Association of Physical Activity and Prognostic Parameters in Elderly Patients With Heart Failure

Melissa Jehn, Arno Schmidt-Trucksäss, Henner Hanssen, Tibor Schuster, Martin Halle, and Friedrich Koehler

Objective: Assessment of habitual physical activity (PA) in patients with heart failure. Methods: This study included 50 patients with heart failure (61.9 ± 4.0 yr). Seven days of PA were assessed by questionnaire (AQ), pedometer, and accelerometer and correlated with prognostic markers including VO2peak, percent left-ventricular ejection fraction, N-terminal pro-B-type natriuretic peptide, and New York Heart Association (NYHA) functional class. Results: Accelerometry showed a stronger correlation with VO2peak and NYHA class (R = .73 and R = −.68; p < .001) than AQ (R = .58 and R = −.65; p < .001) or pedometer (R = .52 and R = −.50; p < .001). In the multivariable regression model accelerometry was the only consistent independent predictor of VO2peak (p = .002). Moreover, when its accuracy of prediction was tested, 59% of NYHA I and 95% of NYHA III patients were correctly classified into their assigned NYHA classes based on their accelerometer activity. Conclusion: PA assessed by accelerometer is significantly associated with exercise capacity in patients with heart failure and is predictive of disease severity. The data suggests that PA monitoring can aid in evaluating clinical status.

Keywords: exercise rehabilitation, accelerometry, physical activity measurement, public health, chronic-disease management

Daily activity levels are closely linked to exercise capacity and clinical prognosis in patients with heart failure (Belardinelli, 1999; Cahalin, 1998; Jehn, Schmidt-Trucksäss, Schuster, Weis, et al., 2009b; Walsh, Charlesworth, Andrews, Hawkins, & Cowley, 1997). Therefore, measurement tools enabling the accurate assessment of daily activity are rapidly gaining in clinical importance (Harris, Caspersen, DeFriese, & Estes, 1989; Paffenbarger, Hyde, Hsieh, & Wing, 1986; Paffenbarger, Hyde, Wing, & Hsieh, 1986).
The most common methods to measure physical activity include activity questionnaires and motion sensors—accelerometers or pedometers. Several studies have used these tools in the past to assess physical activity under controlled and free-living conditions in various patient populations (Kochersberger, McConnell, Kuchibhatla, & Pieper, 1996; Miller, Freedson, & Kline, 1994; Pitta et al., 2006).

Activity questionnaires are able to cover a broad spectrum of activities and are fairly simple and cost-effective. However, they are easily biased by participants who are untruthful and are memory dependent, which can be especially problematic in the elderly (Steele et al., 2000). Moreover, activity questionnaires primarily access purposeful movements in terms of exercise or transport and focus predominantly on activities with moderate to heavy intensities (Lee & Buchner, 2008). Low-intensity occupational or routine activities such as household chores, gardening, walking, or standing are usually only superficially accounted for (Jacobs, Ainsworth, Hartman, & Leon, 1993). Although questionnaires have been composed specifically for patients with functional limitations (Bonnefoy et al., 2001; Garet et al., 2004), it is difficult to compose questions that are general enough to target a large group of people yet, at the same time, capture sufficient detail about ubiquitous, nonspecific activities (Bassett, Cureton, & Ainsworth, 2000; Pereira et al., 1997).

Motion sensors such as pedometers and accelerometers allow for an objective measure of physical activity but are limited to walking-based movements. Pedometers are easy to use and fairly low in cost but have been shown to be unreliable at detecting steps during slow, irregular walking (Cyarto, Myers, & Tudor-Locke, 2004; Jehn, Schmidt-Trucksas, Schuster, Hanssen, et al., 2009; Le Masurier & Tudor-Locke, 2003). Unlike pedometers, accelerometers can provide detailed information about exercise intensities and time spent in activity, but they are expensive and require a computer for data analysis in addition to sufficient technical expertise (Ainsworth, 2009).

