Estimating $VO_2^{\text{peak}}$ from a non-exercise prediction model; The HUNT Study, Norway

Short title: Prediction of $VO_2^{\text{peak}}$

Bjarne M. Nes$^{1,2}$, Imre Janszky$^2$, Lars J. Vatten$^{1,3}$, Tom I. L. Nilsen$^4$ Stian T. Aspnes$^{1,2}$, Ulrik Wisløff$^{1,2,5}$

1 K.G. Jebsen Center of Exercise in Medicine, 2 Department of Circulation and Medical Imaging; 3 Department of Public Health and General Practice, both under the Faculty of Medicine 4 Institute of Human Movement Science, Faculty of Social Sciences and Technology Management; 5 Centre for Sports and Physical Activity Research, all Norwegian University of Science and Technology, Trondheim, Norway

**Corresponding author:** Ulrik Wisløff, NTNU, K.G. Jebsen Center of Exercise in Medicine at Department of Circulation and Medical Imaging, Postboks 8905, Prinsesse Kristinas gt 3, 7491 Trondheim, Norway. Fax: +47 728 28 372. Phone: +47 728 28 113. E-mail: ulrik.wisloff@ntnu.no

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ABSTRACT

PURPOSE: Cardiorespiratory fitness is suggested to be an important marker of cardiovascular risk, but is rarely evaluated in healthcare settings. In the present study directly measured peak oxygen uptake data ($VO_2$peak) from a diverse population of 4637 healthy participants were used to develop and cross-validate a new non-exercise regression model of cardiorespiratory fitness for men and women.

METHODS AND RESULTS: Multivariable regression analysis was used to develop a non-exercise model of cardiorespiratory fitness for men and women separately with $VO_2$peak as the outcome. In the final models 2067 men (mean age 48.8) and 2193 women (mean age 47.9) were included, respectively. Cross-validation of the models was done by standard data-splitting procedures with evaluation of constant error and total error of a model developed on one sample and cross-validated on another sample. Age, waist circumference, leisure time physical activity and resting heart rate, successively, were the most potent predictors of $VO_2$peak for both men and women. Together 61 and 56 % of variance in $VO_2$peak, for men and women respectively, were explained by the full models. Standard error of the estimate was 5.70 and 5.14 for the models including men and women, respectively.

CONCLUSIONS: The non-exercise regression model developed in the present study was fairly accurate in predicting $VO_2$peak in this healthy population of men and women. The model might be generalized to other healthy populations and be a valid tool for a rough assessment of cardiorespiratory fitness in an outpatient setting.

KEY WORDS: Cardiorespiratory fitness, peak oxygen uptake, multiple regression, population sample
INTRODUCTION

Paragraph number 1 Aerobic fitness is a well established and robust indicator of cardiovascular health and predictor of premature all-cause mortality. Large scale epidemiological and experimental studies have identified aerobic fitness as one of the most important determinants of cardiovascular disease and its associated risk factors (2, 7, 17, 33). Direct measurement of peak oxygen uptake ($V_O^{2peak}$) by ventilatory gas analysis is generally accepted as the most valid index of aerobic fitness in both health and disease (30). $V_O^{2peak}$ describes the highest value of oxygen consumption obtained by an individual during dynamical work using large muscle groups (34). Indirect measurement of aerobic fitness estimates $V_O^{2peak}$ from surrogate measures like treadmill time to exhaustion, sub-maximal work load or heart rate response to exercise. Despite the indubitable importance of aerobic fitness for health, measurements of $V_O^{2peak}$ in healthcare settings and population surveillance are rare, maybe for different reasons, including the cost and time consumption of the methods, as well as the potential risks related to maximal physical efforts. $V_O^{2peak}$ is, however, closely associated with many factors associated with health status, including age, body weight, physical activity habits, nutritional status, smoking habits, occupation and some biochemical markers (14, 20). As a whole, these variables may explain a substantial proportion of the variance of $V_O^{2peak}$ in population samples.

Paragraph number 2 Therefore, several non-exercise models of aerobic fitness have been developed with the aim of predicting $V_O^{2peak}$ using easily accessible measures such as age, gender, self-reported level of physical activity (PA) and body composition (11, 13, 15). Some of these prediction models have shown promising accuracy, and may be better than widely accepted sub-maximal exercise procedures (10, 15). However, most studies on this issue have
been limited by small samples, selected populations or indirect measures of \( VO_{2\text{peak}} \), factors that may have threatened the validity and generalizability of the estimated models.

