Validity of the Step Test for Exercise Prescription: No Extension to a Larger Age Range

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The purpose of this study was to determine the validity of a submaximal exercise test, the Step Test Exercise Prescription (STEP), in a broad age range and in individuals in the earliest stages of Alzheimer’s disease (AD). Individuals \((n = 102)\) underwent treadmill-based maximal exercise testing and a STEP. The STEP failed to predict peak oxygen consumption \((\text{VO}_2\text{peak})\), and was a biased estimate of \(\text{VO}_2\text{peak}\) \((p < .0001)\). Only 43% of subjects’ STEP results were within 3.5 ml \(\cdot\) kg\(^{-1}\) \(\cdot\) min\(^{-1}\) of \(\text{VO}_2\text{peak}\). When categorized into fitness levels these 2 measures demonstrated moderate agreement (kappa = .59). The validity of the STEP was not supported in our participants, including those with AD. The STEP may not be appropriate in the clinic as a basis for exercise recommendations in these groups, although it may continue to have utility in classifying fitness in research or community health screenings.

**Keywords**: submaximal exercise test, Alzheimer’s, dementia

Assessment of oxygen uptake capacity \((\text{VO}_2\text{peak})\) remains the gold standard for assessing cardiorespiratory fitness. Low cardiorespiratory fitness has negative implications for physical performance, clinical prognosis, and functional ability (Huggett, Connelly, & Overend, 2005). By their nature, maximal testing protocols have been designed to stress the limits of the cardiorespiratory and muscular systems. However, there are many instances when strenuous testing with expensive equipment is impractical or unfeasible. For example, under some circumstances maximal testing may not be practical for individuals with chronic conditions, instability, and balance problems or those who are frail. Beyond populations with clinical concerns, estimation of \(\text{VO}_2\text{peak}\) is useful in community or rehabilitation settings where maximal testing is impractical (American College of Sports Medicine [ACSM], 2010).

In response to the limitations of maximal testing, several submaximal tests and nonexercise prediction equations have been developed to predict \(\text{VO}_2\text{peak}\). Typically, these estimates include linear combinations of physiologic responses to submaximal
activity (heart rate [HR], workload), body composition (weight, body-mass index), and demographic measures (age, sex; Akalan, Robergs, & Kravitz, 2008). A discussion of the advantages and limitations of several protocols and prediction equations can be found elsewhere (ACSM, 2010). In summary, submaximal tests hold an important place in community, clinical, and research paradigms and when used appropriately can provide useful assessment of aerobic capacity and demonstrate improvement in response to exercise intervention.

Accurate VO$_{2\text{max}}$-prediction protocols are needed in a variety of research and clinical settings. For example, we previously developed submaximal exercise protocols using a recumbent stepper that is valid in healthy populations (Billinger, van Swearingen, McClain, Lentz, & Good, 2012). However, at our institution we have need for a brief test that can be executed in the setting of a typical physician’s office, with low demand of equipment, personnel, and time, that is applicable across the life span and including clinical populations. We identified the self-paced step test, developed for the Step Test Exercise Prescription (STEP) program, as a potentially useful estimate of aerobic capacity for characterizing our cohort. The STEP takes less than 10 min to administer; requires no equipment beyond a staircase, stopwatch, HR monitor, and body-mass scale; and was developed for older adults. The individual is asked to ascend and descend two stairs 20 times at his or her normal, comfortable pace. HR is recorded immediately after completion of the activity. Body mass (kg), time to complete the activity, HR after the activity, age, and sex are used to estimate VO$_{2\text{peak}}$ (Petrella & Wight, 2000).

Multiple prediction models have been published by the group who created the STEP (Petrella, Koval, Cunningham, & Paterson, 1998; Petrella, Koval, Cunningham, & Paterson, 2001; Petrella & Wight, 2000). In consultation with those authors, we focused on the original model validated in a sample of older adults with an average age of 72 years (SD 3; Petrella & Wight, 2000). To our knowledge, this submaximal exercise protocol has not been validated in individuals with early-stage AD who have lower maximal-exercise-testing outcomes than their peers (Billinger, Vidoni, Honea, & Burns, 2011). Furthermore, it remains unclear if the model can be extended to include midlife adults with no cognitive changes. The STEP, with modifications of stepping pace, has been assessed but not validated in a mixed-age population (23–75 years; Hansen et al., 2011). The purpose of this study was to test this model in a broader age range and in individuals with AD.

