Agreement Between Activity-Monitoring Devices During Home Rehabilitation: A Substudy of the AAA STOP Trial

Jonathan Myers, Mandi Dupain, Andrew Vu, Alyssa Jaffe, Kimberly Smith, Holly Fonda, and Ronald Dalman

As part of a home-based rehabilitation program, 24 older adult patients (71 ± 3 years) with abdominal aortic aneurysm (AAA) disease underwent 3 days (12 awake hr/day) of activity monitoring using an accelerometer (ACC), a pedometer, and a heart rate (HR) monitor, and recorded hourly activity logs. Subjects then underwent an interview to complete a 3-day activity recall questionnaire (3-DR). Mean energy expenditure (EE) in kcals/day for HR, ACC, and 3-DR were 1,687 ± 458, 2,068 ± 529, and 1,974 ± 491, respectively. Differences in EE were not significant between 3-DR and ACC, but HR differed from both ACC (p < .001) and 3-DR (p < .01).

ACC and 3-DR had the highest agreement, with a coefficient of variation of 7.9% and r = .86. Thus, ACC provided a reasonably accurate reflection of EE based on the criterion measure, an activity recall questionnaire. ACC can be effectively used to monitor EE to achieve an appropriate training stimulus during home-based cardiac rehabilitation.

Keywords: abdominal aortic aneurysm, exercise training, energy expenditure, physical activity, heart rate, accelerometry

Among patients who have experienced a cardiac event, exercise training has become widely recommended to restore optimal physical and psychosocial function. Benefits of exercise training include increases in exercise tolerance, improved skeletal muscle metabolic capacity, improved endothelial function, and improved quality of life (Leon et al., 2005). Formal programs of cardiac rehabilitation have consistently been shown to reduce health care costs (Lee, Strickler, & Shepard, 2007) and improve survival (Smart & Marwick, 2004; Taylor et al., 2004). In a recent Cochrane meta-analysis, patients with cardiovascular disease who participated in cardiac rehabilitation exhibited a 26% reduction in cardiovascular mortality versus usual care (Smart & Marwick, 2004). National and international guidelines have therefore identified exercise therapy as a central element for the restoration of health following a cardiac event (Corra et al., 2005; Leon et al., 2005). Despite its demonstrated benefits, rehabilitation is dramatically underutilized; in a recent meta-analysis, only 14% of eligible patients were referred for cardiac rehabilitation (Suaya et al., 2007).

Studies have shown that the reasons for underuse of rehabilitation include inadequate insurance coverage, lack of physician referral, and lack of accessibility and transportation (Gravely-Witte et al., 2010; Suaya et al., 2007). In light of these barriers to rehabilitation, creative strategies have been employed to increase participation and reduce costs. One option that has been employed to lower costs and expand delivery of rehabilitation and secondary prevention is home-based programs (Leon et al., 2005; Taylor, Dalal, Jolly, Moxham, & Zawada, 2010). Over the last two decades, home-based programs have become standard in many health care systems in the United States; however, the convenience and reduced costs associated with home-based programs are balanced by a reduced ability to provide accurate surveillance of physical activity. One of the challenges to implementing home programs is assuring that patients remain motivated and that they achieve an adequate and appropriate training stimulus. Self-report instruments have been widely used in the epidemiologic literature, and objective tools such as pedometers, heart-rate (HR) monitors, and accelerometers have been commonly used in short-term assessments of energy expenditure (EE; Corder, Brage, & Ekelund, 2007; Prince et al., 2008; Vanhees et al., 2005). However, less is known regarding the application of these tools in the context of home-based cardiac rehabilitation, in which compliance to an exercise prescription has implications not only for health benefits, but also for cost effectiveness and safety. A better understanding of methods to monitor physical activity in patients with cardiovascular disease would help optimize the design and implementation of these programs.
We recently completed a National Heart, Lung and Blood Institute–sponsored Specialized Center of Clinically Oriented Research Program in older adult patients with abdominal aortic aneurysm (AAA) disease termed AAA STOP. The study was a randomized, prospective longitudinal trial to test the ability of supervised exercise training to modify AAA biology and early disease progression. As a measure of validation for our approach to a combined center-based/home exercise program, we performed a substudy to evaluate agreement between monitoring devices to quantify EE. The home-based rehabilitation setting provided an opportunity to assess the convergent validity of these tools as estimates of EE. Because it has been validated in numerous studies using metabolic rate as the standard, a 3-day activity recall (3-DR) instrument was used as the primary indicator of EE. We hypothesized that combining physiological data (such as HR) and mechanical data (movement recorded by acceleration) would overcome limitations with either method alone.