The purpose of this study was to compare three different methods of measuring physical activity in a sample of heart-failure patients. We wanted to assess how physical activity measurements relate to established prognostic parameters (VO2peak, percent left ventricular ejection fraction [LVEF%], N-terminal pro-B-type natriuretic peptide [NTproBNP], and New York Heart Association [NYHA] class) and which physical activity measurement best predicts laboratory-based exercise capacity (VO2peak). This information will highlight the significance of measuring daily physical activity levels in patients with heart failure and suggest the best method for documenting physical activity in large epidemiological studies.

Methods

Patient Recruitment

Fifty patients with heart failure were recruited with the cooperation of a heart-failure outpatient clinic at the local university hospital and by advertisement in the local newspaper. The study complies with the Declaration of Helsinki and was approved by the local university’s ethics committee. Informed written consent was obtained from all participants. Inclusion criteria were mild to moderate stable systolic and/or diastolic heart failure defined by New York Heart Association (NYHA) Class I–III (van den Broek et al., 1992), regardless of age and medical history, and willingness
to participate in further clinical and laboratory analyses. Exclusion criteria were any unstable medical conditions that were contraindicative to exercise testing. Forty percent of the heart-failure patients participated in a cardiac rehabilitation program (one or two times per week). Participants had a previous medical history at the heart-failure outpatient clinic, including diagnosis and treatment, and were scheduled for their quarterly follow-up. Once included, patients signed an informed consent and were reexamined by two independent physicians. This included medical history, self-perceived exercise tolerance, echocardiography, NTproBNP levels, and cardiopulmonary exercise testing, resulting in NYHA classifications of $n = 12$ NYHA I, $n = 19$ NYHA II, and $n = 19$ NYHA III.

**Echocardiography**

Left-ventricular (LV) remodeling including ejection fraction (%) and systolic and diastolic LV chamber dimensions (LVEDD and LVESD) were assessed by two-dimensional echocardiography with the participants in the left lateral decubitus position, according to the recommendation of the American Society of Echocardiography (Schiller et al., 1989) and after at least 15 min of rest. A standardized imaging protocol was adopted with cross-sectional imaging of the left ventricle immediately distal to the mitral valve tips and apical two-dimensional imaging based on orthogonal four-chamber views. M-mode measurements applied to leading-edge principle as recommended by the American Society of Echocardiography (Lang et al., 2005). M-mode LVEF based was equal to $(EDV – ESV)/EDV$, where the EDV = end diastolic volume and ESV = end-systolic volume.

**Exercise Testing**

After echocardiography, each participant undertook a symptom-limited cardiopulmonary exercise test (fixed ramp protocol: Start 10 W, increase 10 W/min) using an electronically operated cycle ergometer (Sport Excalibur, Lode Medical Technology, The Netherlands). This protocol was chosen based on European recommendations for exercise testing in heart-failure patients (Working Group on Cardiac Rehabilitation and Exercise Physiology & Working Group on Heart Failure of the European Society of Cardiology, 2001). The test was performed in the early afternoon under nonfasting conditions, and participants were encouraged to exercise to exhaustion or until signs of arrhythmia or ischemia developed. Maximal exertion was defined as meeting the following exhaustion criteria: respiratory-exchange ratio $>1.0$, Borg rating of perceived exertion $\geq 18$, and pedaling frequency $\leq 60$ rpm. Respiratory gases were analyzed via ZAN metabolic cart (ZAN 600 USB CPX, nSpire Health GmbH, Germany). VO$_2$ and VCO$_2$ were measured every 10 s, and peak oxygen consumption (VO$_{2peak}$) was defined as the highest oxygen consumption reached during cycle ergometry. Heart rate was measured on a 12-lead ECG, and the electrocardiogram was monitored continuously. Blood pressure was measured at rest, at 1-min intervals during exercise, and during the recovery phase (5 min). Perceived exertion using the Borg scale was recorded at the end of each stage. Maximal heart rate was defined as the highest heart rate achieved during cycle ergometry.
Six-Day Physical Activity Assessment

