Validation of One-Mile Walk Equations for the Estimation of Aerobic Fitness in British Military Personnel Under the Age of 40 Years

Heather Lunt, PhD†; Daniel Roiz De Sa, FFSEM (UK)*; LNN Julia Roiz De Sa, QARNNS*; Adrian Allsopp, PhD**

ABSTRACT Objective: To provide an accurate estimate of peak oxygen uptake (VO_2 peak) for British Royal Navy Personnel aged between 18 and 39, comparing a gold standard treadmill based maximal exercise test with a submaximal one-mile walk test. Methods: Two hundred military personnel consented to perform a treadmill-based VO_2 peak test and two one-mile walk tests round an athletics track. The estimated VO_2 peak values from three different one-mile walk equations were compared to directly measured VO_2 peak values from the treadmill-based test. One hundred participants formed a validation group from which a new equation was derived and the other 100 participants formed the cross-validation group. Results: Existing equations underestimated the VO_2 peak values of the fittest personnel and overestimated the VO_2 peak of the least aerobically fit by between 2% and 18%. The new equation derived from the validation group has less bias, the highest correlation with the measured values ($r = 0.83$), and classified the most people correctly according to the Royal Navy's Fitness Test standards, producing the fewest false positives and false negatives combined (9%). Conclusion: The new equation will provide a more accurate estimate of VO_2 peak for a British military population aged 18 to 39.

INTRODUCTION

The British Royal Navy (RN) has a duty of care that all reasonable steps are taken to ensure personnel are capable of safely performing the tasks requested of them. Therefore, all personnel must take and pass the RN fitness test (RNFT). The standards have been set in accordance with the oxygen uptake VO_2 required to perform safety critical tasks.[1] A laboratory-based test where participants are exercised to exhaustion is considered to be the most accurate measurement of peak oxygen uptake VO_2 peak. However, to accurately determine VO_2 peak, expensive specialized equipment is needed, performing this type of testing is also time consuming, and consequently it is not practical to test large numbers of people. An estimate of VO_2 peak can be attained from field-based assessments where large populations can be tested. These tests require participants to perform high-intensity, high-impact exercise. The RN uses two tests (1.5-mile [2.4 km] run which must be completed in the fastest time possible [adapted from Cooper[2]] and the multistage fitness test[3]). Not all personnel can participate in this type of testing for medical reasons, they may be in a medical category where maximal or high-impact exercise is contraindicated. To report fitness levels in these individuals, an alternative submaximal, lower impact test is required.

The Rockport fitness walk test (RFWT)[4] is a submaximal fitness test which is a commonly used test to estimate VO_2 peak, the RN allow personnel aged 40 or older to undertake this test rather than the high-impact alternatives. This test estimates VO_2 peak by participants performing a one-mile walk. However, such tests have limitations, relying on equations from previous research. Consequently, estimated VO_2 peak values may not be accurate if the population being tested is different to the original research sample (i.e., different ages). There are a number of equations for different populations, which are based upon the one-mile walk test, these groups include older people,[5–7] college-aged students,[8,9] obese people,[10] and adults with learning difficulties.[11] In addition, variants of the test include ¼[12] and ½ mile[10] walk tests and treadmill equivalent equations.[13] Consequently, it is necessary to determine the equation that provides the most accurate estimate of VO_2 peak for RN personnel aged 18 to 39.

There are a number of equations that could be used to estimate VO_2 peak in RN personnel aged 18 to 39. Three studies[4,8,9] had similarly aged participants to the population tested in this article, but produced different estimates of VO_2 peak. For instance, it was reported that the application of the original RFWT equation resulted in an over-prediction of VO_2 peak by between 8% and 23%.[8,9] In addition, evidence suggests that there is a systematic bias in the generalized equation in the study of Kline et al,[4] whereby the VO_2 peak values are over-estimated at the lower end of the fitness scale and under-predicted at the upper end. This is likely to be due to the limited number of individuals at the extremes of fitness in the sample population used to develop the equations. If applied to the group used in the present study, this may result in personnel passing a fitness test when they should fail. Consequently, this may place RN personnel at risk

*Environmental Medicine and Science, Institute of Naval Medicine, Gosport, Hampshire, United Kingdom.

