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Validation of Measures by the Lifecorder EX Activity Monitor

Scott Andrew Schmidt

University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Scott Andrew Schmidt entitled "Validation of Measures by the Lifecorder EX Activity Monitor." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Exercise Science.

Dixie L. Thompson, Major Professor

We have read this thesis and recommend its acceptance:

Edward T. Howley, David R. Bassett, Jr.

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Validation of Measures by the Lifecorder EX Activity Monitor

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Scott Andrew Schmidt

May 2006

Dedication

This thesis is dedicated to my wife Angie and to my parents Jerry and Betsy Schmidt. Their constant encouragement and belief in me is greatly appreciated.

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I would like to thank all of those who helped me complete my Master of Science degree in Exercise Science. I thank my committee, Dr. Dixie Lee Thompson, Dr. Edward T. Howley, and Dr. David R. Bassett Jr. for sharing their knowledge and supporting me in this endeavor. I appreciate Carolyn Albright's advice and assistance with laboratory testing and I thank all of the individuals who volunteered to participate in this study.

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Abstract

The purpose of this study is to determine the validity of the Lifecorder EX activity monitor in calculating resting metabolic rate, counting steps taken at a variety of speeds, reporting energy expenditure across a range of intensities, and categorizing exercise intensity in descriptive units as light (1-3), moderate (4-6), and vigorous (7-9). Ten male (24.6 ± 5.3 years) and ten female (26.6 ± 5.1 years) recreationally active adults participated in this study. Height, weight, resting metabolic rate, and body composition were measured prior to performing treadmill exercise at 9 speeds (54, 67, 80, 94, 107, 121, 134, 147, 161 $m \cdot min^{-1}$), while wearing a Lifecorder EX activity monitor on both the right and left hips. Walking stages were performed for four minutes and running stages were performed for six minutes. Each stage was followed by a two-minute rest period. Energy expenditure was determined by indirect calorimetry and steps were tallied using a hand counter. In a separate trial subjects wore the activity monitor for 24-hours and met the investigator for a 30-minute exercise session on a 400-meter rubberized track. Subjects were randomized into one of three groups: a 30-minute run, 30-minute walk, or three 10-minute walks. The device significantly undercounted steps at the two slowest speeds (92.0% of actual at 54 $m \cdot min^{-1}$ and 98.9% of actual at 67 $m \cdot min^{-1}$), but accurately reported steps at speeds $\geq$ 80 $m \cdot min^{-1}$. Both gross and net caloric expenditure were overestimated at all tested speeds except walking at 134 $m \cdot min^{-1}$. On average, the device underestimated resting metabolic rate by 11.4%. The relationship between accelerometer reported intensity units and measured MET requirement was also determined. The Lifecorder EX has step counting accuracy comparable to other activity monitors studied in the recent past. Although the device overestimated both gross and net caloric

expenditure the intensity units offered can be beneficial for helping describe an individual's physical activity pattern. The underestimation of resting metabolic rate is comparable to the error seen in many resting metabolic rate equations.

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CHAPTER I

INTRODUCTION

The importance of living a physically active lifestyle is widely understood. Leading an inactive life can lead to increased risk of obesity, coronary heart disease, type 2 diabetes, hypertension, and hyperlipidemia (55). Research has shown improvements in, or prevention of, many of these conditions by participating in physical activity (6, 20, 27, 31, 32, 34, 35, 38, 45, 49, 62, 63). More active individuals have lower incidence of coronary heart disease (31, 38, 45), hypertension (6) and hyperlipidemia (27, 62). It has also been found that physical activity can improve glucose tolerance (49), prevent type 2 diabetes (32), lower blood pressure (34, 35, 49), and improve the lipid profile (20).

The exercise science, public health, and fitness communities have offered goals and recommendations for improving health by increasing daily activity levels. The American College of Sports Medicine (ACSM), Centers for Disease Control and Prevention (CDC), and the United States Surgeon General recommend participating in at least 30 minutes of moderate intensity physical activity on most, preferably all, days of the week (39, 55). It is important to understand how moderate intensity is defined. The classification of physical activity intensity can be described in terms of Metabolic Equivalents (METS). The MET number is calculated by measuring the amount of oxygen consumed by the individual and comparing it to resting metabolic rate. One MET is the energy required to sustain the body at rest and has been standardized as 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$. Activities requiring less than 3 METS are generally considered light intensity, those requiring 3-6 METS are considered moderate, and activities requiring more than 6 METS are termed vigorous (15). Generally, walking at speeds of 3-4 miles per hour is considered moderate intensity (60).

An accurate understanding of exercise intensity is important since intensity determines the physiological effects on the body. Measurement of an individual's exertion during exercise has become quite common in a laboratory setting through the use of metabolic analysis systems. However, this type of measure is impractical for the general public due to the need for expensive scientific equipment. Therefore, it is important to find an objective means of measuring physical activity that can be utilized by individuals in an everyday setting.

Activity monitors such as pedometers and accelerometers are becoming increasingly popular devices for objectively measuring physical activity both inside and outside of the laboratory. While pedometers can be accurate tools for counting steps, these devices are unable to assess the intensity of physical activity. Accelerometers are designed to perform this function of measuring intensity. The assessment ability of these monitors depends on the construction of the device. An activity monitor can have one of three internal measurement mechanisms. The most basic is a horizontal lever arm that moves up and down due to movement of the body felt at the waist. This displacement causes an opening and closing of an electrical circuit, which registers a step. The second mechanism is a magnetic reed proximity switch. This mechanism consists of a magnet connected to a horizontal lever arm. When a step is taken, the vertical acceleration of the hip causes the lever to move up and down. The magnetic field triggers the glass encased proximity switch to register a step. The third mechanism is an accelerometer consisting of a horizontal beam and piezoelectric crystal. When steps are taken and vertical acceleration is plotted against time, a sinusoidal curve is charted. Intensity of activity and caloric expenditure can be determined based upon the degree of vertical acceleration. Steps are registered by zero crossings of the acceleration vs. time curve (12).