Patients were given both an accelerometer (Aipermon GmbH, Germany) and a pedometer (Omron HJ-720ITC) to wear at home to record their activity while going about their daily business. The accelerometer and pedometer were attached on the left and right hip, respectively, and patients were instructed to wear the devices consecutively for at least 12 hr/day for 8 consecutive days (i.e., Monday through Monday). The motion sensors were to be attached on rising in the morning and only to be removed for showering, bathing, and sleeping. The first and last days (days on which devices were received and returned) were not complete days, so these data were excluded from our analysis, leaving 6 consecutive days of activity data (Tuesday–Sunday). Patients received the devices on random days of the week, depending on their appointment for their baseline visit. All device settings (date, time, weight, age, and gender) were preprogrammed for each patient on receiving the motion sensors, thereby minimizing the patient’s need to handle the devices during the wearing period. On return of the devices, data from both were copied onto a PC and viewed via customized computer programs (ActiCoach MPAT2Viewer, Aipermon and OMRON Health Management Software). Daily physical activity measurements by pedometer were computed based on the total amounts of steps per day, and accelerometer data were computed based on the total time (min/day) spent walking. Accelerometer detection accuracy has been extensively validated in patients with heart failure, and detailed results are reported elsewhere (Jehn, Schmidt-Trucksaess, Schuster, Hanssen, et al., 2009). In summary, each device was calibrated before each use to accurately detect steps to 99% at walking speeds ranging as low as 20 m/min. There is a 3-s detection delay in recognizing walking activity and initializing step count. We compared accelerometer-detected steps with steps counted by digital hand counter and found a strong correlation between the measurements ($R = .99, p < .001$), with mean difference not statistically significant: $0.1 \pm 2.0$ ($p = .7$). Similarly good detection accuracy (pedometer- vs. hand-counted steps) was found for the Omron pedometer ($R = .95, p < .001$). Because of space limitation these data are not included in this report.

Activity Questionnaire

On return, patients were asked to complete an activity questionnaire about their weekly activity (7 days) that has been validated in Germany particularly for use in cardiac rehabilitation (Frey, Berg, & Keul, 1995). It is composed of 13 main questions, each containing one or more subquestions. Five questions cover the weekly time spent doing occupational activities, daily household tasks, gardening, and climbing stairs; six questions cover the weekly time exercising in terms of targeted sports (bowling, dancing, swimming, running, etc.); and two questions relate to weekly relaxation time and overall self-perception of activity levels. Points are given depending on the time spent in each activity, divided into 15-, 30-, and 60-min time frames and according to the intensity with which this activity was performed, that is, 15 min of walking (0.7 points), brisk walking (1.3 points), and running (1.9 points); 15 min of biking at 75 W (1 point), 100 W (1.4 points), and 150 W (2.5 points); and 15 min of swimming (1.5 points). Points are summed at the end of the questionnaire to give a total point score that was evaluated in terms of meeting certain activity requirements per week:
Daily Activity in Heart Failure

- Insufficient activity levels: <14 points = <1 hr/week or ≤500 kcal/week
- Minimal activity requirements fulfilled: 15–29 points = 1–2.5 hr/week or ≤1,000 kcal/week
- Satisfactory activity levels: ≥30 points = 3–4 hr/week or ≤2,000 kcal/week
- High activity levels: ≥40 points = >4 hr/week or >2,000 kcal/week

Data Analysis

Statistical analysis was conducted with SPSS software (version 17.0, SPSS Inc.). Data were descriptively analyzed and reported as $M \pm SD$ for quantitative measurements and percentages for frequencies. Bivariate correlations of continuous variables were investigated using Pearson’s correlation coefficient ($r$). Scatter charts including linear-regression lines and regression equations were provided to illustrate and quantify correlations of relevant measurements. Chi-square tests were used to compare frequencies between independent samples. To account for multiple comparisons, differences between NYHA groups were assessed by analysis of variance (ANOVA). Therefore, to reduce the fraction of false positive results (significance by chance) a correction of $p$ values was necessary. In all data analyses $p$ values less than .05 were considered statistically significant. Univariate and multivariable regression analyses were performed to test for which of the activity measurements were significantly associated with and independently predictive of $VO_{2\text{peak}}$. Test of variable interaction was confirmed by linear-regression model. A discriminant analysis was performed to assess the accuracy of prediction of each physical activity measurement on correctly classifying patients by NYHA class.