Methods

Subjects

Twenty-four subjects (mean age 71 ± 3 years) with AAA disease participating in a home-based exercise program were studied. The sample was a convenience subgroup of the AAA STOP trial. “Small” AAA was defined as an aortic diameter ≥3.0 and <5.0 cm. Recruitment procedures, ethical concerns, and all study-related activities were reviewed and approved in advance by an institutional review board at Stanford University and an independent data safety-monitoring board organized by the National Heart, Lung and Blood Institute. Informed written consent was obtained from each participant using a protocol approved by both Stanford University and the data safety-monitoring board.

Exercise Program

Participants randomized to the exercise group began the study in a supervised, in-house exercise orientation program before graduating to a home program. As part of the orientation program, subjects were provided an individualized exercise prescription, educational materials, and counseling regarding program requirements. Subjects were counseled to participate for a minimum of 45 min of moderate physical activities daily and to document their activities using hourly logs. A case management approach was employed, in which subjects were contacted weekly to review activity logs, and a weekly activity recall questionnaire was completed. These weekly interviews served the purposes of recognizing study-related complications, quantifying EE, and encouraging subjects to comply with exercise prescriptions. For the current substudy, each subject was contacted twice during a 3-day data collection period to encourage physical activity, review activity logs, and ascertain that the monitoring equipment was working properly.

Assessment of EE

EE data were acquired for 3 consecutive weekdays (awake hours from 7 a.m. to 7 p.m.), during which the subjects were encouraged to perform their normal activities at home. As part of the rehabilitation program, subjects were instructed to include a minimum of 45 min each day dedicated to aerobic activity in accordance with their individualized exercise prescription. Subjects were given an accelerometer (ACC; ActiGraph model GT1M, Pensacola, FL), an HR monitor (Polar model F6, Polar USA, Lake Success, NY), a pedometer (Omron 720-ITC, Bannockburn, IL), and daily activity logs. At the initiation of the study, the HR and ACC monitors and the pedometer were connected to the subject, procedures for their use were reviewed, and recording began. After the data collection period, hourly activities were reviewed with each subject either in person or by phone, during which a 3-DR was completed. Previously validated equations were used to transform HR and ACC data into kilocalories (Crouter, Clowers, & Bassett, 2006; Fogelholm et al., 1998; Spurr et al., 1988).

Participants were provided with activity recording logs, divided into 10-min segments from 7 a.m. to 7 p.m. each of the 3 days. Subjects were instructed to be as precise as possible in recording activities performed during this 36-hr period, including the precise activity performed and its duration. These activity logs were used to assist subjects when the 3-DR interview was conducted. The 3-DR was used as the criterion measure for EE. The 3-DR is similar to widely used 5- and 7-day recall tools (Richardson, Ainsworth, Jacobs, & Leon, 2001), but used for 3 days. The questionnaire was interviewer-administered, took about 10 min to complete, and included work and leisure time activities for the previous 3 days during which the activity devices were worn. Each activity was ascribed a metabolic equivalent (MET) value in accordance with the American College of Sports Medicine Compendium of Physical Activities (Ainsworth et al., 2000). MET-min/day were computed (the product of energy cost in METs and duration of activity in minutes), and using the formula 1 MET = 1 kcal · kg body weight⁻¹ · hr⁻¹, EE was expressed in kcal/day.

The ACC employed was a small (3.8 × 3.7 × 1.5 cm) lightweight (42.6 g) uniaxial device that measured acceleration in the vertical plane. The device was placed on the anterior superior iliac spine along the anterior axillary line. Detailed specifications of the monitor are published elsewhere (Chen & Bassett, 2005; Crouter, Clowers, & Bassett, 2006). The device is sensitive to acceleration from 0.05 to 2.0 g and has a bandwidth frequency of 0.25–2.5 Hz. It samples at a rate of 10 Hz and the signal is digitized by an 8-bit A/D converter. It was initialized to collect data in 1-s epochs, and the results were downloaded directly to a PC-compatible computer using a USB cable. The amount of EE and the cutoff points defining moderate, vigorous, and high-intensity activities were calculated using the formula of Freedson, Melanson, and Sirard (1998) as recommended by the
manufacturer; the algorithm described by Crouter et al. (2006) was used to convert ACC data into METs, and kcals/min were computed.