†Extreme Environments Laboratory, Department of Sport and Exercise Science, University of Portsmouth, Portsmouth, United Kingdom.

doi: 10.7205/MILMED-D-12-00369

of injury, either to themselves or others in the course of their work, as they may not have the level of aerobic fitness required to perform tasks safely.

In matching the population characteristics of interest (males and females aged 18–39) there are three equations that could be applied.[4,8,9] Therefore, the aim of the study is to establish if any of the three equations would provide an accurate and unbiased estimate of VO_2 peak using a British Military population aged between 18 and 39. If the equations do not meet set criteria, a population specific equation would be produced and cross-validated.

METHODS

Participants

Two hundred and six (44 female and 162 male) military personnel serving in UK armed forces gave their written informed consent to participate in the ethically approved study (Ministry of Defence Research Ethics Committee). Five participants did not complete the laboratory-based VO_2 peak test, because of cardiac abnormalities found during the medical assessment and one participant was not able to complete one of the one-mile walk tests because of an injury. The characteristics of the group (n = 200) are shown in Table I. The group consisted of 138 personnel from the RN, 47 from the Royal Air Force, and 15 from the British Army.

All participants were screened by an independent medical officer for their fitness to participate in the study. Upon successful completion of this, and within 14 days, participants undertook one laboratory-based data collection session involving a basic anthropometric assessment (measuring skin fold thicknesses at four sites [Biceps, Triceps, Subscapula, and Suprailliac] using Harpenden callipers [Baty International, West Sussex, UK]), a direct measurement of VO_2 peak, and two field-based sessions, completing a one-mile walk test on each occasion. The estimated VO_2 peak values derived from the one-mile walk tests were compared to the participants' directly measured VO_2 peak achieved under laboratory conditions.

Measured Peak Oxygen Uptake

Participants undertook a continuous progressive uphill treadmill test to volitional fatigue.[14] The treadmill (Woodway PPS 55, Weil am Rhein, Germany) gradient started at 3.5% and increased by 2.5% every 3 minutes, the treadmill belt speed was constant throughout the test. The speed of the belt differed between individuals and was based on a comfortable running speed, treadmill belt speeds ranged from 6 km hr^{-1} to 13 km hr^{-1}. During the final minute of each 3-minute stage, participants' expired air samples were collected and heart rate recorded. Participants also indicated when they believed their final minute was, they continued to exercise while the expired gas was collected for that minute. Of the 200 volunteers, 184 achieved the criteria for maximal oxygen uptake (VO_2 max).[15] For the remaining 16 subjects, VO_2 peak measurements were used.

The expired gas samples were collected through a one-way non-return breathing valve (Hans Rudolph, Shawnee, KS) into Douglas bags, and the gas is then pumped through a gas analyzer (Series 1440; Servomex, Crowbrough, UK) for 2 minutes. A thermometer measured the temperature of the gas (Grant Instruments [Cambridge] Ltd, UK) and a dry gas meter measured the volume of expired air (Harvard Instruments, Kent, UK). Barometric pressure was measured during the Douglas bag evacuations using a Fortin's mercury thermometer (Russell Scientific Instruments, Norfolk, UK). Barometric pressure, expired gas temperature, and volume were used to calculate ventilatory equivalents at standard temperature and pressure of a dry gas (V_{ESTPD}) and VO_2 and VCO_2 values were subsequently calculated using the Haldane transformation using the expired fractions of oxygen and carbon dioxide (F_EO_2, F_ECO_2).

Estimated Peak Oxygen Uptake From a 1-Mile Walk Test

Participants were asked to take part in two data collection sessions that took place at the same time of day on different days on an outdoor 400-m athletics track that had a rubberized top coating. The participants were weighed in socks, shorts, and a t-shirt (recorded to the nearest 0.01 kg [Sartorious, Epsom, UK]), height recorded (measured to the nearest 0.5 cm using a Seca Stadiometer [Leicester, UK]), and instrumented with a heart rate monitor chest strap and watch (Polar Electro, Kempele, Finland). After this, the participants were dressed in clothing appropriate for the weather conditions, the mean and standard (SD) of the ambient temperature and relative humidity during the one-mile walk tests were 23.2 (3.4) °C and 56 (18)%, respectively. They walked four laps of the track at a fast consistent pace, a record of the time taken to complete each lap was made and heart rate data were recorded at 5 second intervals. No verbal feedback was given and they were asked to refrain from looking at their heart rate monitor watch. Estimated VO_2 peak values were calculated using three one-mile walk equations.