Results

Patient Characteristics

Fifty patients with heart failure (12 NYHA I, 19 NYHA II, and 19 NYHA III) participated in the study. Their mean age was 61.9 years, and 79% were men. Patients had similar medical profiles including heart failure secondary to ischemic heart disease (42%) or dilative heart failure (58%). Mean $VO_{2\text{peak}}$ and ejection fractions (EF%) for NYHA I, II, and III were 26.6, 23.1, and 14.1 ml · kg$^{-1}$ · min$^{-1}$ and 53%, 37%, and 33%, respectively. Most patients were taking standard heart-failure medication including either ACE inhibitor or angiotensin-receptor blocker, beta-blocker, and diuretic (see Table 1 for a detailed overview).

Physical Activity Measurements

Means and standard deviations for physical activity measurements and corresponding group differences ($p$ values) are listed in Table 1. Question domains covered in the activity questionnaire (AQ) are as follows (see Methods section for how points are allocated):

1. Levels of activity at work or in the home (min/day)
2. Amount of daily time spent walking to work or shopping (min)
Table 1  Patient Characteristics, $M \pm SD$ or $n$ (%)

<table>
<thead>
<tr>
<th></th>
<th>NYHA I</th>
<th>NYHA II</th>
<th>NYHA III</th>
<th>TOTAL</th>
<th>$p^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$</td>
<td>12</td>
<td>19</td>
<td>19</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.20</td>
</tr>
<tr>
<td>men</td>
<td>8 (66%)</td>
<td>16 (84%)</td>
<td>14 (74%)</td>
<td>38 (76%)</td>
<td></td>
</tr>
<tr>
<td>women</td>
<td>4 (33%)</td>
<td>3 (16%)</td>
<td>5 (26%)</td>
<td>12 (24%)</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>69.9 ± 4.9*</td>
<td>57.3 ± 5.1</td>
<td>58.9 ± 4.8†</td>
<td>61.9 ± 4.0</td>
<td>.03</td>
</tr>
<tr>
<td>Body-mass index (kg/m²)</td>
<td>26.8 ± 4.9</td>
<td>28.3 ± 3.4</td>
<td>29.4 ± 5.2</td>
<td>28.4 ± 4.5</td>
<td>.32</td>
</tr>
<tr>
<td>VO$_2$peak (ml · kg$^{-1}$ · min$^{-1}$)</td>
<td>27.6 ± 6.9*</td>
<td>23.0 ± 5.9§</td>
<td>14.1 ± 2.8†</td>
<td>20.5 ± 7.5</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>LVEF%</td>
<td>53.4 ± 7.6*</td>
<td>38.1 ± 13.2</td>
<td>31.5 ± 8.7†</td>
<td>39.6 ± 14.1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>NTproBNP (pg/ml)</td>
<td>2,108 ± 1,329</td>
<td>1,365 ± 1,074</td>
<td>569 ± 778†</td>
<td>1,471 ± 1,330</td>
<td>.04</td>
</tr>
<tr>
<td>Pedometer (steps/day)</td>
<td>9,466 ± 3,362</td>
<td>7,795 ± 2,726§</td>
<td>5,446 ± 2,650††</td>
<td>7,257 ± 3,226</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Accelerometer (min/day)</td>
<td>167 ± 39.0</td>
<td>138 ± 57.6§§</td>
<td>74.0 ± 21.3††</td>
<td>119 ± 56.6</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Questionnaire (point-scoring system)</td>
<td>62.2 ± 30.1*</td>
<td>41.2 ± 17.7§§</td>
<td>22.0 ± 12.1††</td>
<td>38.7 ± 24.9</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Medication
- ACE inhibitor   | 6 (50%) | 14 (74%) | 15 (79%) | 35 (70%) |
- ARB             | 3 (25%) | 4 (21%)  | 5 (26%)  | 12 (24%) |
- beta-blocker    | 9 (75%) | 17 (89%) | 16 (84%) | 44 (84%) |
- diuretics       | 7 (58%) | 15 (79%) | 19 (100%)| 41 (82%) |

