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# Cross-validation of a non-exercise measure for cardiorespiratory fitness in Singaporean adults

*Robert Alan Sloan*[1], PhD, *Benjamin Adam Haaland*[2,3], PhD, *Carol Leung*[1], PhD, *Uma Padmanabhan*[1], PhD, *Han Chow Koh*[4,5], *Alicia Zee*[4]

**INTRODUCTION** Cardiorespiratory fitness (CRF) is an independent predictor of voluminous health outcomes and can be measured using non-exercise fitness assessment (NEFA) equations. However, the accuracy of such equations in Asian populations is unknown. The objective of this study was to cross-validate the NEFA equation, developed by Jurca et al in 2005, in the adult Singaporean population.
**METHODS** A total of 100 participants (57 men, 43 women; aged 18–65 years) were recruited, and their maximal oxygen consumption ($VO_2$ max) was measured in the laboratory by indirect calorimetry. The participants also completed the NEFA questionnaire, which helps to predict $VO_2$ max with the NEFA equation. The relationship between NEFA-predicted and laboratory-measured $VO_2$ max values was analysed.
**RESULTS** Overall, our study demonstrated a high correlation between the NEFA-predicted and laboratory-measured $VO_2$ max values (r = 0.83). The Pearson's correlation coefficient values for the men and women in the study were 0.61 and 0.77, respectively. To improve the accuracy of the predictive equation, we transformed the original equation developed by Jurca et al into new equations that would allow estimation of $VO_2$ max with and without resting heart rate as a variable.
**CONCLUSION** The modified NEFA equations accurately estimated CRF and may be applied to the majority of adult Singaporeans. With this, health practitioners and researchers are now able to assess CRF levels at both the individual and population levels in either the primary care, fitness or research setting.

*Keywords: Asian population, cardiorespiratory fitness, non-exercise fitness assessment*

## INTRODUCTION

Cardiorespiratory fitness (CRF) is an important component of health-related fitness, which reflects the combination of habitual physical activity, genetics and health status.[1,2] Commonly expressed as maximal oxygen consumption ($VO_2$ max) or maximum metabolic equivalents of task (METs), CRF at the metabolic level quantifies the functional capacity of the body to transport and use oxygen via the respiratory, cardiovascular and skeletal muscle systems. Low CRF level has been identified as an independent predictor for an array of health outcomes, including cardiovascular disease, type 2 diabetes mellitus, cancer, poor mental health, falls and premature death.[2-4]

Although maximal graded exercise testing remains the gold standard for the measurement of CRF, it is often impractical to provide this in allied health, fitness and primary care settings due to a lack of space, equipment, personnel, time and participant cooperation. To overcome these barriers to testing, Jurca et al developed and validated the non-exercise fitness assessment (NEFA) for Caucasian populations in 2005.[5] Derived from a regression equation that used the variables of age, gender, body mass index (BMI), resting heart rate ($HR_{rest}$) and self-reported physical activity level, NEFA is able to estimate CRF level.[5] Although the derived equation was validated against objectively measured $VO_2$ max, the instrument has not been validated in an Asian population, which is physiologically different from a Caucasian population.[6]

The primary objective of the present study was to cross-validate the NEFA equation[5] in an Asian population, specifically Singaporean adults. The secondary objective of the study was to cross-validate a modified NEFA equation without $HR_{rest}$ as a variable, in order to accommodate circumstances where measuring $HR_{rest}$ might not be feasible or accurate.

## METHODS

The participants (n = 100) comprised Singaporean adults recruited from area community centres and tertiary institutions in Singapore. Recruitment was done via electronic and print media advertisements. The required sample size of the study was calculated to give a power of over 80%. Participants underwent medical screening to determine their sutability for inclusion in the study. Written informed consent was obtained from all eligible participants prior to any testing. All performed procedures were approved by the Institutional Review Board of Republic Polytechnic, Singapore.