**Paragraph number 3** In a population based sample of 4637 healthy participants derived from the Nord-Trøndelag Health Study (HUNT) in Norway, we aimed to develop and cross-validate a new non-exercise regression model of cardiorespiratory fitness (\( VO_{2\text{peak}} \)) for men and women.

**MATERIAL AND METHODS**

*Study population*

**Paragraph number 4** Participants in the present study were recruited from the third wave of the HUNT-study (HUNT-3) that is a large, population based health survey of the total adult population in Nord-Trøndelag county in Norway. Information was collected using a self-administered questionnaire and clinical measurements. In a sub-study of HUNT-3, objective measurements of \( VO_{2\text{max}} \) were included, yielding unique reference values for aerobic fitness in the population. A total of 4637 subjects were tested for \( VO_{2\text{peak}} \). Eligible subjects for exercise testing had to be free from known cardiovascular and lung diseases, cancer, sarcoidosis and antihypertensive medications. Hence, the population undergoing exercise testing must be considered apparently healthy. A detailed description of the HUNT study has been published elsewhere (12). The study was approved by the Regional committee for ethics in medical research, The Norwegian Data Inspectorate and the National Directorate of Health. All participants gave their written informed consent and the study was conducted in conformity with the Helsinki declaration.
For this study, 57 subjects were excluded due to missing information on self-reported physical activity. In addition, 320 subjects were excluded due to missing information on waist circumference (WC) or resting heart rate (RHR). Finally, 4260 subjects were included in developing the regression model. Height, weight and waist circumference (WC) were measured by internally standardized measures. Height and WC were read to the nearest centimetre (cm) and weight to the nearest kilogram (kg). Body mass index (BMI) was calculated as body weight (kg) divided by the squared value of height (m). Resting heart rate (RHR) was calculated by electrocardiogram as beats per minute after 5 minutes of rest.

$VO_{2\text{max}}$ testing procedures

Subjects underwent a ten minute warm-up period after a brief introduction to treadmill walking. The warm-up was conducted at moderate intensity where the subjects achieved modest shortness of breath, some sweat, but without exhaustion or lactate accumulation. After the warm-up period, the subjects were equipped with a heart rate monitor (Polar S610 or RS400, Polar, Kempele, 8 Finland) and mask (Hans Rudolph V, Shawnee, Kansas, USA) before entering the test treadmill (DK City, DK7830, Taichung, Taiwan).

During the $VO_{2\text{max}}$ testing, subjects walked or ran on the treadmill at increasing speed and/or incline until exhaustion. Cardiorespiratory variables were measured continuously using portable ergospirometry (Metamax II, Cortex Biophysik GmbH, Leipzig, Germany) directly transferred to a PC using Cortex Metasoft (version 1.11.5) software. $VO_{2\text{max}}$ was defined using the following criteria: 1) levelling off of $VO_2$ ($<2\text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) despite increased speed or incline and, 2) a respiratory exchange ratio (RER) >1.05. A subject’s $VO_{2\text{max}}$ was taken as the mean of the three successive highest $VO_2$ registrations achieved. If the subjects seemed to have reached exhaustion, but not both the $VO_{2\text{max}}$ criteria,
the test was registered as $VO_{2\text{peak}}$. As 17.7% of the subjects did not achieve the $VO_{2\text{max}}$ criteria the term $VO_{2\text{peak}}$ was used throughout the manuscript. HR$_{\text{peak}}$, RER, RPE, speed, elevation and lung ventilation (L·min$^{-1}$) were also registered at the end of the test. The test equipment was routinely calibrated by trained personnel. Volume ventilation was calibrated at every third test and gas at every fifth one. Ambient room air was automatically checked before each test.

*Physical activity questionnaire*

**Paragraph number 8** Prior to the exercise testing participants were completing a basic HUNT questionnaire (Q1) that included questions related to leisure-time physical activity habits. Thus, frequency of exercise, stated as “How often do you exercise?”, contained five different response options (Never, less than once a week, once a week, two to three times a week and four or more times a week). Intensity of exercise, stated as “how hard do you exercise?” contained three options (“No sweat or heavy breath”, “heavy breath and sweat” and “push myself to exhaustion”) and duration of exercise four options (“less than 15 min”, “between 15 and 30 min”, “between 30 and 60 min” and “more than 60 min”).

*Statistical procedures*

**Paragraph number 9** Descriptive statistics of the population are given as means and standard deviations. The dataset was examined for erroneous outliers, and each variable was tested for normality and homoscedasticity of the residuals.