**Methods**

Participants were recruited as part of the University of Kansas Alzheimer’s Disease Center (KU ADC) registry cohort or through a concurrent study in the Research in Exercise and Cardiovascular Health (REACH) laboratory (Billinger et al., 2012). Inclusion criteria for the concurrent study in the REACH laboratory included men and women 18–60 years of age with no physical limitations that would preclude them from participating in exercise testing and the ability to travel to two separate exercise-testing sessions. Individuals were excluded if they presented with high cardiac risk according to ACSM risk-stratification categories (ACSM, 2010), physical limitations on the treadmill or recumbent stepper, a diagnosis of cardiovascular or respiratory disease, or bone or joint problem that may be aggravated by maximal exercise testing. KU ADC cohort inclusion criteria were similar but with an age
range of 60–90 and absence of major psychiatric disorder, depression, or cancer within the last 5 years.

All participants provided institutionally approved informed consent. Individuals in the KU ADC group underwent extensive evaluation as previously described to establish dementia presence and severity (Burns et al., 2008). AD diagnosis was determined by a single clinician based on established diagnostic criteria (McKhann et al., 1984). Dementia severity was determined using the Clinical Dementia Rating (CDR) scale (Hughes, Berg, Danziger, Coben, & Martin, 1982; Morris, 1993). Enrolled individuals with AD met criteria for very mild or mild dementia (Global CDR 0.5 or 1.0). A global CDR score was derived from individual ratings in each domain such that a CDR score of 0 indicates no dementia, CDR 0.5 indicates very mild, CDR 1 indicates mild, CDR 2 indicates moderate, and CDR 3 indicates severe dementia. Individuals in the REACH group were apparently healthy, community-dwelling adults with low to moderate cardiac risk (ACSM, 2010).

All participants were asked to fast for at least 2 hr and avoid caffeine for 6 hr before testing. Participants were weighed on a standardized, calibrated scale and mass recorded in kilograms. Age was recorded in completed whole years at the time of the STEP, as would be commonly reported by a patient in a clinical setting. All participants were assessed for cardiovascular risk factors. Individuals who were categorized as being at moderate or high risk according to American College of Sports Medicine guidelines (ACSM, 2010) performed maximal exercise testing in the presence of a medical monitor.

Methods for maximal testing have been reported previously for the REACH group (Billinger, Tseng, & Kluding, 2008) and for the KU ADC group (Hollenberg, Ngo, Turner, & Tager, 1998). Peak exercise testing performed on the treadmill has previously been shown to be reliable in participants in the early stages of AD (Anderson, Kluding, Gajewski, Donnelly, & Burns, 2011).

The KU ADC group performed the STEP and treadmill testing on the same day, 45 min apart. The STEP (Petrella & Wight, 2000) was always performed before the treadmill test. The REACH group completed the STEP test within 1–2 days of the maximal-effort exercise test. The younger participants (i.e., the REACH cohort) were required to meet a respiratory-exchange ratio (RER) of at least 1.10 to be included in analysis. Older participants were required to meet an RER of at least 1.0 to be included in analysis (Gibbons et al., 1997). For the STEP, participants were fitted with a Polar HR monitor (Polar USA). Resting HR was recorded after 5 min of quiet sitting. Participants were then asked to practice stepping up and down two 20-cm steps to ensure safety and establish a consistent stepping pattern. They then sat quietly until HR was within 5 beats/min of resting HR. When participants achieved a steady-state HR they were instructed to begin the test at their normal pace. Immediately on completion of the 20 cycles, time to complete the test (STEPTime rounded to nearest second) and HR at completion (STEPHR in beats per minute) were recorded.