Note. NYHA = New York Heart Association class; LVEF% = percent left-ventricular ejection fraction; NTproBNP = N-terminal pro-B-type natriuretic peptide; ARB = angiotensin-receptor blocker.

$^a$Overall group comparison by ANOVA/$\chi^2$ test; post hoc group differences were tested by $t$ test with $p < .05$.

*NYHA I vs. NYHA II, $p < .05$. §NYHA II vs. NYHA III, $p < .05$. §§NYHA II vs. NYHA III, $p < .005$. †NYHA III vs. NYHA I, $p < .05$. ††NYHA III vs. NYHA I, $p < .005$. 
3. Amount of daily time spent walking for leisure or exercise (min)
4. Amount of daily time spent riding a bike to work or shopping (min)
5. Amount of daily time spent riding a bike for leisure or exercise (min)
6. Amount of time spent gardening per week (hr)
7. Number of flights of stairs climbed per day and how often (number of flights \( \times \) frequency)
8. Weekly time spent going dancing or bowling (hr)
9. Amount of time spent swimming, walking, or jogging (hr/week)
10. Weekly regular exercise type, frequency, and duration
11. Total amount of regular exercise per week (min)
12. Hours per day spent for relaxation
13. Participant’s self-view in terms of activity levels

The AQ was quantified according to a point-scoring system, pedometer scores were quantified by means of total steps per day, and accelerometer scores were quantified according to time (min/day) spent in walking activities. Mean pedometer and accelerometer wearing times were 13.02 ± 1.4, 12.75 ± 1.4, and 12.51 ± 1.5 hr/day for NYHA I, II and III, respectively.

AQ correlated significantly with VO_{2peak} (\( R = .58, p < .001 \)), LVEF (\( R = .49, p < .001 \)), NTproBNP (\( R = .42, p < .001 \)), and BMI (\( R = .31, p = .03 \)). Likewise, accelerometer activity correlated significantly with VO_{2peak} (\( R = .73, p < .001 \)), LVEF (\( R = .43, p < .001 \)), and BMI (\( R = .35, p = .01 \)) but not with NTproBNP (\( R = .26, p = .073 \)). Meanwhile, pedometer activity only correlated significantly with VO_{2peak} (\( R = .55, p < .001 \)) and BMI (\( R = .42, p = .002 \)) but not with LVEF (\( R = .23, p = .10 \)) or NTproBNP (\( R = .12, p = .42 \)).

We performed a univariate regression analysis to assess which of the three activity measurements was predictive of VO_{2peak} without any additional influencing factors. AQ, pedometer, and accelerometer scores were all significantly associated with VO_{2peak} when assessed independently (\( p < .001 \); see Table 2). Subsequently, we performed a separate multivariable regression analysis for each activity measurement with VO_{2peak} as the dependent variable, each activity measurement as the independent variable, and BMI, age, LVEF, and NTproBNP as influencing factors. Here, too, the AQ score (\( p = .03 \)), pedometer score (\( p = .001 \)), and accelerometer score (\( p < .001 \)) were independently predictive of VO_{2peak} despite additional influencing factors. When we added NYHA class as an additional influencing factor, however, only the accelerometer score remained independently predictive of VO_{2peak} (\( p = .003 \); AQ and pedometer scores lost their significant association with VO_{2peak} (\( p = .66 \) and \( .09 \), respectively). This is also illustrated in Figure 1 (AQ score) and Figure 2 (pedometer score) as the range of scatter for each of the activity measurements increases with increasing VO_{2peak} (decreasing NYHA class), whereas accelerometer scores stay fairly linear throughout all three NYHA classes (Figure 3).