TABLE I. Mean (SD) Physical Characteristics of the Participants

	Age (Years)	Number of Males/Females	Height (m)	Mass (kg)	Measured VO_2 peak ($mL \cdot kg^{-1} \cdot min^{-1}$)	Σ of 4 Skin Folds (mm)
Validation Group (n = 100)	27 (6)	81/19	1.76 (0.08)	78.2 (12.1)	48.6 (7.3)	49 (22)
CV Group (n = 100)	28 (6)	75/25	1.74 (0.07)	78.5 (12.4)	47.2 (8.6)	47 (24)
All (n = 200)	28 (6)	156/44	1.75 (0.08)	78.4 (13.2)	48.0 (7.9)	48 (24)

$$\begin{aligned}VO_2\text{ peak}\left(\text{mL kg}^{-1}\text{min}^{-1}\right) &= 132.853 + 0.0769\text{ body mass (lb)}\\ &- 0.3877\text{ age years}) + 6.315\text{ gender}\\ &- 3.2649\text{ walk time(decimal minutes)}\\ &- 0.1565\text{ HR in last quarter mile }\left(\text{b min}^{-1}\right)^4 \quad (1)\end{aligned}$$

$$\begin{aligned}VO_2\text{ peak}\left(\text{mL kg}^{-1}\text{min}^{1}\right) &= 88.7688 - 0.0957\text{ body mass (lb)}\\ &+ 8.8924\text{ gender}\\ &- 1.4537\text{ walk time (decimal minutes)}\\ &- 0.1194\text{HR at the end of the walk }\left(\text{b min}^{-1}\right)^8 \quad (2)\end{aligned}$$

$$\begin{aligned}VO_2\text{ peak}\left(\text{mL kg}^{-1}\text{min}^{-1}\right) &= 108.94 - 0.84\text{ BMI }\left(\text{kg m}^{-2}\right)\\ &+ 0.21(\text{age[years]gender})\\ &- 8.41\text{ mean walk time (decimal minutes)}\\ &+ 0.34\text{ mean walk time}^2\text{ (decimal minutes)}^9 \quad (3)\end{aligned}$$

where gender = 1 for males; 0 for females.

Body mass (lb) was derived from body mass (kg) by dividing mass (kg) by 0.4536.

Validation Criteria

The cohort of 200 participants were randomly assigned to a validation group (n = 100) or a cross-validation (CV) group (n = 100). The characteristics of the participants are in Table I.

Several criteria were used to establish which of the equations would be a most appropriate for use with this population as follows:

(1) The measured and estimated VO_2 peak values were not significantly different from each other.
(2) A low systematic bias. Systematic bias is assessed by comparing the correlation coefficients of the residuals (i.e., the difference between the estimated and true value) for each prediction equation. The equation with the lowest correlation has the least systematic error.
(3) Low false positive and false negative results.
(4) Strong correlations between estimated and measured VO_2 peak values.
(5) A strong test–retest reliability between the estimated VO_2 peak values for first and second 1-mile walk tests
(6) A low standard error of the estimate (SEE). SEE is a measure of the accuracy of predictions. The SEEs of the CV group were determined according to Equation (4).

$$\text{SEE} = \sqrt{\frac{\Sigma(a-b)}{N}} \quad (4)$$

where a = estimated VO_2 peak value, b = directly measured VO_2 peak value, and N = sample size.

Statistical Analysis

The measured and estimated VO_2 peak values were found to be normally distributed and of equal variance. The validation criteria above were applied to the estimates formed by each of the predictive equations. A repeated measures ANOVA was used to assess differences between the "measured" and "estimated" values. Statistical significance was reported at $p < 0.05$. Backward-stepwise linear regression of the validation group data was used to generate a fourth prediction equation (Equation [5]). Comparative analyses of the derived values from Equation (5) were subsequently undertaken using only the CV group. The mean estimated VO_2 peak for each prediction equation was compared to the measured value and the difference expressed as a percentage.

Residual plots using Bland and Altman's method[16] were used to compare measured and estimated values and systematic error calculated from the correlation coefficients of these residual data.