Predicted VO2peak was calculated using the following equation (Petrella & Wight, 2000):

$$\text{Predicted VO2peak} = \left\{ \frac{0.124 \cdot \text{weight}}{\text{STEPTime} \cdot \text{STEPHR}} - (0.032 \cdot \text{age}) - (0.633 + \{0.633 \cdot \text{female} \}) + 3.9 \right\} \cdot \frac{1000}{\text{weight}}$$
Analysis

Demographic and testing differences between the REACH cohort, the KU ADC cohort without dementia, and the KU ADC early-stage AD cohort were tested using analysis of variance (ANOVA) for continuous measures and Pearson’s chi-square test for categorical measures. Post hoc testing was performed on significant main effects. To evaluate the assumptions of the ANOVA models, box plots of the measures by group, histograms of the residuals with normal distributions overlaid, and quantile–quantile plots were visually inspected. Observed versus predicted plots were examined to assess the constant variance assumption. Expected cell counts were examined to evaluate the assumptions for Pearson’s chi-square test. The data met appropriate assumptions.

To assess validity of the STEP as a proxy measure for $\text{VO}_{2\text{peak}}$ (ml · kg$^{-1}$ · min$^{-1}$), we used ordinary least-square regression with $\text{VO}_{2\text{peak}}$ as the response measure and STEP as the explanatory measure. A perfect proxy measure for $\text{VO}_{2\text{peak}}$ would be unbiased (i.e., result in a regression line with a slope of 1 and a y intercept of 0), with no error (mean square error [MSE] equal to 0). To test the hypothesis that the slope was equal to 1 and the intercept 0 simultaneously, we transformed the response measure to the $\text{VO}_{2\text{peak}}$ minus the STEP score. We combined the linear contrasts of these parameter estimates into a contrast matrix to generate $F$ ratios for comparison against a (central) $F$ distribution. (Analogous hypothesis testing using the original $\text{VO}_{2\text{peak}}$ as the response measure to test this hypothesis required knowledge of the variance parameter to determine the $p$ value for the noncentral $F$ distribution, as the slope parameter included in this composite hypothesis was being tested against a nonzero value—against 1). As our data were derived from two study cohorts (and phenotypes within group, i.e., nondemented versus early-stage AD in the ADC cohort), we allowed for the regression parameters to differ between these groups. $F$-ratio tests were used to test for differences in both slope and intercept parameters across groups. The coefficient of determination ($R^2$) measures were estimated for ordinary least-square models. For model assessment, scatter plots, histograms of the residuals with normal distributions overlaid, and quantile–quantile plots were visually inspected. Observed versus predicted plots were examined to assess the constant variance assumption.

To further assess the utility of the STEP as a proxy measure for $\text{VO}_{2\text{peak}}$, we estimated the proportion of subjects whose STEP value was within (±) 1 metabolic equivalent (MET; 3.5 ml · kg$^{-1}$ · min$^{-1}$). We also generated a contingency table to test whether this proportion differed by group using Pearson’s chi-square test. Expected cell counts for this contingency table were assessed to evaluate the appropriateness of this test. Each measure was categorized into one of six fitness levels (very poor, poor, fair, good, excellent, or superior; ACSM, 2010), and agreement between these categorized measures was estimated using the weighted kappa using quadratic weights (Fleiss, Levin, & Paik, 2003). Finally, we estimated the regression equation that forced the slope to be equal to 1 and the intercept equal to 0. Using this model, which assumed that STEP was a perfectly unbiased estimate of $\text{VO}_{2\text{peak}}$—and therefore having no error about the parameter estimates as they were assumed fixed and known—the square root of the MSE was used to estimate the standard deviation for prediction interval formulas (Rencher, 2000).

We also conducted a Bland-Altman (1986) analysis for assessment of test agreement and systematic bias.
Results

Demographics and average testing values are provided in Table 1. We tested 106 individuals with both a maximal exercise test on a treadmill and the STEP. Of those tested, 4 were excluded from further analysis (all from the KU ADC cohort), 2 terminated tests before reaching RER of 1.0 (tachycardia, severe hypertension), after testing 1 admitted to exercising before testing, and 1 individual was unable to bring resting HR down before the STEP test. The KU ADC group ($n=44$; 27 nondemented and 17 with early-stage AD) was older ($p<.001$) and had lower VO$_{2\text{peak}}$ ($p<.001$) than the REACH group ($n=58$), as would be expected with aging. Those with AD did not differ from those without AD in the KU ADC cohort. The groups did not differ in sex distribution ($p=.20$). Individuals with AD were judged to have either very mild (CDR 0.5, $n=10$) or mild dementia (CDR 1, $n=7$). All were community dwelling and independently mobile.