**Paragraph number 10** The first step of the analysis was to develop an index of physical activity for the purpose of precise $VO_{2\text{peak}}$ estimation. Three different indexes of physical activity were considered. Relative weighting of the different responses were set grossly based on their relation to $VO_{2\text{peak}}$ in a regression model. Hence, intensity was weighted more than
duration and frequency of the index. These indexes were compared to a physical activity index previously validated in the HUNT-population (18). VO_{2peak} was set as the dependent variable and indexes as independent variables in a standard linear regression analysis. Correlations with VO_{2peak} and standard errors of the estimates (SEE) were considered for the two indexes separately.

**Paragraph number 11** Potential predictors of aerobic fitness were checked for zero-order and partial correlation with VO_{2peak}, adjusted for age. In our multivariable models, age, PA-Index and WC or BMI, in separate models, were forced in a priori block-wise manner based on the established relationship of these variables to VO_{2peak}. The remaining variables, resting heart rate, smoking status, HDL cholesterol, total cholesterol and mean arterial pressure were then entered in the subsequent block. Only variables that made a considerable influence on the squared multiple correlation coefficient (R^2) and are easily measureable in a clinical setting, were retained. R^2, corresponding R^2-change, SEE and SEE % were presented. SEE % refers to the percentage of the actual mean VO_{2peak} within which the estimates generally fall and were calculated as SEE %=(SEE/mean VO_{2peak})·100. Tolerance and variance inflation factor were used to assess co-linearity between variables.

**Paragraph number 12** Cross-validation of the model was done by standard data-splitting procedures. Cross-validation was performed by creating the regression analysis on the validation sample and uses this equation to create predicted scores for subjects in the cross-validation sample. The predicted scores were then correlated with observed scores for VO_{2peak} to create the cross-validity coefficient (r_{yy'}). The difference between the original R^2 in the validation sample and the squared cross-validity coefficient constitute the degree of shrinkage one can expect when using the model on an independent, but similar sample. Constant errors (CE) were calculated as the sum of the measured minus the predicted values divided by
sample size for the total validation and cross-validation sample, respectively

\[ CE = \sum \frac{(\text{measured-predicted})}{n}. \]

Total error (TE) was calculated as the squared of the difference divided by sample size \( \left( \sqrt{\sum (\text{measured-predicted})^2} / n \right) \). TE represents the total error of a model developed on one sample and validated on another sample. The validation, cross-validation and total sample were further divided into subgroups according to age, \( VO_{2\text{peak}} \) and physical activity level. We report measured and predicted \( VO_{2\text{peak}} \) within groups, CE and TE. The validation and cross-validation sample were then combined and the multiple regression analysis repeated on the total sample as recommended by others (9, 26).

The statistical analyses were performed with SPSS version 14.0 (SPSS Inc., Chicago, Illinois, USA).

RESULTS

Paragraph number 13 Descriptive characteristics of the total, male and female population are presented in Table 1. Mean characteristics of the validation and cross-validation sample were distributed equally (see Table 1, Supplemental Digital Content 1, which describes the mean characteristics of the samples). Further descriptive data of the HUNT 3 population is extensively described in a previous study (1).

Prediction of \( VO_{2\text{peak}} \)

Paragraph number 14 Age, physical activity and waist circumference accounted for most of the variance in predicting \( VO_{2\text{peak}} \) (\( R^2 = 0.59 \) for men, and \( R^2 = 0.54 \) for women, Tables 2 & 3), while resting heart rate made a small contribution (\( R^2 = 0.61 \) for men, and \( R^2 = 0.56 \) for women, Tables 2 & 3). HDL-cholesterol, total cholesterol, smoking status and mean arterial pressure made no considerable contribution as predictors of \( VO_{2\text{peak}} \). Including BMI as predictor variable instead of waist circumference yielded only negligible alterations in \( R^2 \) and SEE. The final regression equation was 100.27 - (0.269 \cdot \text{age}) - (0.369 \cdot WC) - (0.155 \cdot \text{RHR}) +
(0.226·PA-index) for men, and 74.74 – (0.247·age) – (0.259·WC) – (0.114·RHR) +
(0.198·PA-index) for women (Table 4). Neither the inclusion of interaction-terms nor
polynomials could influence the $R^2$ of the model appreciably.

