9	19.9	17.9	16.1	15.0	13.6	10.1
30	37.4	25.7	23.8	22.0	19.1	16.0	11.1	25.6	18.6	16.6	15.2	14.2	12.9	9.4
20	34.5	22.6	21.9	20.2	17.5	14.7	9.7	21.9	17.0	15.4	14.3	13.4	12.0	8.7
10	28.8	19.1	19.8	17.2	14.7	11.0	8.4	18.8	15.0	13.7	13.0	12.2	10.7	7.8

[a]CRF, cardiorespiratory fitness; CPX, cardiopulmonary exercise test; FRIEND, Fitness Registry and the Importance of Exercise: A National Database; RER, respiratory exchange ratio; VO_{2peak}, peak oxygen uptake.

interest globally, a report from the FRIEND database began the process of establishing the first global CRF reference standards for treadmill tests.[36] Differences in CRF were found between countries. Thus, the current report with updated CRF reference standards should be cautiously applied to individuals from locations outside of the United States and there is a need to continue developing global CRF reference standards.

The strengths of this study include the additional 10,102 tests used in establishing reference standards for directly measured VO_{2peak} for the US population (109.1% (8495) more treadmill tests, 36% (1607) more cycle tests). The sample size for both men and women for all age groups was increased from the original standards, the age distribution was expanded to include individuals 80 to 89 years old, and data were acquired from more laboratories and clinics representing more locations in the United States.

Common to studies using retrospective data, there are some limitations that should be considered. As participants with previously diagnosed CVD and chronic obstructive pulmonary disease were excluded from this dataset, these standards would not apply to individuals with those diseases. Additionally, the term "apparently healthy" may not be appropriate for the entire study population as some had diseases (eg, diabetes and obesity), musculoskeletal concerns (eg, back pain and osteoarthritis), and CVD risk factors. However, objective maximal effort criterion (ie, RER) were used for data inclusion. Although all tests were performed for functional capacity measurement, the individual referral for the tests varied (clinical

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TABLE 4. Mean (± Standard Deviation) Reference Values for CRF With Measured VO_{2peak} ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$) From CPX Tests Using an Inclusion Criterion of Either RER ≥ 1.0 or RER ≥ 1.1[a]

	Age group, years						
	20–29	30–39	40–49	50–59	60–69	70–79	80–89
Treadmill							
Men							
RER ≥ 1.0	n=1278	n=1473	n=2119	n=2082	n=1663	n=776	n=173
	45.2±11.8	40.0±11.8	35.8±10.8	30.2±9.7	25.4±8.3	21.2±6.5	17.9±3.9
RER ≥ 1.1	n=1033	n=1215	n=1707	n=1670	n=1296	n=552	n=108
	44.7±11.5	39.0±11.4	35.4±10.0	30.3±9.2	25.3±7.9	21.4±6.7	18.2±4.1
Women							
RER ≥ 1.0	n=1142	n=1043	n=1372	n=1457	n=1045	n=549	n=106
	36.3±10.2	29.5±9.0	26.6±8.1	23.8±6.6	20.0±5.5	17.5±4.2	15.9±4.8
RER ≥ 1.1	n=813	n=818	n=1029	n=1089	n=712	n=343	n=59
	35.3±9.7	29.3±8.6	26.7±7.8	23.8±6.4	20.0±5.5	17.5±4.1	15.6±5.3
Cycle ergometer							
Men							
RER ≥ 1.0	n=367	n=251	n=446	n=601	n=465	n=257	n=52
	45.1±13.3	32.4±12.8	28.9±9.0	26.2±8.8	22.7±7.3	18.9±6.4	13.8±5.1
RER ≥ 1.1	n=319	n=221	n=412	n=543	n=414	n=213	n=30
	44.2±12.4	31.6±11.1	28.7±8.3	26.3±8.0	22.7±7.0	19.6±6.4	14.4±6.0
Women							
RER ≥ 1.0	n=411	n=377	n=674	n=1115	n=750	n=308	n=27
	32.0±10.6	23.0±8.5	20.0±6.0	17.6±4.5	16.1±3.6	14.4±3.0	11.7±4.2
RER ≥ 1.1	n=342	n=317	n=575	n=894	n=624	n=257	n=15
	32.0±10.1	22.8±7.7	20.0±5.8	17.9±4.2	16.3±3.5	14.6±2.8	11.0±3.1

[a]CRF, cardiorespiratory fitness; CPX, cardiopulmonary exercise test; RER, respiratory exchange ratio; VO_{2peak}, peak oxygen uptake.

assessment as part of a comprehensive physical exam, fitness assessment, and participants in research studies) and the choice of treadmill protocols, measurement equipment, and data collection procedures — although consistent with published recommendations — was specific to each contributing laboratory.[21,22] Finally, although the current report added values for individuals 80 to 89 years old, the sample size for this oldest age group was relatively small (1.6% (358 out of 22379).

CONCLUSION

As the FRIEND database has continued to grow, it allowed the opportunity to update the CRF reference values derived from CPX in the United States. This updated report includes larger samples for each group for both men and women. Coupled with data from 34 participating laboratories across the United States, these updated CRF reference standards should make these more representative for the US population.

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SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at http://www.mayoclinicproceedings.org. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: **AHA**, American Heart Association; **CRF**, cardiorespiratory fitness; **CPX**, cardiopulmonary exercise testing; **CVD**, cardiovascular disease; **FRIEND**, Fitness Registry and the Importance of Exercise: A National Database; **MET**, metabolic equivalent; **RER**, respiratory exchange ratio; **VO_{2peak}**, peak oxygen uptake

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