Parameter estimates for the regression lines for VO$_{2\text{peak}}$ as a function of STEP differed significantly by group. Specifically, the simultaneous test for equal slopes and intercept parameters across the three groups (REACH, ADC nondemented, and ADC early-stage AD) was rejected ($p<.0001$). However, the subgroups within the ADC cohort were similar, as indicated by the $F$ test ($p=.96$) and the scatter plot of the raw data. Thus, our final model included slope and intercept parameters for the REACH cohort and for the ADC cohort, resulting in two separate regression lines. The estimated regression line for the REACH cohort was VO$_{2\text{peak}} = –12.52 + (1.22 \times \text{STEP})$ and for the ADC cohort was VO$_{2\text{peak}} = 11.86 – (0.37 \times \text{STEP})$. The formal $F$ tests of whether the regression line significantly differed from a line with a slope of 1 and intercept of 0 rejected this hypothesis for both groups ($p<.0001$). The MSE was 21.98, so the estimated standard deviation for this regression

### Table 1  Demographics and Exercise Testing Measures of Study Participants, $M$ (SD) [Range]

<table>
<thead>
<tr>
<th></th>
<th>REACH, $n=58$</th>
<th>KU ADC nondemented, $n=27$</th>
<th>KU ADC AD, $n=17$</th>
<th>Group effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, (years)</td>
<td>42.0 (9.5)</td>
<td>73.4 (6.3)</td>
<td>73.1 (7.3)</td>
<td>$p&lt;.001$</td>
</tr>
<tr>
<td>[24–59]</td>
<td>[63–85]</td>
<td>[59–84]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>76.3 (15.7)</td>
<td>77.8 (15.1)</td>
<td>77.8 (14.7)</td>
<td>$p=.9$</td>
</tr>
<tr>
<td>[54.6–134.7]</td>
<td>[55.8–112.4]</td>
<td>[46.3–104.3]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex, % female</td>
<td>50%</td>
<td>67%</td>
<td>41%</td>
<td>$p=.2$</td>
</tr>
<tr>
<td>Actual VO$_{2\text{peak}}$ (ml $\cdot$ kg$^{-1}$ $\cdot$ min$^{-1}$)</td>
<td>43.7 (10.5)</td>
<td>22.0 (4.7)</td>
<td>21.9 (4.8)</td>
<td>$p&lt;.001$</td>
</tr>
<tr>
<td>[22.7–62.8]</td>
<td>[13.0–32.6]</td>
<td>[14.5–32.5]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time required for STEP</td>
<td>65.0 (9.6)</td>
<td>80.0 (22.2)</td>
<td>101.5 (32.7)</td>
<td>$p&lt;.001$</td>
</tr>
<tr>
<td>[48–101]</td>
<td>[51–140]</td>
<td>[64–200]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR immediately after STEP</td>
<td>119.1 (12.6)</td>
<td>115.4 (13.8)</td>
<td>104.9 (18.5)</td>
<td>$p=.002$</td>
</tr>
<tr>
<td>[85–143]</td>
<td>[93–144]</td>
<td>[78–139]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted VO$_{2\text{peak}}$ (ml $\cdot$ kg$^{-1}$ $\cdot$ min$^{-1}$)</td>
<td>46.2 (7.5)</td>
<td>27.6 (8.1)</td>
<td>27.6 (7.3)</td>
<td>$p&lt;.001$</td>
</tr>
<tr>
<td>[27.7–64.0]</td>
<td>[10.8–43.0]</td>
<td>[15.4–42.6]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. REACH = Research in Exercise and Cardiovascular Health; KU ADC = University of Kansas Alzheimer’s Disease Center; AD = Alzheimer’s disease; VO$_{2\text{peak}}$ = peak oxygen consumption. The $p$ values are $F$ tests from ANOVA models for continuous measures and Pearson’s chi-square tests for the categorical measures.*
Validity of the STEP model was 4.69 (square root of MSE). The coefficient of determination ($R^2$) for this model was .89.