Apparently healthy[7] men (n = 57) and women (n = 43) aged between 18 and 65 years were recruited for the study. Participants were screened using the American Heart

[1]Physical Activity Centre of Excellence, Health Promotion Board, [2]Centre for Quantitative Medicine, Duke-NUS Graduate Medical School, [3]Department of Statistics and Applied Probability, National University of Singapore, [4]School of Sports, Health and Leisure, Republic Polytechnic, [5]Clinical Nutrition Research Centre, Singapore Institute for Clinical Sciences, Singapore

**Correspondence**: Dr Robert Alan Sloan, Centre Head/Chief Exercise Physiologist, Physical Activity Centre of Excellence, Health Promotion Board, 3 Second Hospital Ave, Singapore 168937. Robert_Alan_Sloan@HPB.gov.sg

Association/American College of Sports Medicine Health (ACSM)/Fitness Facility Preparticipation Screening Questionnaire[8] and excluded based on the ACSM Guidelines for Exercise Testing and Prescription.[9] High-risk individuals with any known signs or symptoms of cardiovascular, pulmonary and metabolic diseases were excluded from the study. Individuals on medications that influence $HR_{rest}$ (e.g. beta-blockers) were also excluded. Additional exclusion criteria included highly active[7] individuals (> 300 mins of moderate-intensity physical activity per week) and those with BMI > 27 kg/m². Participants without any signs or symptoms but with two or more cardiovascular disease risk factors listed in the guidelines, such as hypertension and dyslipidaemia, were classified as moderate-risk and were required to obtain clearance by a doctor before participation in the study.[9] Participants were instructed to adhere to the following before all tests: (a) no strenuous physical activity the day before the test; (b) no alcohol consumption the day before the test; (c) no caffeine intake three hours before the test; (d) no consumption of heavy meals three hours before the test; and (e) adequate fluid comsumption (500 mL of water or isotonic drink) before the test.

To measure $VO_2$ max by indirect calorimetry, test sessions were conducted with the participants walking on a motorised treadmill in a laboratory setting at 25°C. Calibration with premixed gas was done on every test day and an air calibration was done just before each test. Participants who had no experience walking on a treadmill were given about 3–4 mins to walk on it before the test. Participants underwent cardiopulmonary exercise testing (CPX), in which the exercise intensity was progressively increased until the individual terminated the test at his or her own discretion. The Bruce Treadmill Ramp Protocol[10] was used and each participant started the test with a treadmill speed of 2.70 km/hr and a gradient of 0° on a running machine (H/P/Cosmos Pulsar; H/P/Cosmos Sports & Medical Gmbh, Nußdorf- Traunstein, Germany). The treadmill speed and gradient were progressively increased every minute until volitional exhaustion.

Expired air was collected breath by breath, and $VO_2$ max was determined as the average of 30 s at the peak and analysed using Cortex MetaLyzer® 3B (CORTEX Biophysik GmbH, Leipzig, Germany). Heart rate was measured using wearable heart rate monitors (T31 coded™ transmitter and FT1 watch; Polar, NY, USA) while blood pressure was measured using a blood pressure monitor (Omron SEM2; Omron, Kyoto, Japan). Heart rate, blood pressure and Borg's rating of perceived exertion scale score[11] were measured at regular intervals of 3 mins. The $VO_2$ max of participants was determined as the highest value reached, when two of the following three criteria were achieved: (a) a plateau of $VO_2$ value, even with an increase in power output; (b) age-predicted maximal heart rate ($HR_{max}$) is reached (where $HR_{max} = 220 - \text{Age}$)[12]; and (c) respiratory exchange ratio > 1.15. In all, five patients were excluded from the study as they did not reach $VO_2$ max (i.e. fulfil two of the above three criteria).

The BMI of each participant was calculated from their measured height (m) and weight (kg) using the Seca 763 digital medical scale (Seca Ltd, Birmingham, UK). Before CPX, participants were asked to rest quietly for 5 mins before $HR_{rest}$ was measured using the Polar® heart rate monitor with participants in the seated position. In accordance with the procedure outlined by Jurca et al,[5] participants were asked to select one of the five levels of self-reported physical activity that best described their usual activity pattern: (a) level 0 – inactive or little activity other than usual daily activities; (b) level 1 – regular (> 5 days/wk) participation in physical activities requiring low levels of exertion that result in slight increases in breathing and heart rate for at least 10 mins at a time; (c) level 2 – participation in aerobic exercises such as brisk walking, jogging or running, cycling, swimming or vigorous sports at a comfortable pace, or other activities requiring similar levels of exertion for 20–60 mins/wk; (d) level 3 – participation in aerobic exercises such as brisk walking, jogging or running at a comfortable pace, or other activities requiring similar levels of exertion for 1–3 hrs/wk; and (e) level 4 – participation in aerobic exercises such as brisk walking, jogging or running at a comfortable pace, or other activities requiring similar levels of exertion for > 3 hrs/wk. Each physical activity level corresponds to a score calculated by Jurca et al.[5] Together with other variables such as gender, age, $HR_{rest}$ and BMI, the predicted CRF level of each participant was calculated in terms of METs (where 1 MET is equivalent to 3.5 mL of oxygen uptake/ kg/min), utilising the original regression equation proposed by Jurca et al[5]:

$$\text{Caucasian-based NEFA} = (\text{Gender}^{*}\,[2.77] - \text{Age}\,[0.10] - \text{BMI}\,[0.17] - HR_{rest}/\text{min}\,[0.03] + \text{Physical activity score} + 18.07)$$

*Male = 1; female = 0

To achieve better prediction of $VO_2$ max using the NEFA equation, the equation suggested by Jurca et al[5] was modified, and equations with and without $HR_{rest}$ as one of its components were developed. The modified NEFA equation with $HR_{rest}$ as a factor is as follows:

$$\begin{aligned}\text{Male NEFA} &= 9.528 + 2.049\,(\text{Gender}\,[2.77] - \text{Age}\,[0.10] - \text{BMI}\,[0.17] - HR_{rest}/\text{min}\,[0.03] + \text{Physical activity score} + 18.07)\\ &= 52.23 - \text{Age}\,(0.20) - \text{BMI}\,(0.35) - HR_{rest}/\text{min}\,(0.06) + \text{Physical activity score}\,(2.05)\end{aligned}$$

$$\begin{aligned}\text{Female NEFA} &= 10.224 + 2.079\,(\text{Gender}\,[2.77] - \text{Age}\,[0.10] - \text{BMI}\,[0.17] - HR_{rest}/\text{min}\,[0.03] + \text{Physical activity score} + 18.07)\\ &= 47.79 - \text{Age}\,(0.21) - \text{BMI}\,(0.35) - HR_{rest}/\text{min}\,(0.06) + \text{Physical activity score}\,(2.08)\end{aligned}$$

**Table I. Physical characteristics of participants (n = 100).**

| Characteristic | Mean ± SD | |
|---|---|---|
| | Male (n = 57) | Female (n = 43) |
| Age (yrs) | 41.4 ± 11.8 | 43.9 ± 12.5 |
| BMI ($kg/m^2$) | 23.4 ± 2.5 | 23.3 ± 2.6 |
| $HR_{rest}$ (bpm) | 62.0 ± 9.5 | 68.1 ± 11.4 |
| $HR_{max}$ (bpm) | 173.3 ± 16.2 | 173.4 ± 15.9 |
| Laboratory-measured $VO_2$ max (mL/kg/min) | 35.2 ± 5.0 | 26.9 ± 4.6 |

BMI: body mass index; bpm: beats per minute; $HR_{max}$: maximal heart rate; $HR_{rest}$: resting heart rate; SD: standard deviation; $VO_2$ max: maximal oxygen consumption

The modified NEFA equation without $HR_{rest}$ as a factor ($NEFA_1$) is as follows:

$$\text{Male NEFA}_1 = 5.819 + 2.117\ (\text{Gender } [2.77] - \text{Age } [0.10] - \text{BMI } [0.17] + \text{Physical activity score} + 18.07)$$
$$= 49.9 - \text{Age } (0.21) - \text{BMI } (0.36) + \text{Physical activity score } (2.12)$$

$$\text{Female NEFA}_1 = 3.984 + 2.174\ (\text{Gender } [2.77] - \text{Age } [0.10] - \text{BMI } [0.17] + \text{Physical activity score} + 18.07)$$
$$= 43.27 - \text{Age } (0.22) - \text{BMI } (0.37) + \text{Physical activity score } (2.17)$$

We hypothesised that the use of these modified NEFA equations for men and women would result in 95% of the predicted $VO_2$ max values falling within the indicated limits of agreements (LOAs) of their true $VO_2$ max (where LOA = bias + 1.96 × standard deviation).