Pedometers and accelerometers are potentially powerful tools for assessing physical activity. These devices differ in their measurement capabilities. Accelerometers are designed to distinguish intensity and pattern of physical activity, while pedometers offer an accumulation of activity reported as steps and/or distance and sometimes estimate caloric expenditure. Pedometers offer immediate feedback by displaying activity data on the display face where, in most cases, accelerometer data must be downloaded and converted into descriptive results. The Lifecorder EX combines the capabilities of a pedometer and accelerometer. This device counts steps, estimates resting metabolic rate, determines caloric expenditure, categorizes physical activity into 9 intensity zones, stores data for up to 200 days, and transfers data to a personal computer where reports and charts are created showing trends in the individual's activities. The pedometer characteristic allows immediate feedback on the digital display while the accelerometer function allows data to be downloaded to a personal computer and displayed as intensity units over the entire course of the day. Therefore, this device can give immediate feedback or can be used to reflect on daily activity pattern. This new device allows the user to define daily goals and therefore can be useful for helping individuals reach many different physical activity goals such as accumulating 10,000 steps per day, participating in 30 minutes or more of moderate intensity activity, or reaching a desired caloric expenditure. However, this information is only valuable if it is accurate. Recent research has shown the older model Lifecorder to be accurate in measuring steps (12, 42, 43) and classifying activity levels (28), but to underestimate total daily energy expenditure and resting metabolic rate (28). Crouter et al. (12) found that the Lifecorder was within ± 1% of actual step count at speeds of ≥ 80 m/min on a treadmill, while Schneider et al. found that the Lifecorder was within ± 3% of actual steps taken during a 400-meter outdoor walk (43) and reported mean values that were not significantly different from the criterion Yamax Digiwalker SW-200 during a 24-hour measurement period (42). Kumahara et al. (28) found a strong correlation between the Lifecorder's reported activity levels and measured MET levels, but also found that the Lifecorder tended to underestimate total daily energy expenditure by an average of 8% when compared to energy expended measured in a metabolic chamber and underestimated basal energy expenditure by 7% compared to sleeping metabolic rate.

Since the validation studies of the Lifecorder, the new version, Lifecorder EX, has been developed. New features of this device include increased memory storage capacity and improved software capabilities such as key lock and measurement standby. The accuracy of this device to measure volume and intensity of physical activity has yet to be validated.

Purpose

The purpose of this study is to determine the validity of the Lifecorder EX activity monitor in calculating resting metabolic rate, counting steps taken at a variety of speeds, reporting energy expenditure across a range of exercise intensities, and categorizing exercise intensity in descriptive units as light (1-3), moderate (4-6), and vigorous (7-9).

Hypotheses

Based on activity monitor studies of the past we hypothesize that the Lifecorder EX activity monitor will underestimate steps at the two slowest speeds and will count steps accurately at all other tested speeds. The device will likely underestimate resting metabolic rate, gross energy expenditure, and net energy expenditure. The Lifecorder EX activity units will not be equivalent to measured MET units.

CHAPTER II

LITERATURE REVIEW

Physical Activity Recommendations

As we continue to learn more about the detrimental effects of living an inactive lifestyle, the exercise science, public health, and fitness communities have provided recommendations for improving health by increasing daily activity levels. Studies have shown improvements in, or prevention of many adverse conditions by participating in physical activity (6, 20, 27, 31, 32, 34, 35, 38, 45, 49, 62, 63). The American College of Sports Medicine (ACSM), Centers for Disease Control and Prevention (CDC), and the United States Surgeon General recommend that every American adult should strive to participate in at least 30 minutes of moderate intensity physical activity on most, preferably all, days of the week (39, 55). The addition of a 30 minute moderate intensity bout of exercise will come at a cost of approximately 150 kilocalories (55).

Another approach to increasing daily physical activity is through the 10,000 steps per day program. According to Tudor-Locke and Bassett (53) the 10,000 steps program origin can be traced to Japanese walking clubs and a pedometer manufacturer's slogan in the 1960's and this value is a reasonable estimate of the daily activity level of healthy adults. Dr. Yoshiro Hatano (17, 18) is a major advocate of striving to accumulate 10,000 steps per day. According to Hatano (18) accumulating 10,000 steps equates to approximately a 300-400 kilocalorie expenditure. Studies have shown improvements in blood pressure (17, 23, 34, 49) and glucose tolerance (49) when sedentary individuals increase their daily walking to accumulate at least 10,000 steps per day. Recent research has shown that the 10,000 steps program is a possible means of reaching the 30-minute recommendation. Wilde et al. (61) found that when sedentary women were asked to perform 30 minutes of walking in addition to their normal activity, they accumulated approximately 10,000 steps. Similarly, Le Masurier et al. (29) found that individuals who accumulate 10,000 steps are likely to meet the 30 minute recommendation, and Welk et al. (58) found that 73% of individuals who walked 30 minutes per day reached 10,000 steps. Hultquist et al. (22) recently found that when previously sedentary middle-aged women added a 30 minute brisk walk to their daily activity, 9505±326 steps were accumulated. Jordan et al (25) attempted to quantify the number of steps associated with 50, 100, and 150% of the 30 minute physical activity recommendation. The sedentary, postmenopausal women in this study averaged < 5400 steps•day^{-1} at baseline. The researchers found that performing 50, 100, and 150% of the public health recommendation added 2800, 5500, and 6500 steps•day^{-1}, respectively.

According to Tudor-Locke and Bassett (53) individuals who accumulate <5000 steps per day are sedentary, 5000-7499 are low active, 7500-9999 are somewhat active and > 10,000 are active. An addition of 30 minutes of moderate intensity walking would add at least 3,000 steps, which would approach 10,000 steps per day for many low active individuals (53). The overall goal of physical activity recommendations is for individuals to increase their daily activity whether it is taking a 30-minute walk or adding more activity into their daily routine.

It is important to monitor physical activity to determine whether health and fitness goals are being achieved. The frequency, intensity, duration, and mode of physical activity are important factors in promoting health improvements. Assessment of progress, or lack of progress needs to take all of these factors into account. Common means of assessing physical activity are through the use of questionnaires, activity logs, pedometers, and accelerometers.