When we combined all independent cofactors into a multivariable regression model including all three physical activity measurements with VO_{2peak} as the dependent variable and LVEF, BMI, NTproBNP, age, and NYHA class as influencing
factors, only accelerometer activity remained independently associated with and predictive of VO_{2peak} \((B = 0.051 \pm 0.02; \ p = .014)\), whereas pedometer and AQ scores did not \((p = .82 \text{ and } p = .61, \text{ respectively})\).

Finally, we performed a discriminant analysis to assess the accuracy of prediction of each physical activity measurement in correctly classifying patients into their

### Table 2 Univariate and Multivariable Regression Analyses

<table>
<thead>
<tr>
<th>Regression Analysis</th>
<th>Univariate&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Multivariable&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(B \pm SE) (p)</td>
<td>(B \pm SE) (p)</td>
</tr>
<tr>
<td>Activity questionnaire (points)</td>
<td>.17 ± .04 &lt;.0001 \</td>
<td>.09 ± .04 .03 \</td>
</tr>
<tr>
<td>Pedometer (steps/day)</td>
<td>.0001 ± .0001 &lt;.0001 \</td>
<td>.001 ± .0001 .001 \</td>
</tr>
<tr>
<td>Accelerometer (walking in min/day)</td>
<td>.01 ± .013 &lt;.0001 \</td>
<td>.07 ± .014 &lt;.0001 \</td>
</tr>
</tbody>
</table>

<sup>a</sup>Dependent variable is VO_{2peak}. <sup>b</sup>Multivariable analysis including body-mass index (BMI; kg/m^2), age (years), % left-ventricular ejection fraction (LVEF%), and N-terminal pro-B-type natriuretic peptide (NTproBNP; pg/ml). <sup>c</sup>Multivariable analysis including BMI, age, LVEF%, NTproBNP (pg/ml), and New York Heart Association class.

**Figure 1** — Scatter plot showing the relation of VO_{2peak} and physical activity measured by means of activity questionnaire (AQ): \(n = 12\), New York Heart Association class (NYHA) I; \(n = 19\), NYHA II; and \(n = 19\), NYHA III. Estimated regression equation for VO_{2peak}: \(14.2 + 0.17 \times \text{AQ} \ (R = .57; \ p < .001)\).
Figure 2 — Scatter plot showing the relation of VO_{2peak} and physical activity measured by means of pedometer: \( n = 12 \), New York Heart Association class (NYHA) I; \( n = 19 \), NYHA II; and \( n = 19 \), NYHA III. Estimated regression equation for VO_{2peak}: \( 11.1 + 0.001 \times \text{steps} \) (\( R = .55; p < .001 \)).

Figure 3 — Scatter plot showing the relation of VO_{2peak} and physical activity measured by means of accelerometer: \( n = 12 \), New York Heart Association class (NYHA) I; \( n = 19 \), NYHA II; and \( n = 19 \), NYHA III. Estimated regression equation for VO_{2peak}: \( 8.9 + 0.098 \times \text{walking time} \) (\( R = .73; p < .001 \)).
Table 3  Discriminant Analysis: Test for Accuracy (%) of Prediction

<table>
<thead>
<tr>
<th>Measure</th>
<th>NYHA I</th>
<th>NYHA II</th>
<th>NYHA III</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity questionnaire (points)</td>
<td>67%</td>
<td>33%</td>
<td>80%</td>
<td>60%</td>
</tr>
<tr>
<td>Pedometer (steps/day)</td>
<td>42%</td>
<td>39%</td>
<td>75%</td>
<td>54%</td>
</tr>
<tr>
<td>Accelerometer (walking min/day)</td>
<td>59%</td>
<td>22%</td>
<td>95%</td>
<td>60%</td>
</tr>
</tbody>
</table>

Note. NYHA = New York Heart Association class. Percent correct classification of patients into the assigned NYHA class; each physical activity measurement is assessed separately.