The measured and estimated VO_2 peak measurements were compared against the RNFT pass standards; the number of true and false positives and true and false negatives were calculated.

The correlations (r) between the measured and estimated values were examined and used to determine the proportion of outcome variance attributable to the measures within predictive equation (R^2). Pearson product moment correlation coefficients (r) were also used to assess the test–retest reliability of the two one-mile walk tests each participant performed.

RESULTS

The descriptive data for the validation and CV groups are presented in Table I.

The validation criteria above were applied to the estimates formed by each of the predictive equations (Equations [1]–[3]); none of which fully met the requirements and hence a further predictive equation (Equation [5]) was generated as described.

$$\begin{aligned}VO_2\text{ peak}\left(\text{mL·kg}^{-1}\text{·min}^{-1}\right) &= 51.047 + 8.336\text{ gender}\\ &+ 635.012\text{ speed (1/Decimal minutes)}\\ &- 0.225\text{·HR in the last 1/4 mile }\left(\text{b min}^{-1}\right)\\ &- 0.271\text{·body mass (kg)} - 0.231\text{ age (years)} \quad (5)\end{aligned}$$

Estimated VO_2 peak values did not differ from the measured value in three of the four equations but Equation (3)[9] resulted in a significant (P < 0.05) underestimate (Table II). Table II also shows the percentage difference of the estimate from the measured value for each equation. Using the CV group, Equation (5) underestimates VO_2 peak the least (by 0.5%). In contrast, Equation (3) performed the worst on this criteria underestimating the measured value by 18.3%. The SEEs were also calculated for each equation from the CV group (Table II), the smallest SEEs were found for the newly derived equation (Equation [5]), the original RFWT

TABLE II. Mean (SD) Measured and Estimated VO_2 Peak Using the One-Mile Walk Equations, the Standard Errors of Estimate and the Percentage Difference Between Measured and Estimated VO_2 Peak

Equation	Measured VO_2 Peak ($mL \cdot kg^{-1} \cdot min^{-1}$)	Estimated VO_2 Peak ($mL \cdot kg^{-1} \cdot min^{-1}$)	Standard Error of the Estimates ($mL \cdot kg^{-1} \cdot min^{-1}$)	Difference Between Measured and Estimated VO_2 Peak (%)
1	47.2 (8.6)	48.9 (5.6)	4.8	+2.0
2		44.2 (5.0)	6.1	−9.0
3		41.5 (5.4)*	9.0	−18.3
5		48.4 (6.6)	4.6	−0.5

*Different from directly measured VO_2 peak $p < 0.05$.