Measurement by Self-Report

Self-report through questionnaires and/or activity logs is a simple, inexpensive means of collecting physical activity data, whereby the participant must attempt to accurately report the amount, type, and intensity of physical activity performed. The self-report method has obvious weaknesses. It is possible that participants could underestimate or overestimate the actual amount of exercise performed and it may be difficult for an individual to correctly quantify the intensity of each bout. Advantages of self-report are the ease of administration for both individuals and large epidemiological studies, and the relatively low cost. Some of the more common instruments administered include the College Alumni Questionnaire (CAQ), the International Physical Activity Questionnaire (IPAQ), and the 7-day recall. Numerous studies have attempted to determine the usefulness and reliability of self-report methods for assessing physical activity (1, 5, 11, 40, 48, 51).

Tudor-Locke et al. (54) spoke with 196 women of African American or Native American descent through interviews and focus groups. The researchers strove to understand how these women interpreted terms such as physical activity, exercise, leisure, recreation, moderate, vigorous, and strenuous. It was found that individuals had differing perspectives on the meanings of these terms. Many women described physical activity as structured exercise; however, physical activity is not necessarily structured, and can range from planned exercise to any normal daily movement. The women also tended to have differing views on the definitions of exercise intensities. They felt that strenuous and vigorous were interchangeable terms that described activities that "involved moving fast, working up a sweat, and pushing oneself." Moderate intensity was seen as more enjoyable activities. The authors conclude that it is extremely important that researchers ensure that participants clearly understand the terms being used to describe physical activity and/or exercise.

Bassett et al. (5) compared daily walking distance measured by a Yamax Digiwalker (DW-500B) pedometer to subject reported distance collected through the College Alumni Questionnaire. The subjects were 96 men and women with varying activity habits, who were asked to wear a pedometer for 7 consecutive days excluding time spent sleeping, showering, or participating in sports and recreational activities. The subjects self-reported walking 1.43 ± 1.01 km•day^{-1}, while the pedometer reported a distance of 4.17 ± 1.61 km•day^{-1}. Energy expenditure reported by the CAQ was 555 ± 405 kcals•wk^{-1}, while the energy expenditure reported by the pedometer was 1608 ± 640 kcals•wk^{-1}. Thus, the researchers found that the CAQ tended to underestimate distance walked and energy expended when compared to the criterion pedometer.

Strath et al. (48) compared physical activity measured by heart rate motion sensor technique (HR + M) to a 7-day recall on the College Alumni Questionnaire Physical Activity Index (CAQ-PAI). The subjects were 12 males and 13 females with varying daily activity levels. The subjects were asked to go about their normal daily routine for 7 days. Motion sensors were used to identify between upper and lower body movements and heart rate was measured to predict VO_2 from an individualized regression equation. On the 8th day, the participants were asked to fill out the CAQ that contains questions on number of city blocks walked, number of flights of stairs climbed, and the frequency and duration of sports or recreational activities performed. The researchers found that for moderate and vigorous activities the CAQ-PAI and HR + M techniques did not differ in mean physical activity values. However, at light intensity, the CAQ-PAI only accounted for 1.5% of the HR + M values (124 vs. 8052 MET-min•wk^{-1}), which resulted in an overall underestimation of total physical activity levels. The findings of this study and of Bassett et al. (5) suggest that the use of standard physical activity questionnaires often miss physical activity performed as a part of one's daily routine.

Many studies have found questionnaires, which report activities normally performed daily and recall devices that ask subjects to report activities performed in the past, to be adequate measures of physical activity (11, 40, 51). Craig et al. (11) and Sallis et al. (40) reported that the International Physical Activity Questionnaire (IPAQ) instruments have an acceptable level of accuracy for recalling physical activity when compared to direct measurement and that the IPAQ is as good as other self report methods. Craig et al. (11) studied the validity and reliability of both the IPAQ long and short forms. The reliability study consisted of filling out two IPAQ forms, up to one week apart and comparing the responses. The validation study consisted of the same and wearing a CSA accelerometer for one week between completing the two forms. The researchers found that the IPAQ produced repeatable data (correlation coefficients clustered around 0.80) with comparable results from the short 9 item (ranged from 0.32-0.88) and long 31 item (ranged from 0.46-0.96) forms. Criterion validity for the IPAQ compared to the CSA accelerometer showed fair to moderate agreement for the long and short forms (correlation coefficients of 0.33 and 0.30, respectively). Sallis et al. (40) found similar results when comparing 7 self report questionnaires in adults. The investigators reported reliability correlations ranging from 0.34 to 0.89 with a median of 0.80. Criterion validity correlations ranged from 0.14 to 0.53 with a median of 0.30 when compared to doubly labeled water, pedometers, accelerometers, direct observation, or heart rate monitoring.

Timperio et al. (51) examined the validity and reliability of survey items for recalling one-week physical activity in overweight and non-overweight males and females. Subjects answered a questionnaire on frequency and duration of physical activity on two occasions, three days apart, and then again after a seven-day period wearing an MTI/CSA accelerometer. Correlation coefficients for reported physical activity and measured physical activity were 0.29 for men and 0.25 for women ($p < 0.05$). Men self-reported duration of moderate intensity physical activity compared to accelerometer measurement, regardless of weight, fairly accurately (rho = 0.40, $p < 0.01$). For women, a significant relationship was found between self-reported moderate intensity physical activity and accelerometer data only for non-overweight participants (rho = 0.52, $p < 0.001$). Overweight males were the only group to show a significant correlation between reported vigorous activity duration and accelerometer-measured duration (rho = 0.40, $p < 0.05$). The authors report that their recall instrument gives a consistent measure of physical activity and offers validity similar to other questionnaires. However, the accuracy of self-report compared to the accelerometer varied by subject weight.

While questionnaires and recall forms can provide useful information regarding an individual's physical activity patterns, specific data is often inaccurate. These methods tend to offer a general description of activity, while activity monitors can provide an opportunity to gather specific information such as steps taken, calories expended, distance walked, or time spent in activity.