The relationship between laboratory-measured and NEFA-predicted $VO_2$ max values was analysed using linear regression analysis. Bland-Altman plots were used to examine the mean prediction bias with 95% LOA by calculating the mean difference between the two methods of measurement, i.e. the measured and predicted $VO_2$ max values.

## RESULTS

The physical characteristics of the participants are shown in Table I. Participants were grouped according to age: (a) 18–30 years: 14 men, 8 women; (b) 31–40 years: 11 men, 9 women; (c) 41–50 years: 18 men, 12 women; and (d) 51–65 years: 14 men, 14 women. The scatter plot in Fig. 1 shows the relationship between laboratory-measured $VO_2$ max and the $VO_2$ max predicted using the original Caucasian-based NEFA equations by Jurca et al.[5] The combined Pearson's correlation for both genders was 0.83 ($p < 0.001$), while the gender-specific Pearson's correlation values for men and women were 0.61 ($p < 0.001$) and 0.77 ($p < 0.001$), respectively.

The Bland-Altman plots of the participants in our study (grouped according to gender) shows the agreement between the laboratory-measured $VO_2$ max and the $VO_2$ max predicted by the gender-respective modified NEFA equations (Fig. 2). Table II shows the mean bias and 95% LOA of $VO_2$ max

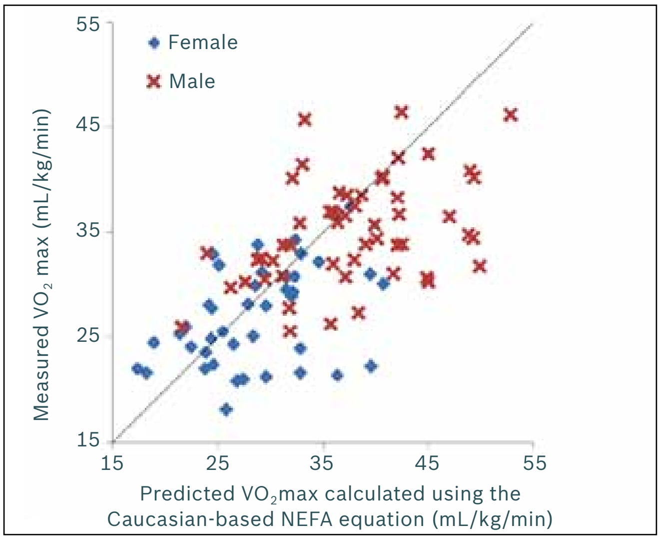


**Fig. 1** Scatter plot shows the relationship between laboratory-measured $VO_2$ max and $VO_2$ max estimated using Jurca et al's Caucasian-based NEFA equation[5] in men (n = 57) and women (n = 43). The line of identity is shown.
$VO_2$ max: maximal oxygen consumption

values when the respective modified NEFA equations were used. Compared to the laboratory-measured $VO_2$ max, the Caucasian-based NEFA equation overestimated $VO_2$ max for both genders, with a mean bias of 6.69 ± 4.30 mL/kg/min for men and 2.87 ± 3.91 mL/kg/min for women. Compared to the original Caucasian-based NEFA equation, both our modified NEFA and $NEFA_1$ equations reduced the mean bias of $VO_2$ max values for both genders.

## DISCUSSION

CRF is a strong predictor of health outcomes and provides a more accurate measure of health-related fitness than self-reported physical activity.[2] According to ACSM,[9] there are numerous benefits to measuring CRF. The measurement of CRF: (a) educates people about their present health-related fitness status while matching it to norms; (b) aids in the development of exercise prescriptions; (c) allows for and facilitates the evaluation of progress by participants of exercise programmes; and (d) motivates participants through the establishment of attainable and reasonable fitness goals. The importance of CRF measurements was further emphasised in a recent international meta analysis,[4] which found that for every ~12% increase in CRF, there were corresponding 13% and 15% reductions in all-cause mortality and coronary heart/vascular disease morbidity, respectively. Given that coronary heart/vascular disease accounts for 30% of all deaths in Singapore,[13] a readily available measure of health outcomes such as CRF would not only be useful in general medical practice but also primary care settings, as it would help practitioners determine risk and provide real-time, tailored physical activity advice.