The Polar HR monitor was worn around the chest at the level of the xiphoid process and secured with an elastic strap. At the start of the study, the monitor was initialized with participant information (height, weight, age, gender, resting and maximal HR, and peak VO₂). HR was recorded every 5 s for the duration of data collection. The Polar watch was synchronized with the accelerometer using the same laptop computer at the beginning of data collection for each subject.

To express energy expenditure in kilocalories, the “flex” method was used as described previously (Fogelholm et al., 1998; Spurr et al., 1988), in which EE is estimated from individual linear regressions (EE = constant + slope × HR). The flex method is designed to reduce variability in the HR–EE relationship between subjects by applying each individual’s regression between HR and VO₂ during a maximal cardiopulmonary exercise test performed before entry into the rehabilitation program.

Pedometer recordings were initialized following duplicate measurements of stride length using a hallway walk over a distance of 30 ft (~9 m). The pedometer was zeroed at the beginning of the study and attached to the hip. The device has a 7-day memory, and steps were recorded continuously for the duration of participation. Pedometers quantify steps but generally do not accurately quantify kcals expended from a wider range of activities (Corder et al., 2007; Vanhees et al., 2005).

However, because total daily steps have been considered surrogates for broader measures of EE (Bassett, Cureton, & Ainsworth, 2000; Corder et al., 2007; Vanhees et al., 2005), we included total daily steps in the analyses.

**Statistical Analysis**

Data are presented as $M \pm SD$. Differences between EE estimated by 3-DR, HR, and ACC were compared using ANOVA. Post hoc tests were performed using the Bonferroni correction. Linear correlation and intraclass correlation coefficients were used to assess the associations between 3-DR, ACC, HR, and pedometry, and coefficients of variation were calculated to express variation in EE as a percentage relative to the mean. Bland-Altman plots were constructed to graphically illustrate the variance between estimates of EE. These analyses were performed for each of 3 days of surveillance for each subject. Forward step-wise multiple regression was performed to assess multivariate determinants of EE using the 3-DR as the criterion.

**Results**

Clinical and demographic information of the study population are presented in Table 1. The sample was 90% male and overweight (mean BMI 29.3 ± 6 kg/m²); 89% were on antihypertensive therapy, and 83% were taking statins. While no subject was smoking at the time of the study, there was a mean 35 ± 25-packs/year history of smoking. Peak oxygen uptake (21.3 ± 4.8 ml · kg⁻¹ · min⁻¹) represented 81.2% of the age-predicted value (Wasserman, Hansen, Sue, Stringer, & Whipp, 2005).

Total average kcal/day expended for HR, ACC, and 3-DR were 1,687 ± 458, 2,068 ± 529, and 1,974 ± 491, respectively. Differences in EE were not significant between 3-DR and ACC, but EE estimated from HR was lower than both ACC ($p < .001$) and 3-DR ($p < .001$). The coefficient of variation between HR, ACC, and 3-DR was 26.9%. Agreement between ACC alone and 3-DR was superior, with a coefficient of variation of 7.9%.

EE estimated from ACC was strongly associated with the 3-DR questionnaire ($r = .86, p < .001$, Figure 1), whereas EE from HR (Figure 2) and total steps measured...
by pedometry were modestly associated with 3-DR ($r = .45$, $p < .01$ and $r = .47$, $p < .01$, respectively). The respective regression equations for predicting EE from ACC and HR were kilocalories from 3-DR = $312 + 0.80 \times$ kilocalories from ACC, $F(1, 65) = 13.5$, $p < .001$, and kilocalories from 3-DR = $1,154 + 0.49 \times$ kilocalories from HR, $F(1, 66) = 4.1$, $p < .001$. A Bland-Altman plot comparing ACC with 3-DR (Figure 3) revealed a nonsignificant bias of $-95$ kcal and 95% limits of agreement of $-630$ to $440$ kcal. A Bland-Altman plot comparing HR with 3-DR (Figure 4) revealed a significant bias of $-377$ kcal ($p < .001$) and 95% limits of agreement of $-1,515$ to $762$ kcal. The intraclass correlation coefficient between the three estimates of EE was $.64$ ($p < .001$). By multiple regression, ACC was a significant predictor of 3-DR ($R^2 = .74$, $p < .001$), whereas HR and pedometer steps added minimally to the model ($R^2 = .04$ and $.004$, respectively). Adding age and peak VO2 to the model did not improve the estimation of EE.

**Discussion**

The primary aim of the current study was to assess agreement between several commonly used tools to estimate EE and to examine how these tools could be applied broadly in a home-based cardiac rehabilitation.
Figure 3 — Bland-Altman plot between estimated energy expenditure from 3-day activity recall and energy expenditure estimated from accelerometer.