Measurement by Activity Monitors

The use of pedometers and accelerometers for assessment of physical activity has become increasingly popular. Use of these devices may give a more precise, accurate portrayal of physical activity than self-report instruments and they can be useful in following physical activity recommendations such as the 10,000 steps per day goal. In addition, new devices with accelerometer mechanisms offer an opportunity to fully understand an individual's pattern of physical activity over the course of a day. Most pedometers display total steps, distance, and sometimes, caloric expenditure. New devices like the Lifecorder EX allow users to see the duration and intensity of each bout of activity making it possible to identify whether the user is reaching the ACSM/CDC physical activity recommendation. It can also be determined whether the majority of physical activity takes place in one bout or through small sessions over the entire course of the day and the intensity of this activity can be identified as light, moderate, or vigorous. However, it is important that researchers determine which devices report the most accurate measures. Many studies exploring the accuracy of pedometers have found a tendency for underestimation of steps during slow walking performed on a treadmill (3, 12, 26, 30, 41, 44) and an underestimation of distance walked at fast speeds due to subject's varying stride length (3, 12, 57). Accelerometers offer output that must be analyzed and converted into usable units and it has been shown that these devices can have a tendency to misreport energy expenditure (2, 7, 8, 19, 21, 24, 28, 37, 47).

Melanson et al. (33) studied the accuracy of step counting by the Yamax SW-200 at self-selected walking speeds for 259 subjects. They found that the device was >96%

accurate at walking speeds ≥ 80 m•min^{-1} and accuracy decreases as speed decreases. The magnitude of step count error increased with age due to a decrease in self-selected walking speed. The 18-30 year olds averaged 78 m•min^{-1} and the >70 year olds chose an average speed of 62 m•min^{-1}. The step count error was 3% and 19% for the younger and older group, respectively. Steps were also underestimated at brisk walking speeds for the 61-70 year olds (average speed = 86 m•min^{-1}) and the > 70 year olds (average speed = 75 m•min^{-1}) by 6.5% and 13%, respectively. For subjects ≤ 60 years old (average speed = 94 m•min^{-1}), the error in step count during brisk walking was ≤ 1.5%. In a second part of this study, 32 subjects performed slow walking (27, 48, and 70 m•min^{-1}) on a treadmill while wearing three pedometers. The Omron HF-100 was placed on the right hip and the Walk-4-Life LS-2500 and Step Keeper HSB-SKM were placed above either the left or right foot. The researchers found that all three devices reported steps poorly at 27 m•min^{-1} recording 7.5-56.4% of steps. However, the Omron device, which consists of a piezoelectric crystal, was more accurate than the other two spring levered pedometers at 27 and 48 m•min^{-1} (56.4 ± 33.8% and 97.8 ± 9.6% (Omron) versus 7.5 ± 16.3% and 52.1 ± 38.7% (Walk-4-Life) and 20.5 ± 28.4% and 73.4 ± 36.7% (Step Keeper)). The Omron and Step Keeper were not significantly different at 70 m•min^{-1} (101 ± 4.3% and 95.3 ± 12.3%, respectively). The researchers conclude that all of the tested pedometers were very accurate (> 96%) at speeds ≥ 80 m•min^{-1}, but at slower speeds piezoelectric devices are more accurate than spring levered pedometers. This could be important when working with elderly and obese individuals who tend to walk at slower speeds.

Bassett et al. (3) studied five pedometers to assess accuracy of measuring distance walked. Subjects were asked to wear five different pedometers (Accusplit Fitness Walker, Eddie Bauer Compustep II, Freestyle Pacer 798, L.L. Bean, and Yamax Digiwalker DW-500) while performing three separate activities including sidewalk walking, treadmill walking, and track walking. For the sidewalk-walking portion of the study 20 subjects walked 4.88 km while wearing two devices of the same brand (one on each side of the body) for each of the five brands. The Yamax, Pacer, and Accusplit were the most accurate in estimating distance, but only the Yamax pedometers showed close agreement between the left and right side of the body. Track walking was performed by 10 of these 20 subjects and it was found that walking surface had no effect on pedometer accuracy. Lastly, the effect of walking speed on accuracy was explored and the researchers found that there was a tendency for miscounting steps during slow walking at 54 m•min^{-1} and distance was underestimated during walking at fast speeds of 107 m•min^{-1}. The researchers concluded that although pedometers may vary in accuracy, some of these devices can be useful tools in monitoring physical activity.

Crouter et al. (12) examined the accuracy of ten pedometers for measuring steps taken, distance walked, and energy cost while walking at five treadmill speeds. The ten subjects (five male and five female) were asked to perform 5-minute bouts of treadmill walking at five different speeds (54, 67, 80, 94, and 107 m•min^{-1}) while wearing one of the ten pedometers. Researchers counted steps taken with a hand counter and determined energy expenditure by indirect calorimetry. The researchers found that while most pedometers underestimated steps at 54 m•min^{-1}, accuracy improved as walking speed increased. At speeds of 80 m•min^{-1} and greater, six pedometers (Yamasa Skeletone, Omron, Digiwalker SW-701, Kenz Lifecorder, New Lifestyles 2000, and Walk4Life LS

2525) gave mean values within ± 1% of actual steps taken. The devices that were programmed to calculate distance walked tended to overestimate distance at slow speeds and underestimate distance at fast speeds. This error is due to differences in stride length. At slow speeds, subjects take smaller steps than the stride length programmed into the device. Conversely, at faster speeds, subjects take longer strides than the value programmed into the device. Of the devices that displayed kilocalories expended, only two (Kenz Lifecorder and New Lifestyles 2000) specified whether the energy expenditure reported was net or gross kilocalories. For the other devices, if the energy expenditure was assumed to be net, then the devices tended to overestimate at all tested speeds. If the energy expenditure was assumed to be gross, then seven of the eight devices were within ± 30% of actual energy expenditure at all speeds. The Kenz Lifecorder was the most accurate overall by only significantly overestimating gross expenditure at two speeds (80 and 94 m•min^{-1}) and net expenditure at one speed (94 m•min^{-1}) (12). The researchers concluded that pedometers are most accurate in counting steps, less accurate in calculating walking distance, and least accurate in estimating energy expenditure (12).

Schneider et al. (43) examined the accuracy and reliability of ten pedometers for counting steps during a 400-meter walk. Ten males and ten females walked around a 400-meter track while wearing the devices. They wore two pedometers of the same model (one on each side of the body) for each trial while the researchers tallied steps with a hand counter. The Kenz Lifecorder, New Lifestyles NL-2000, and Yamax Digiwalker SW-701 were the most accurate in counting steps. These devices were within ± 3% of actual steps taken 95% of the time. The Kenz Lifecorder, Omron HJ-105, New Lifestyles

NL-2000, and Yamax Digiwalker SW-701 produced an exceptionally high intra-model reliability (>0.99).