The objective of the current study was to cross-validate the Caucasian-based NEFA equation by Jurca et al[5] in an adult Singaporean population. Additionally, we developed and tested

**Table II. Comparison of the various NEFA equations with laboratory-measured $VO_2$ max.**

| Equation used | Laboratory-measured $VO_2$ max (mL/kg/min) | | | |
|---|---|---|---|---|
| | Male | | Female | |
| | Bias* | 95% LOA | Bias* | 95% LOA |
| **Caucasian-based NEFA[5]** | 3.69 ± 4.30 | −1.74 to 15.11 | 2.87 ± 3.91 | −4.80 to 10.54 |
| **Modified NEFA equations** | | | | |
| NEFA (with $HR_{rest}$) | −1.05 ± 3.81 | −8.51 to 6.40 | 0.95 ± 2.99 | −4.90 to 6.811 |
| $NEFA_1$ (without $HR_{rest}$) | −0.10 ± 3.84 | −7.62 to 7.43 | −0.09 ± 3.20 | −6.36 to 6.18 |

*Data is presented as mean ± standard deviation.
$HR_{rest}$: resting heart rate; NEFA: non-exercise fitness assessment; LOA: limits of agreement; SD: standard deviation; $VO_2$ max: maximal oxygen consumption

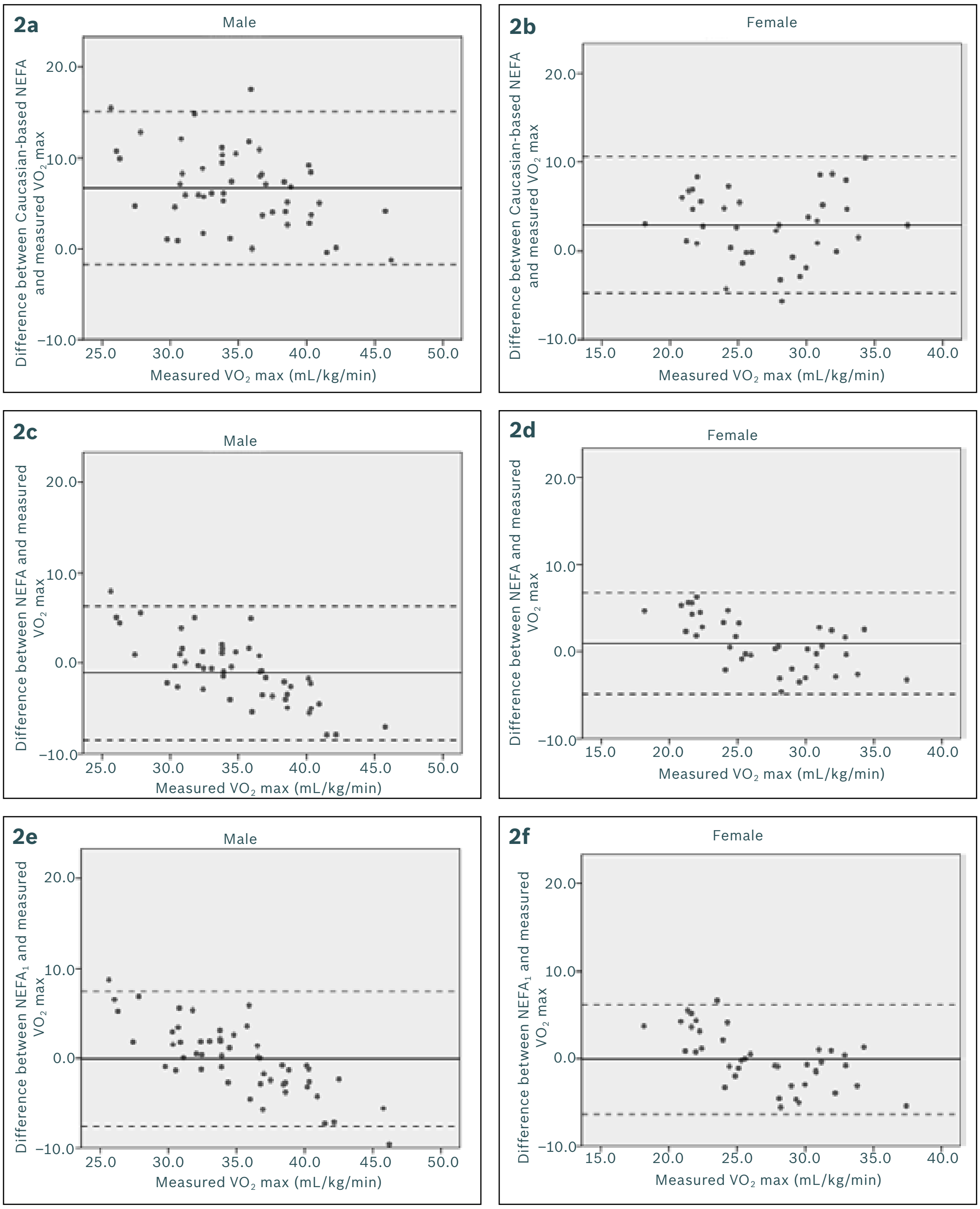


**Fig. 2** Bland-Altman plots for men (left) and women (right) show the difference between laboratory-measured $VO_2$ max and $VO_2$ max estimated using (a & b) the Caucasian-based NEFA equation by Jurca et al[5]; and the present study's (c & d) modified NEFA equations, and (e & f) $NEFA_1$ equations. The solid line in each plot indicates the mean difference, and dashed lines indicate the 95% limits of agreement. NEFA: non-exercise fitness assessment; $VO_2$ max: maximal oxygen consumption

the NEFA$_1$ equation, which did not have $HR_{rest}$ as a factor. Overall, the results of our study demonstrated a high correlation between the laboratory-measured $VO_2$ max and the $VO_2$ max predicted by the modified NEFA equations (r = 0.83). Notably, 69% of the variance in the $VO_2$ max values could be explained by independent variables. Our overall findings were similar to the correlation reported in the study by Jurca et al for a Caucasian population (r = 0.81).[5] Overall, we found that the accuracy of the NEFA equation improved when it was modified to be gender-specific.