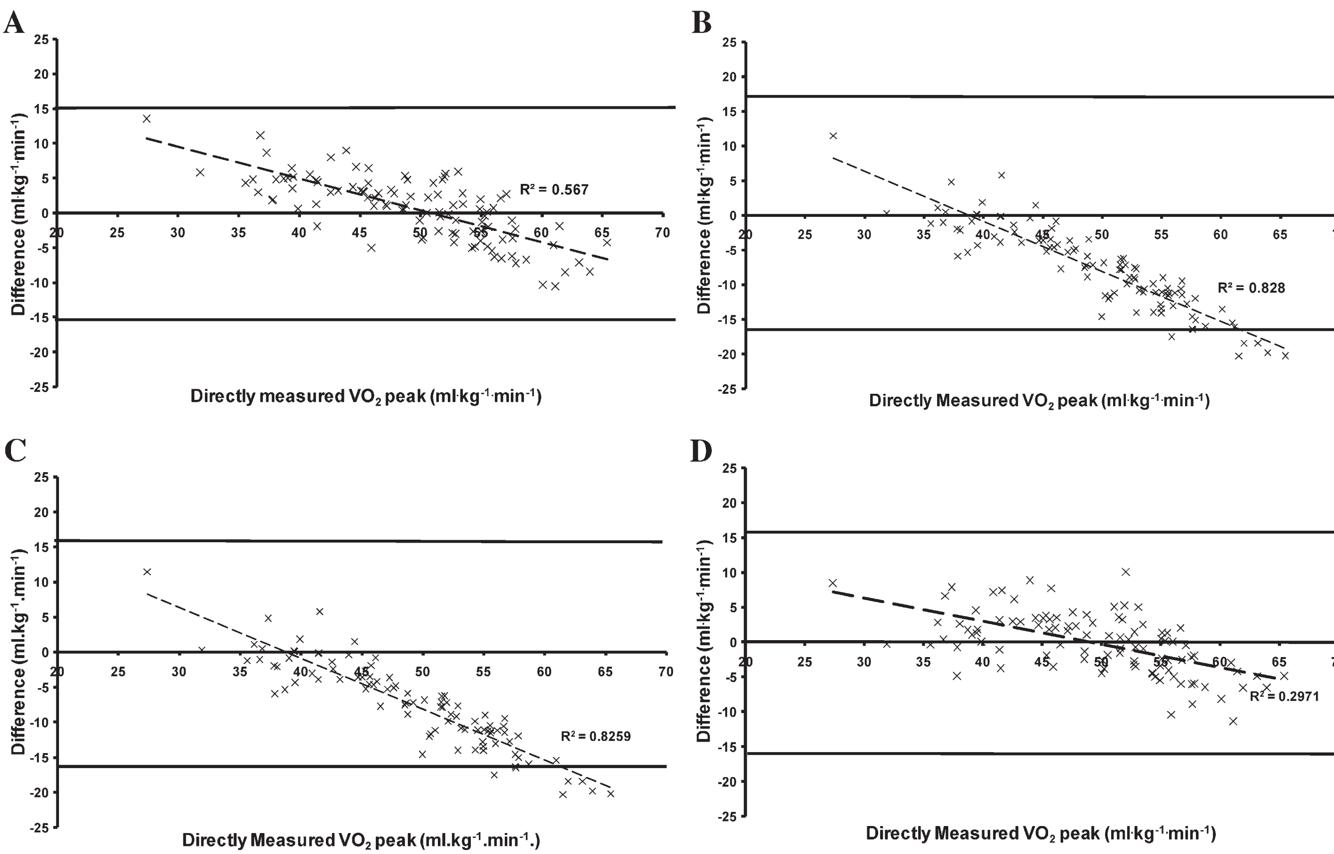

FIGURE 1. Residual plots of the measured VO_2 peak values against the difference between the measured and estimated VO_2 peak values of the CV group using (A) Equation (1),[1] (B) Equation (2),[6] (C) Equation (3),[7] and (D) the equation derived from the validation group of the present study (n = 100). Horizontal bold lines indicate 2 SD from the mean.

equation[4] had similar SEEs, whereas SEEs for Equations (2) and (3) were larger.

Figure 1 shows residual R^2 values for each equation, the lowest values having the least systematic bias dependent on measured VO_2 peak. These figures show that the equation with the least systematic bias was Equation (5) (residual $R^2 = 0.297$). In contrast, the equation with the greatest amount of systematic bias was Equation (3) (residual $R^2 = 0.828$).[9]

In addition, estimated and measured VO_2 peak values of the CV group using each equation were compared to the RNFT pass standards; the number of true positives, true negatives, false positives, and false negatives are shown in Table III. Equation (5) correctly classified the largest number of cases, with 91% classified correctly; the original equation was close with 89.5%. Just over 80% were correctly classified using Equation (2) and just over half (56.2 %) of the CV group were correctly classified by Equation (3).

Each of the equations used to estimate VO_2 peak were correlated with the directly measured VO_2 peak values. Moderate correlations between the measured and estimated VO_2 peak values (Table IV) were found within the validation and CV groups for Equations (1) to (3), which indicates that between 18% and 62% of the variance within the data is attributable to the predictive equations. Moreover, a strong correlation was found between measured VO_2 peak and the estimate calculated using the new equation (Equation [5]); this indicates that nearly 70% of the variance found in the data can be attributed to the new predictive model (Equation [5]).