Schneider et al. (42) examined 13 pedometers' ability to measure free-living physical activity. Ten males and ten females wore two pedometers for a 24-hour period. The criterion pedometer (Yamax Digiwalker SW-200) was worn on the left side of the body, while the tested devices were placed on the right side of the body. The researchers found that step counts varied greatly among the different devices. When compared to the criterion, step counts ranged from a 25% underestimation to a 45% overestimation. The investigators reported that the Kenz Lifecorder, New Lifestyles NL-2000, Yamax Digiwalker SW-701, and Sportline 330 yielded mean values that were not significantly different from the criterion.

Kumahara et al. (28) investigated the accuracy of the Kenz Lifecorder in assessing total energy expenditure, physical activity energy expenditure, and report of activity intensity levels. In part one of the study, 79 subjects (28 male and 51 female) spent 24 hours in a respiratory chamber while wearing the Lifecorder. In part two of the study, ten male subjects wore the Lifecorder and performed treadmill walking (2.4, 3.3, 4.2, 5.1, 6.0, and 6.9 $km \cdot h^{-1}$) and running (7.8, 8.7, and 9.6 $km \cdot h^{-1}$) for four-minute stages with a two-minute rest between stages. Volume of oxygen consumed was measured during the last minute of each stage and METs were calculated. The researchers found that the Lifecorder significantly underestimated total energy expenditure and physical activity energy expenditure while in the metabolic chamber (91.9 and 92.7% of chamber value, respectively). However, they reported a strong correlation between the Lifecorder generated activity levels and measured METs while performing treadmill walking at various speeds. They used a regression equation to estimate MET values equivalent to each of the Lifecorder activity levels for light (1-3), moderate (4-6), and vigorous (7-9) to be 1.8, 2.3, and 2.9, 3.6, 4.3, and 5.2, and 6.1, 7.1, and >8.3 METs, respectively. The investigators conclude that the Lifecorder is a useful tool for objectively assessing intensity of daily physical activity and approximating energy expenditure throughout the day. They further add that improvements in the Lifecorder algorithm that include individual calibration factors could reduce error and improve energy expenditure estimation (28).

Le Masurier et al. (30) compared the Yamax SW-200 pedometer and the dual-mode Computer Science Applications (CSA) accelerometer accuracy during a treadmill walking protocol and the effects of a 32.8 kilometer vehicle ride. The walking protocol consisted of treadmill walking for five minutes at five different speeds (54, 67, 80, 94, and 107 $m \cdot min^{-1}$), while wearing the pedometer and accelerometer. Actual step count was determined by observation and verified by video recording. The researchers found that both devices were accurate in detecting steps taken on the treadmill at all speeds except 54 $m \cdot min^{-1}$. At this slow speed the Yamax pedometer reported significantly fewer steps than actually taken (75.4%), while the accelerometer detected 98.9% of steps taken. The vehicle travel portion of the study consisted of wearing the two devices while riding in a motor vehicle. The accelerometer detected 17 times more erroneous steps than the pedometer (250 vs. 15 erroneous steps). The authors speculate that the accelerometer would report a 4-7% and 10-14% error in total daily steps for healthy and sedentary/chronically ill populations, respectively. This larger error in the sedentary/chronically ill patients is based on the fact that they take much fewer steps than the typical healthy population. The pedometer's low incidence of false steps would report less than 1% error for both populations when riding in a vehicle. This study shows that different devices will have varying sources of error due to different measurement mechanisms. They concluded that both devices are useful in measuring physical activity, but the accelerometer may give inaccurate measurement in individuals who travel by motor vehicle and the pedometer may report erroneously in elderly/ill individuals with a slow gait.

Hendelman et al. (21) examined the validity of three activity monitors in assessing moderate physical activity. Subjects performed 5 minute walking bouts at self-selected leisurely, comfortable, moderate, and brisk speeds. They also played golf and performed indoor and outdoor household tasks such as washing windows, dusting, vacuuming, lawn mowing, and planting shrubs. Energy expenditure was measured using a portable metabolic system and subjects wore a Yamax Digiwalker pedometer, CSA uniaxial accelerometer, and Tritrac triaxial accelerometer. The Digiwalker undercounted steps during the self-selected leisure and comfortable speeds. The two accelerometers were in general agreement for the walking (r=0.87) and other activity sessions (r=0.93). There was a stronger relationship between accelerometer counts and METs during walking (r=0.77 (CSA) and r=0.89 (Tritrac)) than during the other activities (r=0.59 (CSA) and r=0.62 (Tritrac)). Regression analyses from the walking trials were used to develop equations to predict METs from accelerometer counts. Energy expenditure derived from these equations significantly underestimated measured expenditure of golf and the household activities by 30-60%. The researchers state that the devices could not detect upper body movement, carrying of a load, or changes in terrain.

Bassett et al. (4) performed a similar study as Hendelman and colleagues (21). They found that the Yamax SW-701 pedometer and three accelerometers (CSA 7164, Caltrac, and Kenz Select 2) overestimated energy expenditure while walking. They also found that these devices underestimated energy expenditure during other activities such as yard work and housework due to the device's inability to monitor upper body movements. Therefore, there would likely be an overall underestimation of caloric expenditure over the course of a full day.

Tudor-Locke et al. (52) compared the output of a Yamax SW-200 pedometer and a CSA accelerometer. Subjects wore the two devices for 7 days to assess their daily physical activity. The accelerometer reported 1,845 ± 2,116 steps•day^{-1} more than the pedometer. The researchers state that this difference is likely due to different sensitivity thresholds for these two devices. The CSA recognizes forces at ≥ 0.30g while the Yamax pedometer needs a force of 0.35g to register a step. The researchers found that there was a strong linear relationship between the pedometer and accelerometer outputs (pedometer steps•day^{-1} correlated with CSA counts•minute^{-1}•day^{-1} $r = 0.74$, CSA total counts•day^{-1} $r = 0.80$, and CSA steps•day^{-1} $r = 0.86$). They also reported that approximately 33 CSA-minutes per day of moderate intensity activity corresponded with 8064 ± 766 pedometer steps.