NYHA class (Table 3). Both the AQ and accelerometer score reached an overall correct classification of 60% (AQ: 67% NYHA I, 33% NYHA II, 80% NYHA III; accelerometer: 59% NYHA I, 22% NYHA II, 95% NYHA III). The pedometer score (steps/day) was weakest in correctly classifying patients into their NYHA class, with only 54% overall correct classification (42% NYHA I, 39% NYHA II, 75% NYHA III). Although weakest in its singular predictive strength for NYHA I and III patients, the pedometer did show the highest accuracy of prediction for classifying NYHA II patients in comparison with the AQ and accelerometer-based measurements.

Discussion

The results of this study suggest that in patients with varying degrees of heart failure, daily activity measurements by means of accelerometer are more closely associated with clinical prognosis (VO₂peak) than questionnaire or pedometer-based measurements. This is supported by the strong correlation of accelerometer score with important prognostic parameters (VO₂peak, LVEF, and NTproBNP), in addition to its significant and independent association with VO₂peak in the regression analyses. Although all three physical activity measurements were significantly associated with VO₂peak in the univariate analysis, accelerometer score was the only consistent independent predictor of VO₂peak when all factors associated with clinical prognosis (NYHA class) were combined into a multivariable regression model. In addition, accelerometer score (walking min/day) showed the highest accuracy of prediction in discriminating between patients with mild versus more severe heart failure by correctly classifying 95% of NYHA III patients and 59% of NYHA I into their NYHA classes.

Overall correct classification incorporating the entire study population (NYHA I, II, and III) was equally strong in both accelerometer- and AQ-based measurements, whereas the pedometer (steps/day) showed highest singular discrimination strength in NYHA II patients only. The poor accuracy of prediction in pedometer score of NYHA I and III patients could be a result of the fact that NYHA III patients move too slowly for accurate pedometer step detection, whereas NYHA I patients also engage in many nonwalking activities. A similar statement can be made for the inaccuracy of prediction of NYHA I patients regarding the accelerometer. Here too, mostly ambulatory walking activity is measured, but because of higher movement-detection sensitivity, a much more detailed analysis of walking activity is provided. This is what seems to be decisive
in regard to its association with clinical prognosis (NYHA III). The poor accuracy of prediction strength in accelerometer score in correctly classifying NYHA II patients can be accounted for by the rather large heterogeneity in exercise capacity and activity levels in this subgroup. It also emphasizes the aspect that in higher activity levels (NYHA I) that tend to include more strenuous, non-walking-based ambulatory activities (i.e., swimming, biking, etc.), the AQ is probably a more suitable assessment technique. However, patients with stronger functional limitations adhere mostly to walking-based activities and low-intensity activities such as small steps around the house (including getting up and sitting down), which are better detected by the accelerometer than the pedometer and hard to recall on an AQ. Nevertheless it must be emphasized that pedometers are much more cost-effective (≤$50) than accelerometers (≥$300). Cheaper pedometers might be available, but the improved sensitivity and sophistication of pedometers suggests that cheaper is not better and consumers should consider pedometers in a $30–50 range.

These findings suggest a potential usefulness of activity monitoring by means of accelerometer in patients with varying disease severity, which might enable the identification of individuals with more advanced stages of heart failure. Timely detection of disease progression is critical in facilitating conventional therapy and guiding the rehabilitation progress in patients with heart failure.

Total activity assessed by the AQ showed a moderate but significant correlation with prognostic parameters but failed to be independently predictive of VO2peak. This is most likely because our study population was composed of individuals in whom walking is the predominant activity. Little bouts of walking, however, are difficult to recall and thus often underestimated. This is a clear limitation of recall questionnaires and supports the use of more objective measures of physical activity (Ainsworth, 2009). Similar findings have been reported by other investigators showing a marked underestimation of questionnaire-based activity in direct comparison of both methods (Bassett et al., 2000; Sequeira, Rickenbach, Wietlisbach, Tullen, & Schutz, 1995). This is most likely because of the nature of the AQ; it is limited to measuring purposeful activity in terms of exercise or transport as opposed to ubiquitous movement associated with daily living (Bates et al., 2005; Lee & Buchner, 2008).