Physical activity index

**Paragraph number 15** $VO_{2\text{peak}}$ in subgroups of different intensity, frequency and duration of
physical activity was similar if subjects reported to exercise at low intensity, independent of
frequency and duration of the physical activity (data not shown). Hence, we developed an
index of physical activity where responding "No sweat..." on the intensity questions was
weighted equally as not being active at all, independent of the response on frequency and
duration, giving a summary index of 0. The new index was compared to a formerly validated
index of physical activity in the HUNT-population (18) (Table 4), and it showed a slightly
better correlation with measured $VO_{2\text{peak}}$ than the former index ($r= 0.44$ vs. 0.38 and 0.39 vs.
0.34 for men and women, respectively).

Cross-validation of the prediction model

**Paragraph number 16** The coefficient of determination ($R^2$) was stable between the
validation sample (0.62 and 0.55) and the cross-validation sample (0.61 and 0.56) in both men
and women, respectively, indicating a robust model (see Table 2, Supplemental Digital
Content 2, for results of the regression analysis for the validation sample). In addition the
constant errors for the validation sample and the cross-validation sample were close to zero in
both men (0.12 and 0.10, respectively) and for women (0.02 in both), indicating a valid
estimation of the mean $VO_{2\text{peak}}$ (see Tables 3 & 4, Supplemental Digital Content 3 and 4, for a
description of the errors of prediction in the validation and cross-validation sample of men
and women). The total sample yielded similar CE values as the validation sample with
insignificant CE values for women (0.00) nor men (0.00) (Table 5).
In subgroups of age, \( VO_{2\text{peak}} \) and PA, our model remained stable with the exception of \( VO_{2\text{peak}} \) subgroups. In the latter subgroups, the model tended to overestimate \( VO_{2\text{peak}} \) among the least fit participants (<35 mL·kg\(^{-1}\)·min\(^{-1}\) for men, and <30 mL·kg\(^{-1}\)·min\(^{-1}\) for women) with a subsequent underestimation of the most fit subjects (>50 mL·kg·min\(^{-1}\) for men, and >40 mL·kg·min\(^{-1}\) for women). CE values in the total population were -5.35 and -3.85 for the least fit men and women and 4.39 and 4.37 for the most fit. Corresponding TE values were 6.91 and 5.51 for least fit and 6.73 and 6.43 for most fit. For the medium fit subjects (\( VO_{2\text{peak}} \) between 35 and 50 mL·kg\(^{-1}\)·min\(^{-1}\) for men and 30 to 40 mL·kg\(^{-1}\)·min\(^{-1}\) for women) the model seemed to predict \( VO_{2\text{peak}} \) well (CE, 0.49 and -0.23 for men and women, respectively).

**Cross-classification of subjects**

Cross-classification into quartiles of measured and predicted \( VO_{2\text{peak}} \) showed that the model reasonably well managed to classify subjects into the correct fitness-categories (Table 6). 64.2 % of women in the lowest predicted quartile (Q\(_1\)) were correctly classified into the lowest measured quartile (Q\(_1\)), while 90.2 % were correctly classified into one of the two lowest quartiles (predicted Q\(_{1-2}\)) . Similarly, 67.9 % of women were correctly classified into the lowest predicted and measured quartile and 92.5 % correctly classified into one of the two lowest quartiles (predicted Q\(_{1-2}\)). In the upper quartiles (Q4), 65.2 % of women and 68.4 % of men were correctly classified into the correct one, while 91.2 % of women and 93.6 % of men were classified within the closest quartile (Q\(_{3-4}\)). Upper bound cut-off values for predicted Q1 and Q2 were 31.9 and 35.9 mL·kg\(^{-1}\)·min\(^{-1}\) for women and 39.2 and 44.0 mL·kg\(^{-1}\)·min\(^{-1}\) for men, respectively.
DISCUSSION

Paragraph number 19 The non-exercise regression model developed in the present study was fairly accurate in predicting \( \dot{V}O_{2\text{peak}} \) in this healthy population of men and women (\( R^2 \), 0.61 and SEE, 5.70 for men, and \( R^2 \), 0.56 and SEE 5.14 for women). Approximately 90 % of the subjects obtained the predicted \( \dot{V}O_{2\text{peak}} \) within the nearest quartile of measured \( \dot{V}O_{2\text{peak}} \), applied to both genders. The cross-validation, assessed by data-splitting procedures, showed a good model stability, suggesting that it may be generalized to other similar populations without major shrinkage of accuracy. Our model bears a close resemblance to other non-exercise equations by including similar variables such as age, PA, body composition and resting heart rate (11, 13, 23). Comparison of beta weights suggest that age may be the most potent determinant of \( \dot{V}O_{2\text{peak}} \), followed by waist circumference (WC), PA and resting heart rate (RHR). In general, BMI and WC contributed equally to the explained variance but WC was chosen in the final model due to slightly better fit among men. Similar contribution of BMI and WC to prediction of aerobic fitness is also described in previous studies (6, 32).