TABLE III. The Percentage of False Positive and False Negative Results Produced When Comparing the Directly Measured and Estimated VO_2 Peak Values to the RNFT Pass Standards Using the CV Group, $n = 100$

Equation	True Positive Results (%)	True Negative Results (%)	False Positive Results (%)	False Negative Results (%)
1	82.5	7.0	9.5	1.0
2	72.6	11.5	5.0	10.9
3	44.3	11.9	4.5	39.3
5	82.1	8.9	8.0	1.0

TABLE IV. Correlation Coefficients of the Estimated and Measured VO_2 Peak Values Using Each of the Equations With the Validation Group, CV Group, and Both Groups Together (All)

Equation	Validation Group ($n = 100$)	Validation Group Variance (R^2)	CV ($n = 100$)	CV Group Variance (R^2)
1	0.75*	0.56	0.79*	0.62
2	0.73*	0.53	0.77*	0.59
3	0.43*	0.18	0.62*	0.38
5			0.83*	0.68

*Significant correlation $p < 0.05$.

TABLE V. Correlation Coefficients for Test–Retest Reliability of the Repeated One-Mile Walk Tests

Equation	r Value
1	0.94*
2	0.95*
3	0.86*
5	0.96*

*Significant correlation $p < 0.05$.

In addition, strong test–retest correlations were found for all equations (Table V).

DISCUSSION

This study evaluated four equations (three previously published and one derived from the validation group in this study) used to estimate VO_2 peak from a one-mile walk assessment against a treadmill VO_2 peak test in military personnel aged 18 to 39. Compared to directly measured VO_2 peak, this study found that the equation derived from the validation group used in this article gave the most accurate estimate of VO_2 peak. Of the equations already published, the original RFWT equation,[4] gave the second closest estimate.

Previously, researchers have suggested that Kline et al's[4] equation overestimated VO_2 peak by between 8% and 23%.[8,9] Equations (2)[8] and (3)[9] were specifically included as they had similarly aged volunteers in their samples, but in this study, they provided the least accurate estimates of VO_2 peak. Moreover, Equation (3)[9] significantly underestimates VO_2 peak compared to the measured value. In contrast, the original equation (Equation [1]) and the new equation (Equation [5]) were the most accurate estimates. This suggests that Equations (2) and (3) would not be suitable for use in a British RN population aged 18 to 39, whereas Equations (1) and (5) should be considered.

Systematic bias has previously been reported, whereby the RFWT overestimates the VO_2 peak of the least fit people and underestimates values for the most fit.[8] Cureton et al[9] also acknowledge that this is the case with their equation. This study confirms that all three previously published equations cause systematic over- and underestimation of VO_2 peak compared to measured values at the low and high ends of the fitness spectrum, respectively. Using only the CV group from this study, the new equation appears to have less systematic error than the other equations, despite there being few people at the extreme VO_2 peak values. Therefore, the new equation (Equation [5]) is favored, according to the second validation criteria that states an equation should have low systematic bias.

In practical terms, the RN has a duty of care to ensure that personnel are capable of safely performing the tasks requested to them. Consequently, all personnel must take and pass the RNFT. A problem arises when the predictive equation overestimates the VO_2 peak of a person who is less fit than the required standard (a false positive result). In this case, the individual may be asked to undertake safety critical tasks that they are not physically capable of performing in a safe manner, as a result putting theirs and others' safety at risk. Therefore, it is important that the equation used to calculate VO_2 peak is as accurate as possible. In addition, the equation used should not result in many false negative results (the equation under-predicting the VO_2 peak to a value below the RNFT pass standard, when the measured value would indicate a pass), this may have implications on the numbers of personnel considered fit enough to perform the safety critical tasks and could limit operational capability. The new equation (Equation [5]) correctly classified a greater percentage of the CV group than the other equations; the original RFWT (Equation [1])[4] classified the most true positive results, but fewer true negative results than Equation (5).

Consequently, the use of Equation (5) would minimize the number of personnel who are incorrectly awarded a pass or fail for their fitness test. Therefore, in accordance with the third validation criteria, use of the equation that correctly classifies the largest number of personnel (Equation [5]) is desirable.

As the newly derived equation meets more of the validation criteria, this equation was chosen over the three previously published equations.[4,8,9] The differences between the equations may be due to the samples tested in the original studies. The studies of Dolgener et al[8] and Cureton et al[9] (Equations [2] and [3], respectively) used a smaller age range (between 18 and 25) rather than the broader age ranges used in this study (18–39) and that of Kline et al[4] (30–69 years of age). In addition, the physical characteristics of the samples were different; in this study, participants were taller, heavier, and had higher VO_2 peak values than the samples used in Equations (2)[8] and (3)[9]. The study of Kline et al[4] incorporated a wider range of body masses and VO_2 peak values than Equations (2) and (3), the greater range of physical characteristics found in their sample has more similarities to the sample in this study. This may explain some of the similarities and differences between this study and previous research. Furthermore, the one-mile walk tests in all studies were performed outside, therefore a limitation of previous research is that no environmental data were included in the previous articles to enable a comparison to this work. As a result, the effect the environment has on the walk time and physiological variables cannot be compared between the studies.