Despite the differences in regression lines indicated by visual inspection of the scatter plot (Figure 1) and formal results of the simultaneous test for equal slopes and intercepts across all of the groups, we generated a simple linear-regression model that generated a single equation from these combined cohorts. (Based on the separate regression-equation results cited, it seemed that this equation would be closer to resulting in the desired slope of 1 and intercept of 0 representing STEP as an unbiased estimate of VO$_{\text{peak}}$. ) This model produced the equation $\text{VO}_2\text{peak} = -5.37 + (1.04 \times \text{STEP})$, and the $F$ test indicated that the slope and intercepts still differed from 1 and 0, respectively ($p < .0001$). This reduction to a single model also increased the estimated variance (MSE) from 21.98 to 35.76, and $R^2$ was .81.

**Figure 1** — Scatter plot of peak oxygen consumption (ml·kg$^{-1}$·min$^{-1}$) measured during the treadmill test plotted against STEP-predicted peak oxygen consumption. The solid black line represents the line of best fit across all participants in the study ($R^2 = .81$). The dashed gray line with wide gaps represents the line of best fit in the younger, Research in Exercise and Cardiovascular Health (REACH) cohort. The dashed black line with narrow gaps represents the line of best fit in the older, University of Kansas Alzheimer’s Disease Center (KU ADC) cohort. The model with separate slope and intercept points for the REACH and KU ADC cohorts improves the fit ($R^2 = .89$). AD = Alzheimer’s disease; STEP = Step Test Exercise Prescription.
Overall, 43% (95% confidence interval [CI] 33–53%) of subjects had values for STEP within 1 MET. Within groups, these values (95% CIs) were 52% (38–65%), 33% (17–54%), and 29% (10–56%) for the REACH, ADC nondemented, and early-stage AD groups, respectively. Comparing these percentages across groups resulted in a $p$ value of .13. Agreement between fitness categories was estimated at kappa = .59, which was in the range of “fair to good agreement beyond chance” (Fleiss et al., 2003). For the prediction intervals based on the model that assumed STEP was a perfectly unbiased estimate of VO$_{2\text{peak}}$, the estimate of the variance (MSE) was 35.64. A 95% prediction interval would be STEP ± 11.8, or within about 3.4 METs. A 90% prediction interval would be within 2.8 METs, and an 80% prediction interval within 2.2 METs.

We then created a Bland-Altman plot (Figure 2) to assess systematic bias. We found a tendency for the STEP to overestimate VO$_{2\text{peak}}$ in the middle quartiles of measured VO$_{2\text{peak}}$ and underestimate VO$_{2\text{peak}}$ at the highest and lowest quartiles.

**Figure 2** — Agreement plot of the difference in predicted peak oxygen consumption (VO$_{2\text{peak}}$) and measured VO$_{2\text{peak}}$ (STEP treadmill test) against the mean of the measures. The heavy black line represents the mean difference (5.94). The light gray dashed lines with wide gaps are the $2 \times$ standard deviation limits of agreement ($2 \times 3.84$). The dashed black lines denote agreement within 1 MET, a more clinically relevant limit of agreement. REACH = Research in Exercise and Cardiovascular Health; KU ADC = University of Kansas Alzheimer’s Disease Center; AD = Alzheimer’s disease; STEP = Step Test Exercise Prescription.
Validity of the STEP

Discussion

The utility and attraction of submaximal exercise tests for the estimation of cardiorespiratory fitness is apparent in the number of different protocols available. Our goal was to assess the validity of the STEP in a broad age range and in individuals in the earliest stages of AD. Our specific need for validation of a submaximal test comes from our previous finding that individuals in the earliest stages of AD have lower VO2peak, higher ventilation, and lower lean mass (Billinger et al., 2011; Burns, Johnson, Watts, Swerdlow, & Brooks, 2010). While we have previously investigated the use of simple clinical tests for establishing cardiorespiratory compromise (Vidoni, Billinger, Lee, Hamilton, & Burns, 2012), we are unaware of any measures specifically validated in those with or at risk for AD.