Figure 4 — Bland-Altman plot between estimated energy expenditure from 3-day activity recall and energy expenditure estimated from heart rate.
setting. This evaluation provided a measure of convergent validity (the degree to which an instrument’s output is similar to other instruments designed to measure the same thing), as well as providing a measure of validity for the approach to activity surveillance used in the larger AAA STOP trial. We hypothesized that combining physiological data (such as HR) and mechanical data (movement recorded by acceleration) would overcome limitations with either method alone, and more precisely estimate EE. We observed that EE estimated from ACC was strongly associated with the criterion, 3-DR (Figure 1). Although EE estimated from HR and pedometry had significant independent associations with 3-DR, they added minimally to the multivariate prediction of EE estimated by 3-DR. These results suggest that an ACC device provides reasonable estimates of EE in patients participating in a home rehabilitation program, and the routine or intermittent application of such a device may be effective for assessing surveillance of EE, improving compliance, and quantifying adherence to training targets among participants in home programs.

We employed four indirect tools to assess EE. Direct measures of EE (e.g., a portable VO$_2$ system or doubly labeled water) are the most accurate techniques, and the fact that these were not employed is a limitation of our study. We also used the daily recall/interview method as the criterion because this method has been validated in numerous studies using metabolic rate as the standard (Racette, Schoeller, & Kushner, 1995; Washburn, Jacobsen, Sonko, Hill, & Donnelly, 2003), provides activity type and intensity not available with monitoring devices, and is most applicable to broader estimates of EE germane to the rehabilitation setting (Le Grande, Elliott, Worchester, Murphy, & Goble, 2008). The 3-DR was compared with ACC because the latter is simpler to use, and while extensively studied, little is known regarding its applications to home-based cardiac rehabilitation. In addition, we used 3 consecutive days of wear, as this duration has been shown to be the period required to provide a reliable reflection of broader habitual activity patterns (Washburn et al., 2003). It should also be noted that there has been a wide variety of methods employed to estimate EE using monitoring devices, including differences in placement, data sampling, and equations to convert data to EE (Chen & Bassett, 2005; Corder et al., 2007; Vanhees et al., 2005). Our objective was not to validate or improve upon previous methods; rather, our aim was to determine the validity of these devices in the context of a home rehabilitation program. We therefore used methods validated by others, equations recommended by the manufacturers, or both (Corder et al., 2007; Crouter et al., 2006; Fogelholm et al., 1998; Spurr et al., 1988).

Among the methods used to estimate EE, the superior association between ACC and the criterion, 3-DR, is evidenced by the strong correlation and lower bias compared with HR (Figures 1 and 2). The coefficient of variation between ACC and 3-DR (7.9%) suggests a high level of agreement between these two methods. Relative to ACC, the associations observed between EE estimated from 3-DR, HR recordings, and pedometer steps were modest ($r = .45$ and .47, respectively). Because HR is a close correlate of metabolic rate and is easy to measure, it has long been the primary metric used for the purposes of individualizing an exercise prescription. HR monitors have also been widely used to predict EE because modern recording devices can store large amounts of continuous HR data over several days (Strath, Brage, & Ekelund, 2005). However, while HR accurately reflects EE during a given bout of moderate exercise, the relationship between EE and HR is not linear at rest or low levels of exercise because it is confounded by factors other than energy demands, including caffeine, stress, smoking, body position, and others (Livingstone, 1997; Vanhees et al., 2005). This may in part explain the less precise estimate of EE using HR during daily activities in the current study. The association between EE estimated from HR and 3-DR in the current study, while modest, was in the range typical of previous studies (Harris et al., 2009; Prince et al., 2008). In a recent review, the mean difference between EE estimated from HR monitoring and self-reported activity was ~20% (Prince et al., 2008). The overall 15% difference between EE from HR and self-report we observed compares favorably to these earlier studies.