The percentage of RN personnel achieving a pass for their fitness test was similar to the percentage meeting the standard in the sample of this study. Therefore, it is assumed that the cohort tested is similar to the personnel who will use the equation to estimate VO_2 peak. As with all the predictive equations, a note of caution is necessary; a greater degree of confidence can be assumed in areas where there are many data points, and less confidence with outliers. Consequently, for Equation (5) the smallest confidence intervals are in the range of VO_2 peak values between 30 and 55 mL kg^{-1} min^{-1}. Outside this range, there are fewer data points and consequently larger confidence intervals (Fig. 2).

During this study, participants repeated the one-mile walk test on a second occasion. High test–retest correlations were found. Volunteers from Kline et al[4] and Kunde and Rimmer[11] repeated the one-mile walk test up to five times. For all studies including this work, it can be concluded that reliable estimates of VO_2 peak can be attained from the initial trial without pacing assistance or familiarization. This indicates that little or no practice is necessary, if adequate instruction is given and followed, and the measurement of body mass and heart rate are accurate.

To achieve an accurate estimate of VO_2 peak from the one-mile walk test, Kline et al[4] recommend a consistent brisk walking pace be maintained, and heart rate must be submaximal and within the range where HR and VO_2 increase linearly. Similarly, Golding et al[17] suggested that an accurate estimate could only be achieved when HR and VO_2 increase linearly with a minimum heart rate of 110 beats·min^{-1}. In contrast, according to Astrand et al,[18] heavier workloads that elicit HRs above 150 beats·min^{-1} remove the confounding effect of emotion. However, during the final stage of the walk tests 71 participants in this study had heart rates between 85 and 109 beats·min^{-1} and 188 participants had heart rates under 150 beats min^{-1}. Given that the new equation (Equation [5]) has a small SEE and strong correlation with measured VO_2 peak, the prescriptive heart rate zone to achieve accurate estimates of VO_2 peak appears to be less important than previously thought. It may be more important to ensure that the test is performed by walking the mile at a consistent speed and maintaining a steady-state heart rate, rather than walking most of the mile quickly, and slowing down toward the end in an attempt to reduce heart rate.

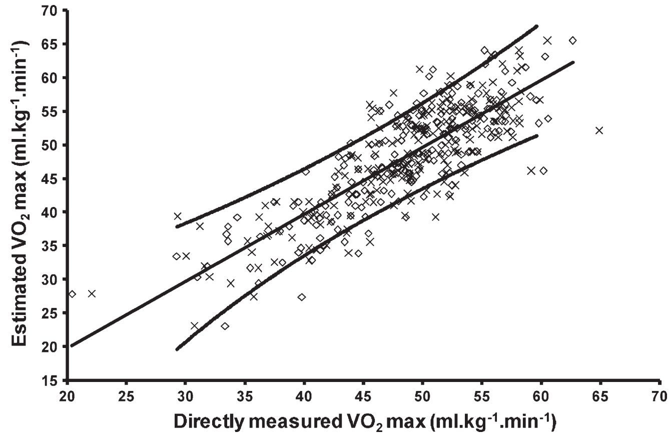

FIGURE 2. Directly measured versus estimated VO_2 peak values of the CV group using the new equation. Curved lines indicate the confidence intervals. X = walk one, O = walk two (n = 100).

It is also noteworthy that the RFWT was published 25 years ago and despite this study using a U.K. military population with a slightly different age profile, the original equation required only minor changes to the weightings to improve the accuracy of the estimated VO_2 peak. These changes in the weightings resulted in the newly derived equation (Equation [5]), which has now been adopted by the British Royal Navy and Royal Air Force.