Paragraph number 20 The accuracy of our model is similar to that of other studies with large population samples. A widely cited model by Jackson et al (1990) (13) reported a SEE of 5.70 mL·kg\(^{-1}\)·min\(^{-1}\) including age, PA, BMI and gender as predictor variables, while Whaley et al (31) and Malek et al (23) reported SEE values of 5.60 and 4.90 mL·kg\(^{-1}\)·min\(^{-1}\). Considering the mean \( \dot{V}O_{2\text{peak}} \) in those studies, SEE % corresponds to 11-13 %, but was not reported in all studies. The error of prediction in our model was comparable to commonly used submaximal exercise models which typically show a 10-20 % margin to the actual \( \dot{V}O_{2\text{peak}} \). For example, a multistage shuttle-run test (22), Rockport 1-mile walk test (16) or 6-min walk-test (28), report SEE of 3.8 to 5.4 mL·kg\(^{-1}\)·min\(^{-1}\). Compared to the well-known
Åstrand-Rhyming maximal treadmill test ($r=0.83$, SEE=$5.7 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), our non-exercise equations show a slightly better accuracy (8).

**Paragraph number 21** A thorough cross-validation analysis was done to avoid the potential problem of over-fitting that could weaken external validity of the regression equation (27). Across subgroups of age and physical activity, the error estimates of the model seemed quite stable. Across subgroups of $VO_{2\text{peak}}$, however, there was a tendency to systematically over- and underestimate predicted values for the low fit and high fit subjects, respectively. This finding is in accordance with previous findings by Jackson et al. (13), Heil et al. (11) and Jurca et al. (15) who also found larger errors of the estimate at the extremes of fitness. Consequently, specific models have arisen that more properly estimate fitness of younger and aerobically trained subjects (23), while accurate prediction models for the least fit groups are sparse. As pointed out by Wier et al (32) loss of predictive accuracy in a high fit population may not sustain a pressing problem in public health settings because high fitness is not associated with any potential harm or disease. The systematic overestimation in the low fitness group could be more precarious because aerobic fitness is suggested to be a continuum from health to disease with particularly increasing risk of chronic disease among the least fit subjects. However, cross-classification of subjects into corresponding quartiles of predicted and measured $VO_{2\text{peak}}$ showed that approximately 90% of subjects, of both sexes, were classified correctly within the nearest quartile of measured $VO_{2\text{peak}}$. For women, this indicates that a woman with a predicted value less than 32 mL·kg\(^{-1}\)·min\(^{-1}\), most probably has an actual $VO_{2\text{peak}}$ less than 35 mL·kg\(^{-1}\)·min\(^{-1}\). A man with a predicted value less than 40 mL·kg\(^{-1}\)·min\(^{-1}\) equally is very likely to have an actual $VO_{2\text{peak}}$ less than 44 mL·kg\(^{-1}\)·min\(^{-1}\). According to a recent cross-sectional study of the present population, $VO_{2\text{peak}}$ below 35 mL·kg\(^{-1}\)·min\(^{-1}\) for women and 44 mL·kg\(^{-1}\)·min\(^{-1}\) for men were associated with increased odds of the metabolic
syndrome (1). Hence, the present model may identify subjects with aerobic fitness levels associated with increased cardiovascular risk.

**Paragraph number 22** A potential reason for the increasing error in prediction among low and high fit subjects in the present study may be due to a limitation of the self-reported physical activity variables to discriminate exercise behaviours with different effect on aerobic fitness. By putting together an index that takes into account the limited ability of low intensity exercise to influence $VO_{2\text{peak}}$ we gained improvement in accuracy of prediction. It seems reasonable, however, that especially the range of intensity response options was too narrow to properly discriminate subjects of high and low fitness. Intensity is reported to be the strongest characteristic of both self-reported and objectively measured PA’s association to a fitness response in a population and should therefore be measured properly (6, 25). However, Kurtze et al (18) reported that the HUNT questionnaire was a better measure of intense PA than overall objective energy expenditure, supporting its utility in research with interest in moderate to high intensity PA. The correlation between PA-Index and $VO_{2\text{peak}}$ in the present study was 0.39 for women and 0.44 for men, which is close to the estimates in an assessment of 12 studies that had validated self-reported PA indices to $VO_{2\text{peak}}$, that showed a median correlation of 0.41 (29).