While individual CRF may be better predicted when $HR_{rest}$ was accounted for, accurate measurements of $HR_{rest}$ as part of field tests and population surveys at the population level may not be logistically feasible. To help practitioners overcome these barriers, we developed the NEFA$_1$ equation, a modified NEFA equation that excludes $HR_{rest}$ as a factor. The NEFA$_1$ equation resulted in a reduced mean bias and a narrower LOA, with the overall correlation remaining consistent (r = 0.83), thus providing a feasible method of assessing CRF without $HR_{rest}$ as a variable. Our findings were similar to that of Jackson et al's study,[14] which also developed non-exercise predictive equations without $HR_{rest}$ in a Caucasian sample. Any minor differences that may exist between Caucasian and Singaporean populations are likely related to physiological differences on the account of ethnicity.[6]

The present study has its share of advantages and disadvantages. A key strength was that the various fitness equations for $VO_2$ max were cross-validated against CPX, which is the gold standard test for cardiopulmonary fitness. Also, to the best of our knowledge, this is the only study to have cross-validated NEFA equations in Asian adults and older adults. However, one limitation was that the NEFA algorithms used in our study were developed from cross-sectional data using the exclusion criteria mentioned earlier. While this might have provided accurate estimations of acute CRF, the ability to detect changes in CRF over time may be limited.[15] CRF has been estimated to decrease by nearly 4.5% with every decade of age, with the decrease becoming more significantly accelerated in the elderly.[16] Therefore, we limited our study to participants aged 18–65 years. Also, as Jackson et al found that their prediction model was less accurate for highly fit individuals,[14] we did not attempt to validate our equations in individuals who were highly active. Based on our exclusion criteria, and taking into account the recent National Health Survey,[17] the modified NEFA equation used to predict CRF in our study can be generalised to about 56% of the population in Singapore.

In conclusion, the present study's modified NEFA equations with and without $HR_{rest}$ were found to accurately predict CRF for apparently healthy adult Singaporeans. The derivation of NEFA equations with and without $HR_{rest}$ provides a cost-effective method for measuring CRF in healthcare, fitness and research settings. Further studies to determine the accuracy of NEFA in elderly and obese populations are warranted.

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