It is concluded that the equation derived from the validation group in this study provides the best estimate of VO_2 peak in a British military population aged between 18 and 39. This equation is a modification of the original RFWT. The other two equations tested tended to underestimate the most physically fit and overestimate the least fit personnel. The new equation described in this article has less systematic bias, correctly classifies most people according to the RN fitness standards, and should be used with populations with similar physical characteristics.

ACKNOWLEDGMENTS

The authors thank the volunteers Dr. Howard Oakley, WO1 Rod Newman RN, Lt Andrew Wade RN, Lt Mark Middleton RN, Mr. David Grist, Miss Gemma Milligan, Dr. Simon Delves, Mr. Rowan Taylor, Miss Christine Foster, and Miss Kerry Christopher. For their statistical support thanks go to Dr. Beverley Hale and Dr. Shaun Kilminster. Thank you also to Dr. Jo Fallowfield for her constructive comments on the manuscript. This research was funded by the U.K. Ministry of Defence.

REFERENCES

1. Bilzon JL, Scarpello EG, Smith CV, Ravenhill NA, Rayson MP: Characterization of the metabolic demands of simulated shipboard Royal Navy fire-fighting tasks. Ergonomics 2001; 44(8): 766–80.
2. Cooper KH: A means of assessing maximal oxygen intake. Correlation between field and treadmill testing. JAMA 1968; 203(3): 201–4.
3. Ramsbottom R, Brewer J, Williams C: A progressive shuttle run test to estimate maximal oxygen uptake. Br J Sports Med 1988; 22(4): 141–4.
4. Kline GM, Porcari JP, Hintermeister R, et al: Estimation of VO_2 max from a one-mile track walk, gender, age, and body weight. Med Sci Sports Exerc 1987; 19(3): 253–9.
5. Bazzano C, Cunningham L, Cama G, Falconia T: Physiology of 1-mile walk test in older adults. J Aging Phys Act 1995; 3: 373–82.
6. Bazzano C, Cunningham L, Cama G, Falconia T: The relationship of lactate to 1-mile walk performance in women aged 60–70 years. J Aging Phys Act 1998; 6: 285–9.
7. Peloquin L, Gauthier P, Bravo G, Lacombe G, Billard J-S: Reliability and validity of the Five-minute walking field test for estimating VO_2 peak in elderly subjects with knee osteoarthritis. J Aging Phys Act 1998; 6: 36–44.
8. Dolgener FA, Hensley LD, Marsh JJ, Fjelstul JK: Validation of the Rockport Fitness Walking Test in college males and females. Res Q Exerc Sport 1994; 65(2): 152–8.
9. Cureton KJ, Sloniger MA, O'Bannon JP, Black DM, McCormack WP: A generalized equation for prediction of VO_2 peak from 1-mile run/walk performance. Med Sci Sports Exerc 1995; 27(3): 445–51.
10. Donnelly J, Jacobsen D, Jakicic J, et al: Estimation of peak oxygen consumption from a sub-maximal half mile walk in obese females. Int J Obes Relat Metab Disord 1992; 16: 585–9.
11. Kunde K, Rimmer J: Effects of pacing vs. nonpacing on a one mile walk test in adults with mental retardation. Adapt Phys Activ Q 2000; 17: 413–20.
12. George JD, Fellingham GW, Fisher AG: A modified version of the Rockport Fitness Walking Test for college men and women. Res Q Exerc Sport 1998; 69(2): 205–9.
13. Pober DM, Freedson PS, Kline GM, McInnis KJ, Rippe JM: Development and validation of a one-mile treadmill walk test to predict peak oxygen uptake in healthy adults ages 40 to 79 years. Can J Appl Physiol 2002; 27(6): 575–89.
14. Taylor H, Buskirk E, Henschel A: Maximal oxygen intake as an objective measure of cardio-respiratory performance. J Appl Physiol 1955; 8(1): 73–80.
15. Astrand P-O, Rodahl K: Textbook of Work Physiology: Physiological Bases of Exercise, Ed 3. London, McGraw-Hill, 1986.
16. Bland JM, Altman D: Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986; 8476: 307–10.
17. Golding J, Mayers C, Sinning W: The Y's Way to Physical Fitness. Rosemont, IL, YMCA of America, 1989.
18. Astrand P, Rodahl K, Dahl H, Stronmme S: Textbook of Work Physiology: Physiological Basis of Exercise. Champaign, IL, Human Kinetics, 2003.