**Paragraph number 23** Another source of prediction error is the genetic contribution to $VO_{2\text{peak}}$ that obviously weakens the correlation between PA and aerobic fitness. It has been suggested that heredity may be responsible for as much as 25-50 % of the variation in $VO_{2\text{peak}}$ in a heterogeneous population, whereas factors such as PA, body composition and lifestyle constitute the remaining proportion (3). Furthermore, a series of studies by Bouchard et al (4) revealed a considerable heterogeneity in the ability to respond to exercise. A sample from the HERITAGE Family Study was followed over 20 weeks with a uniform exercise program. The
range of $VO_{2peak}$ response was reported from 0 to 1 L·min$^{-1}$ (0-50%), and about 75-80 % of the heterogeneity in training response could not be explained by factors such as age, gender, race or baseline training status. Bearing that in mind, a $R^2$ of approximately 0.60 in the present study, meaning that 60 % of the variation is accounted for by the selected variables, could be as close as one may come with non-exercise predictor variables in an unselected population.

**Paragraph number 24** The main strength of the present study is its size and its population based design. A direct, maximal exercise test to determine $VO_{2peak}$ by ventilatory gas analysis is an advantage compared to the indirect estimates commonly used in population studies. Jurca et al (15) reported that prediction models obtained in a cohort where $VO_{2peak}$ was measured directly, showed a better correlation and lower error of the estimate than cohorts using indirect measures. Also, the independent variables used in this study are valid, easily obtainable and therefore feasible in a time-limited healthcare setting.

**Paragraph number 25** The HUNT-population is suggested to be fairly representative for Norway as a whole, and not very different from many communities in the western world (12). The population is, however, homogenous with respect to ethnicity and socio-economic circumstances, and a generalization of our findings may be limited to similar populations. It could be a limitation that the study only included apparently healthy people. Compared to the total HUNT-population, the HUNT-Fitness sample has a slightly lower BMI and waist circumference as well as higher HDL-cholesterol and physical activity levels (1). Nevertheless, a recent study of the HUNT-Fitness sample showed that the prevalence of metabolic syndrome only differed by 0.8 % between the HUNT-Fitness sample and the total HUNT-population (1).
It is possible that some variables not included in this study, could have yielded a better estimate. It has been suggested that a single question on personal perception of functional ability (i.e. their ability to exercise comfortable for 1 and 3 miles) may be effective in predicting aerobic fitness (10). In fact, that variable outperformed questions related to level of physical activity as a correlate to $VO_{2peak}$. Questions on PA in the HUNT-study are not identical to questions used in other studies, and this limits our ability to compare and cross-validate our findings to other populations. Furthermore, we were not able to measure percent body fat which may be a slightly better predictor than BMI and waist circumference (32). However, percent body fat is a more complicated measure of body composition and may not be feasible for practical use in public health settings. Similarly, objective measurements of physical activity with accelerometers or step counts have yielded more accurate estimates of $VO_{2max}$ in previous studies, but may be practically inconvenient (5, 6).

In order to be a useful tool for risk stratification in health care settings, it is important that prediction models can identify low fitness subjects. Cross-classification of subjects within quartiles of measured and predicted $VO_{2peak}$ revealed reasonable ability of the model to correctly classify subjects. Furthermore, consensus about a specified threshold of aerobic fitness that may substantially increase cardiovascular risk is essential and not yet established.

It seems clear that an evaluation of cardiorespiratory fitness provides valuable additional information to conventional markers of cardiovascular risk (19, 21, 24). Currently, lack of simple and accurate devices for direct measurement of peak oxygen uptake is restricting objective and quick assessment in an outpatient setting. Hence, a non-exercise model as presented in the present study, may be a useful and feasible tool for a rough estimate.
of cardiorespiratory fitness, whereas direct measurement of $VO_{2\text{peak}}$ should be used for a more precise examination in people identified as being low-fit.
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SUPPLEMENTAL CONTENT

Supplemental digital content 1: Table 1: Descriptive data of the male and female validation and cross-validation sample

Supplemental digital content 2: Table 2: Results of regression analysis for validation sample

Supplemental digital content 3: Table 3: Cross-validation analysis of subgroups of age, \( V_{O2}^{peak} \) and physical activity in men

Supplemental digital content 4: Table 4: Cross-validation analysis of subgroups of age, \( V_{O2}^{peak} \) and physical activity in women
REFERENCES