A number of recent studies have reported an improvement in the prediction of EE by combining HR monitoring with ACC (Corder et al., 2007; Le Grande et al., 2008; Prince et al., 2008; Strath et al., 2005; Vanhees et al., 2005), although we did not find this to be the case. Generally, these studies have reported incremental improvements in $R^2$ values from the range of .50–.60 for ACC alone, to .70–.90 for combined HR and ACC (Corder et al., 2007; Corder, Brage, Wareham, & Ekelund, 2005; Strath et al., 2005). In contrast, we observed an $R^2$ of .78, with the majority of the variance (.74) explained by ACC. Our findings are similar to those of Corder et al. (2005), who studied a series of controlled activities in children and reported that ACC explained most of the variance in EE ($R^2 = .87$), while the combination of HR and ACC improved the prediction only slightly ($R^2 = .90$). Notably, many previous studies have assessed EE over specified periods of time (often a few hours) under controlled conditions, while we studied EE over the spectrum of activities of daily living during 3 days, undoubtedly introducing more variability.

The assessment of physical activity using ACC has an extensive history in the literature, as evidenced by the number of reviews and meta-analyses in this area (Chen & Bassett, 2005; Corder et al., 2007; Le Grande et al., 2008; Livingstone, 1997; Prince et al., 2008; Vanhees et al., 2005). The association between ACC and 3-DR in the current study (.86) is considerably stronger than that in most previous investigations, in which this relationship has been reported to vary widely in the range of .40–.70 (Corder et al., 2007; Harris et al., 2009). These differences are no doubt attributable in part to variability in methods, including differences in the criterion measure which has included both direct (e.g., measured VO$_2$
or doubly labeled water) and indirect (questionnaire) assessments. Our approach differed somewhat from other indirect studies in that we requested subjects to carefully maintain daily activity logs; the 3-DR interview was performed in combination with a review of each subject’s activity log, and specific MET levels were ascribed to all activities over a 36-hr period. This contrasts other studies that have only generally categorized activities as low, moderate, and high (Vanhees et al., 2005), likely resulting in less precise estimates of EE. Under- and overestimation of EE by questionnaire has been shown to be influenced by many factors, including the method used (self- or interviewer-administered), complexity of the questionnaire, age, seasonal variation, and length of period surveyed (e.g., 3–10 days; Corder et al., 2007; Klesges et al., 1990; Vanhees et al., 2005).

Although pedometers are widely used in surveys of activity patterns, including cardiac rehabilitation programs (Corder et al., 2007; Racette et al., 1995), we did not expect pedometer steps to be closely associated with broader measures of activity. Pedometers measure volume of walking and have been used as motivational tools (Bravata et al., 2007; Gardner & Campagna, 2011)—or surrogates for broader measures of EE (Basset et al., 2000)—but would be unlikely to accurately capture activities other than walking. In addition, these devices cannot determine walking speed, and therefore exercise intensity based on a pedometer is unknown. The modest but significant associations between EE from the pedometer, 3-DR, and ACC ($r = .40$–.60) reflect the fact that while step-based ambulation accounts for a significant proportion of EE from activity in most individuals (Basset et al., 2000), it does not account for the many activities that do not involve walking.

**Clinical Implications**

Home rehabilitation programs are increasingly common, and ensuring an exercise stimulus that is safe and will facilitate health benefits is important to document. Because the typical cardiac rehabilitation session has been reported to be associated with an EE of ~250 kcal (resulting in a total EE of 700–800 kcal/week; Savage, Brochu, Scott, & Ades, 2000; Schairer et al., 1998), additional activity outside the rehabilitation setting is required to achieve an EE of 1,000–2,000 kcal/week widely recommended for health benefits. Although activity recall instruments (such as the 3-DR) have been widely used and validated, the current results suggest that the ACC is another option to provide reasonable estimates of EE in a home-based cardiac rehabilitation program. In addition to estimating EE, this information is important for maintaining an appropriate exercise prescription, patient motivation, validating activity reports, and the like.

**Limitations**

A true validation of EE would require continuous monitoring of activity and comparison with a standard; however, we did not have direct measures of EE such as oxygen uptake or doubly labeled water. EE was estimated for a relatively short period of time (36 hr), during which the subjects were aware they were part of a study; the results would likely be different in a more general cardiac rehabilitation setting. Different ACC filter settings may have more optimally captured lower level activities in our sample of older adults, and we did not collect data using different filter settings. The subjects were a convenience sample of adult patients from the AAA-STOP trial, and the results may differ in younger, more typical (e.g., post-myocardial-infarction) patients participating in a rehabilitation program.

**Summary**

ACC provides an acceptably accurate reflection of EE based the criterion measure, an activity recall questionnaire. The inclusion of HR and pedometry added minimally to the multivariate estimation of EE. ACC can effectively be used as a tool to document the adequacy of a training stimulus as part of surveillance during home-based cardiac rehabilitation.

**Acknowledgments**

Clinicaltrials.gov identifier: NCT00349947

**References**