Brage et al. (7) examined the reliability and validity of the CSA accelerometer during both treadmill and field exercise. Subjects wore two CSA accelerometers on each hip to determine reliability. Oxygen uptake was measured during the final two minutes of each treadmill trial to examine validity. CSA activity output rose linearly with increased speed (r^2=0.92) up to 9 km•hr^{-1}. During running speeds the activity count stayed constant at approximately 10,000 counts•min^{-1}, or slightly decreased. The devices were deemed reliable with an intraclass correlation coefficient of 0.91. The VO_2 prediction equation derived from the output significantly underestimated VO_2 during moderate to vigorous running speeds. The error increased as speed increased with a 48% error at 16 km•hr^{-1}. The researchers state that the device is able to discriminate intensity between different walking speeds, but it is not able to discriminate between running speeds. They feel that this device may be satisfactory for a general population that accumulates most of its energy expenditure through light or moderate intensity activity, but would be less useful in discriminating among individuals who perform regular vigorous activities.

Nichols et al. (36) developed regression equations to predict energy expenditure based on CSA accelerometer activity counts during treadmill walking and running. These equations, based on treadmill exercise, could not be generalized to field exercise. Inserting the field velocity into the laboratory equations caused an overestimation of light (15.4%), moderate (5.6%), and vigorous (31.6%) CSA activity counts. They determined count ranges associated with light (2.0-3.9 METs), moderate (4.0-6.9 METs), and vigorous activity (≥ 7.0 METs) performed on the treadmill to be 755-3206, 3207-6884, and ≥ 6885, respectively. Accelerometer counts in the field study were 1577-3284, 3285-5676, and ≥ 5677 for light, moderate, and vigorous intensity, respectively. The researchers state that the difference between laboratory and field activity may be due to biomechanical differences in gait.

Jakicic and colleagues (24) examined the validity of the triaxial Tritrac R3D accelerometer to estimate energy expenditure during treadmill walking, treadmill running, stepping, stationary cycling, and lateral sliding. Twenty subjects performed each of these exercises for 20-30 minutes with the intensity increasing at 10-minute intervals. A Tritrac device was worn on each side of the body to assess reliability and indirect calorimetry was used to examine validity. There was a significant correlation in energy expenditure between the right and left device for all activities at all workloads with the highest being for walking and sliding (r = 0.92-0.98). There was a difference between the right and left devices for mean energy expenditure per minute during walking, stepping, and sliding (1 kcal•min^{-1}), but not for running or cycling. It was found that the Tritrac had a tendency to underestimate energy expenditure and the magnitude of underestimation increased with increasing workload. The correlation coefficients for the Tritrac and indirect calorimetry during walking, running, and sliding were 0.68-0.92, for stepping was 0.54-0.75, and there was no significant correlation for cycling.

Nichols et al. (37) examined the validity and reliability of the Tritrac accelerometer during treadmill walking and running and attempted to calibrate the device based on indirect calorimetry. Reliability was assessed by placing a device on the right and left side of the body during treadmill exercise and by placing four devices on a shaker table. Intraclass reliability coefficients for right versus left placement ranged from 0.73 to 0.87 and there was no difference between the means of the devices placed on the shaker table. The Tritrac overestimated energy expenditure during treadmill walking at all tested speeds. The device could not determine a difference between horizontal walking at 6.4 km•h^{-1} and walking at 5% grade at 6.4 km•h^{-1}. The mean vector magnitudes for light, moderate, and vigorous intensity activity were 650-1771, 1772-3454, and ≥ 3455 counts, respectively. The investigators report that the Tritrac can distinguish different intensities of horizontal walking and jogging, is highly sensitive to changes in speed, but not grade, and can categorize activity intensity with limitations.

Welk and colleagues (59) examined the reliability of four accelerometers during a standardized bout of exercise. The devices tested were the uniaxial CSA/MTI, uniaxial Biotrainer Pro, triaxial TriTrac-R3D, and the omni-directional Actical monitor. Subjects performed three five-minute trials of treadmill walking at 80 $m \bullet min^{-1}$, while wearing multiple units of the same device. The researchers tested seven to ten units of each model using Generalizability theory to describe variance between units, trials, and subjects. They found that the CSA/MTI showed the least variability and highest reliability ($G = 0.64$ and $r > 0.80$) of all the devices tested (Tritrac $G = 0.573$ and $r = 0.73$, Biotrainer $G = 0.557$ and $r = 0.68$, and Actical $G = 0.432$ and $r = 0.62$). They state that the CSA device has acceptable reliability for use in research settings, but more research should be conducted to improve general accelerometer measures and calibration techniques.

Activity monitors can offer an opportunity to gather specific information regarding an individuals activity patterns. These devices can monitor step count, distance walked, calories expended, or time spent in physical activity. They can be useful for monitoring activity performed or for setting and pursuing activity goals. They can be valuable devices if their measures are valid and reliable.

Equations for Calculating Resting Metabolic Rate

Knowledge of one's resting metabolic rate can be an extremely powerful tool in the battle of maintaining a healthy body weight. To maintain current body weight, an individual must balance caloric intake with caloric expenditure. Caloric intake can be calculated with the help of food labels, books, and websites. Caloric expenditure must be calculated based on energy used throughout the day. This comes from structured activities such as exercise, activities of daily living, the thermic effect of food, and resting energy expenditure, which accounts for 65-75% of total energy expenditure (56). It is important to know the resting metabolic rate when designing a nutrition and exercise program to fit an individual's weight loss needs. Numerous equations have been derived to predict resting metabolic rate and scientific advancements have allowed these equations to be programmed into activity monitors. These formulas vary in accuracy due to factors such as gender, age, height, weight, and fat-free mass (56). Accuracy is improved when equations can be derived and applied on a homogenous population.