In the current study mean age of NYHA I patients was over 70 years, leading to the assumption that an underestimation of the AQ could be a result of poor recollection of the participants (Harris, Owen, Victor, Adams, & Cook, 2008). However, difficulties in accurately recalling weekly activity from memory have also been observed in younger participants, indicating that memory skills are not entirely age dependent and that questionnaire outcome is not entirely memory dependent (Epstein, Paluch, Coleman, Vito, & Anderson, 1996). Part of the problem lies in the difficulty of differentiating between recent versus habitual activity and underlines the fact that different activity dimensions are being measured in the AQ than by motion sensors (Miller et al., 1994). Moreover, the actual performance and memory of a skill depends on the individual’s perceived ability to accomplish that skill and its associated level of difficulty (Garet et al., 2004). This explains why most individuals without symptom limitations do not recall effortless, mundane activities but focus their attention more on vigorous activities in terms of exercise when completing a questionnaire.
Jehn et al.

Pedometer count of total steps per day also showed a moderate correlation with prognostic parameters but was also unable to independently predict VO2peak. In addition, it had the lowest predictive value in terms of identifying patients with more advanced heart failure (NYHA III) and overall. The benchmark of 3,500–5,000 steps/day has been set for sedentary individuals and those with chronic diseases (Tudor-Locke, Hatano, Pangrazi, & Kang, 2008; Tudor-Locke & Bassett, 2004), and less than 25,000 steps/week has been associated with an increased mortality risk in patients with heart failure assessed by means of pedometer scores (Walsh et al., 1997). Our participants all had step counts of 5,000–9,999 steps/day, which is in the low-active to somewhat active category (Tudor-Locke & Bassett, 2004). This might be partly a result of their motivation (Bravata et al., 2007), in addition to the improved technologies (pendulum vs. piezoelectric) with which pedometers are equipped these days, allowing steps to be detected more precisely even at slow walking speeds (Hendelman, Miller, Baggett, Debold, & Freedson, 2000; Holbrook, Barreira, & Kang, 2009). Considering the evidence suggesting that 30 min of minimally moderate walking translates into 3,000–4,000 steps (Tudor-Locke, Sisson, Collova, Lee, & Swan, 2005), our participants should have presented with even higher actual step counts when directly comparing the relationship between pedometer-based steps per day and accelerometer-based walking time per day in this study. The only explanation we have for this discrepancy is that participants moved at relatively slow walking speeds and that a significant portion of this walking time is accumulated by intermittent walking and standing as opposed to continuous walking.

There are several limitations to this study. The AQ-based activity levels were computed by means of a cumulative weekly activity score, whereas both pedometer and accelerometer data were analyzed according to daily activity (steps/day or min/day). In addition, we only covered 6 days of activity with the motion sensors, whereas the AQ was based on a typical 7-day week. It seems unlikely that this incongruity in the number of assessment days greatly affected our data outcome, but we cannot exclude the possibility. Finally, our study population was small, and the cross-sectional study design limits any conclusions about the prognostic significance of our findings. Clearly, a longitudinal study with a larger patient group is required to validate these findings to better understand the association of daily activity and clinical prognosis, especially in patients with stronger functional impairment.

In conclusion, accelerometer-based activity measurements showed the strongest association with VO2peak and other prognostic parameters when comparing three different methods of assessing physical activity levels in individuals with various degrees of heart failure. Our data suggest that accelerometer-based physical activity measurements are indicative of overall exercise capacity and are the strongest predictor in discriminating patients with mild (NYHA I) from more advanced stages (NYHA III) of heart failure. Not only targeted walking but also ubiquitous walking associated with daily living seems to play a contributing role in terms of clinical prognosis. In other words, “every step counts.” In this regard, accelerometers enable a more detailed analysis of activity. This should be taken into consideration when documenting physical activity in large epidemiological studies or monitoring patient progress in rehabilitation programs.
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