Research and Clinical Use

The STEP holds considerable appeal for its ease of execution and brief nature. One can easily envision the test being used clinically to serve as a starting point for a discussion of healthy lifestyle and increased physical activity between a physician and patient. It is quick and easy to administer, and predicted VO2peak was simple to calculate with a worksheet-based formula. However, we found that the STEP measures produced biased estimates of the fitness level. We found the bias to be inconsistent across the different cohorts. Furthermore, we have considerable concern about a prediction equation that was only 43% accurate to within 1 MET. We tried all published versions of the model with no better fit (data not shown).

These results suggest that the STEP may be inadequate for clinical or research estimation of VO2peak for exercise prescription or in a group of sedentary older adults, some of whom have AD. The STEP appears to underestimate VO2peak at the lowest and highest levels of performance. This is perhaps only clinically relevant at the lowest levels given that those in the highest quartile of performance can readily participate in standard, treadmill-based maximal exercise testing and are unlikely to need health or wellness coaching that includes establishing baseline aerobic capacity. We have previously noted that individuals with AD demonstrate generally lower VO2peak and speculated that this may be in part due to a diminished capacity of effort, changing body composition (Burns et al., 2008; Burns et al., 2010; Vidoni, Townley, Honea, & Burns, 2011), or pulmonary performance (Billinger et al., 2011). It also possible that our results differed from those of Petrella et al. (Petrella et al., 1998; Petrella & Wight, 2000) due to HR-altering medications such as acetylcholinesterase inhibitors or beta-blockers. All participants in the KU ADC cohort with dementia were on an acetylcholinesterase inhibitor, and 5 were on a beta-blocker. Of the nondemented participants in the KU ADC cohort, 6 were on a beta-blocker. No one in the REACH cohort reported use of an HR-altering medicine.

Further investigation is warranted to validate a submaximal protocol in those with AD. There are several candidate protocols, each with strengths and drawbacks to clinical or research application. The Total Body Recumbent Stepper protocol (Billinger et al., 2012) offers ease of administration and safety but requires special equipment and takes approximately 12 min. The YMCA step-test protocol is brief and similar to the STEP, but the rigid pacing may be taxing for older adults (ACSM, 2010). Like the STEP, this test may stress lower extremity endurance over aerobic capacity. The 6-min-walk (American Thoracic Society, 2002) test is a popular
research measure that has been validated in many clinical populations, but space may be a limiting factor in a clinical setting.

The STEP may continue to have utility in research and clinical practice as a brief measure of physical function and aerobic capacity. For example, stepping time in the STEP was responsive to a walking program in sedentary adults with arthritis (Ng, Heesch, & Brown, 2010) and those with multiple sclerosis (Aizawa, Shoemaker, Overend, & Petrella, 2009). The STEP has also been used successfully to classify individuals into fitness groups, for example, tertiles of fitness (high, moderate, and low; Brandon, Gill, Speechley, Gilliland, & Jones, 2009). This use has particular appeal because the range within any tertile will likely wash out individual deviation from a true fitness measure. Our analysis used the six-level classification scheme of the ACSM (very poor, poor, good, very good, excellent, and superior) and achieved fair to good agreement between the treadmill test and STEP.

**Limitations**

There are several factors that may affect our results. The tests were performed at two different sites. While both sites operated from the same instruction script and executed tests in the same manner, small systematic biases could have been introduced. In addition, the cohorts were tested under different schedules. Fatigue could have influenced the treadmill test. However, given the amount of rest between tests for the KU ADC group, we believe it unlikely that the testing order influenced the results. Finally, we acknowledge the difference in age between the two cohorts (i.e., heterogeneous). However, both groups gave a good effort on their maximal exercise (defined by RER), which should eliminate some performance bias.

**Conclusions**

Despite its clinical appeal the STEP did not adequately predict VO$_{2peak}$ in a cohort with a broader age range or in a group in the earliest stages of AD. However, the KU ADC may continue to use the STEP to categorize our participants’ fitness levels both for the purposes of characterization for future studies and as general feedback regarding their cardiorespiratory health.

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