Thompson et al. (50) compared predicted metabolic rate from four common equations to measured metabolic rate. Subjects were 24 male and 13 female athletes who trained for at least one hour per day, four or more days per week. The subjects were asked to perform a 12-hour fast and refrain from physical activity prior to resting metabolic rate measurement. All measurements were made between 6:00 a.m. and 8:00 a.m. on two separate occasions. The subjects performed a 30-minute rest period followed by a 30-minute measurement period in which expired gases were collected. The researchers then compared the results from the predictive equations with the measured resting metabolic rates and found that the Harris-Benedict, Mifflin, and Owens equations significantly underestimated resting metabolic rate in both males and females. The Cunningham equation was the best prediction equation for both males and females by predicting resting metabolic rate within 158 $kcals \cdot day^{-1}$ and 103 $kcals \cdot day^{-1}$, respectively. The researchers also determined the factors that were the best predictors of resting metabolic rate. The best predictor for men was fat-free mass and for women was energy intake. The researchers state that the accuracy of a prediction equation varies between different populations and that for these athletes, the Cunningham equation worked best. Individuals should use an equation that was developed from a population similar to themselves.

Frankenfield et al. (14) evaluated the accuracy of four resting metabolic rate equations (Harris-Benedict, Harris-Benedict using adjusted body weight in obese subjects, Owen, and Mifflin) in obese and non-obese subjects. The participants were 130 adults (54 male and 76 female) with BMI's ranging from 15.9 to 96.8 kg•m^{-2}. Measurement of resting metabolic rate was performed in the morning following a 12-hour fast and subjects were instructed to avoid physical activity in the 12 hours prior to testing. Metabolic rate was measured for 30 minutes by indirect calorimetry with the last 25 minutes being used for determining resting metabolic rate. Measured resting metabolic rate was then compared to the predicted metabolic rates produced by the four equations. The researchers found that the Mifflin equation was the most accurate equation for this population with an accuracy of within 10% of measured metabolic rate 78% of the time. Calculated rate was more than 10% different than measured 33% of the time for Harris-Benedict, 35% of the time for Owen and 74% of the time for the adjusted Harris-Benedict.

De Lorenzo et al. (13) examined the accuracy of seven resting metabolic rate equations in 51 male athletes. Resting metabolic rate was measured by indirect calorimetry and compared with predicted values from FAO/WHO/UNU, Harris-Benedict, Mifflin, Owen, Cunningham, Robertson-Reid, and Fleisch equations. The researchers found that all of the equations except Cunningham significantly underestimated resting metabolic rate. The Cunningham equation overestimated by 59 kcals•day^{-1}. The authors found that resting metabolic rate is best correlated with body surface area, body weight, and height.

Siervo et al. (46) examined the accuracy of six predictive equations in normal weight, overweight, and obese women. The resting metabolic rate of 157 Caucasian women was measured by indirect calorimetry. Measured resting metabolic rate was compared to predicted metabolic rate from the Harris-Benedict, Owen, Mifflin, WHO, Bernstein, and Robertson-Reid equations. The researchers found that the Owen equation was best in normal weight women (underestimation of 9.75 ± 144.77 kcals•day^{-1}), Bernstein equation was best in overweight women (overestimation of 11.15 ± 141.42 kcals•day^{-1}), and the Robertson-Reid equation was best in obese women (overestimation of 10.47 ± 170.72 kcals•day^{-1}). The Harris-Benedict, WHO, and Mifflin equations overestimated resting metabolic rate for all subjects (approximately 3%-13% overestimation).

According to Garrell et al. (16) the Harris-Benedict equation is one of the most commonly used resting metabolic rate prediction equations. They state that on average, this equation is thought to overestimate resting metabolic rate by 10-15%. They found that Harris-Benedict overestimation is inversely related to resting metabolic rate. That is that the equation overestimates more for individuals with the lowest resting metabolic rate levels. The researchers found a similar trend for the Owen's equation. They report that the WHO equation was within 10% of measured resting metabolic rate for all cases in this study.

Activity monitors like the Kenz Lifecorder, New Lifestyles NL 2000, and the Lifecorder EX offer estimates of energy expenditure. All three of these devices estimate basal metabolic rate using the following formula:

$$BMR = K_b \bullet BSA \bullet T \bullet (1 \bullet 10{,}000^{-1})$$

The factor K_b (kcals • m^{-2} • h^{-1}) is a Japanese value corresponding to age, body surface area is determined by multiplying weight in $kilograms^{0.444}$ by height in $centimeters^{0.663}$ by 88.83, and time is expressed in hours (28). Kumahara et al. found that the Lifecorder underestimated resting metabolic rate by 7%. They state that this underestimation in resting metabolic rate likely led to the underestimation of total energy expenditure and physical activity energy expenditure when compared to values determined in a respiratory chamber (91.9% and 92.7% of expended kilocalories respectively) (28).

Conclusion

The risks associated with inactivity (55) and the benefits of daily physical activity (6, 20, 27, 31, 32, 34, 35, 38, 45, 49, 62, 63) are becoming increasingly common knowledge. As healthcare and fitness professionals strive to educate and motivate the public to improve their physical condition, improved means of assessing physical activity should continue to be developed. Self report measures such as activity logs and physical activity recall questionnaires are simple to administer and relatively inexpensive. However, the accuracy of these instruments varies due to subjects inability to objectively assess or recall the activity performed (1, 5, 11, 40, 48, 51). Activity monitors such as pedometers and accelerometers vary in price from a few dollars to hundreds of dollars and can help to quantify activities throughout the day. However, these devices are only as valuable as their accuracy and research shows that the validity of these measures varies (2-4, 7, 8, 12, 19, 21, 24, 26, 28, 30, 33, 36, 41-44, 47, 52, 57-59). It is also important for individuals to be able to assess their current condition and to understand how to improve their health. One powerful tool for the individual and researcher is knowing how much energy is required to maintain a certain body weight. Knowledge of one's resting metabolic rate can help to design a fitness and nutrition plan to reach an optimal body weight. Mathematical equations have been developed to estimate resting metabolic rate and vary in accuracy (13, 14, 16, 46, 50, 56). Measurement can be performed in the laboratory, but this seems impractical for the public. Individuals should use an equation developed from a population similar to themselves.

The Lifecorder EX activity monitor attempts to improve the current methods of assessing physical activity. This device counts steps taken, calculates resting metabolic rate, estimates energy expenditure, and describes intensity of physical activity performed. It not only offers a means of assessing activity performed, but it can function as a motivational tool by presenting step, calorie, and activity duration accumulation goals. As potentially powerful as this device may be, there are currently no published studies assessing the validity of its measures.

CHAPTER III

MANUSCRIPT

Abstract

Purpose: The purpose of this study was to determine the validity of the Lifecorder EX activity monitor in calculating resting metabolic rate, counting steps taken at a variety of speeds, reporting energy expenditure across a range of intensities, and categorizing exercise intensity in descriptive units as light (1-3), moderate (4-6), and vigorous (7-9).

Methods: Ten male (24.6 ± 5.32 years) and ten female (26.6 ± 5.06 years) recreationally active adults participated in this study. Height, weight, resting metabolic rate, and body composition were measured prior to performing treadmill exercise at 9 speeds (54, 67, 80, 94, 107, 121, 134, 147, 161 m•min^{-1}), while wearing a Lifecorder EX activity monitor on both the right and left hips. Walking stages were performed for four minutes and running stages were performed for six minutes. Each stage was followed by a two-minute rest period. Energy expenditure was determined by indirect calorimetry and steps were tallied using a hand counter. In a separate trial, subjects wore the activity monitor for 24 hours and met the investigator for a 30-minute exercise session on a 400-meter rubberized track. Subjects were randomized into one of three groups: a 30-minute run, 30-minute walk, or three 10-minute walks.

Results: The Lifecorder EX accurately displayed steps taken at speeds ≥ 80 m•min^{-1}. The device undercounted steps at the slowest speeds (92.0% of actual at 54 m•min^{-1} and 98.9% of actual at 67 m•min^{-1}). Both gross and net caloric expenditure were overestimated at all tested speeds except walking at 134 m•min^{-1}. On average, the device underestimated resting metabolic rate by 11.4%. During outdoor walking and running,

the Lifecorder EX was able to differentiate moderate intensity and vigorous intensity activities.

Conclusion: The Lifecorder EX is highly accurate at counting steps at speeds ranging from 80 to 161 $m \cdot min^{-1}$. Although the device overestimated both gross and net caloric expenditure, the intensity units, which describe activity as light, moderate, or vigorous, can be beneficial for helping describe an individual's physical activity pattern. The underestimation of resting metabolic rate is comparable to the error seen in many resting metabolic rate equations.

Key Words: ACCELEROMETER, ENERGY EXPENDITURE, EXERCISE, PHYSICAL ACTIVITY, STEPS

Introduction

Research has shown that leading an inactive lifestyle can lead to increased risk of obesity, coronary heart disease, type 2 diabetes, hypertension, and hyperlipidemia (55). Participating in physical activity can promote improvements in, or prevention of, many of these conditions (6, 20, 27, 31, 32, 34, 35, 38, 45, 49, 62, 63). The American College of Sports Medicine (ACSM), Centers for Disease Control and Prevention (CDC), and the United States Surgeon General recommend participating in at least 30 minutes of moderate intensity physical activity on most, preferably all, days of the week (39, 55). Moderate intensity is generally considered to be activities requiring 3-6 METS, where one MET is the energy required to sustain the body at rest and has been standardized as 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (15). It is important for both researchers and individuals to be able to properly assess the amount of physical activity being performed.

The use of pedometers and accelerometers for counting steps has become increasingly popular, especially with the increased public attention to the 10,000 steps per day program. New devices with accelerometer mechanisms offer an opportunity to fully understand an individual's pattern of physical activity over the course of the day by identifying the duration and intensity of each bout of activity. This can be beneficial for monitoring whether the user is reaching the ACSM/CDC recommendation of 30 minutes of moderate intensity activity. It can also be determined whether the majority of physical activity takes place in one bout or through small sessions over the entire course of the day. One must be careful when using pedometers and accelerometers as research shows that accuracy of the measures varies (2-4, 7, 8, 12, 19, 21, 24, 26, 28, 30, 33, 36, 41-44, 47, 52, 57-59).

A new accelerometer, the Kenz Lifecorder EX, has recently become available on the market. This device is based on the mechanisms of the older model Kenz Lifecorder. New features of this device include increased memory storage capacity and improved software capabilities such as key lock and measurement standby. The accuracy of this device to measure volume and intensity of physical activity has yet to be validated. Therefore, the purpose of this study was to determine the validity of the Lifecorder EX activity monitor in calculating resting metabolic rate, counting steps taken at a variety of speeds, reporting energy expenditure across a range of intensities, and categorizing exercise intensity in descriptive units as light (1-3), moderate (4-6), and vigorous (7-9).

Methods

Subjects: Ten male (24.6 ± 5.3 years) and ten female (26.6 ± 5.1 years) recreationally active individuals volunteered for this study. All procedures were approved by the University of Tennessee Institutional Review Board (IRB). Prior to participation, subjects read and signed an informed consent form (see Appendix A) and had an opportunity to discuss any questions or concerns with the investigators. Subjects completed a health history questionnaire (see Appendix B) and participant information sheet (see Appendix C). The purpose of the questionnaire was to insure that the subjects could safely participate in the study. Subjects were asked to report the frequency, duration, and type of physical exercise they normally performed. They were also asked about past medical conditions that might be aggravated by exercise and of any current symptoms that might represent an underlying illness. The investigators and subjects discussed any medical issues to ensure safety of participation in the study.

Anthropometric Measurements: Height was measured without shoes, using a wall-mounted stadiometer (Seca Corporation, Columbia, MD). Weight was measured in light clothing without shoes, using a physician's scale (Health-O-Meter Inc, Bridgeview, IL) and body mass index (BMI) was calculated by dividing body weight in kilograms by height in meters squared ($kg \cdot m^{-2}$). Body composition was determined by air displacement plethysmography using the Bod Pod ® system (Life Measurement Instruments, Concord, CA). Subjects were asked to remove all jewelry and to wear minimal clothing (either a bathing suit or spandex shorts) and a swim cap during the measurement. Calibration procedures were followed according to the manufacturer's specifications.

Resting Metabolic Rate Measurement: Resting metabolic rate (RMR) was determined by indirect calorimetry using the True Max 2400 computerized metabolic system (Parvo Medics, Salt Lake City, UT). Calibration of the gas analyzers and flowmeter was performed prior to testing using gases of known concentration and a 3.00-L syringe, respectively. Subjects reported to the laboratory in the morning following an overnight fast of at least 8 hours. They avoided the use of stimulants such as caffeine and nicotine and limited their physical activity prior to testing (see Appendix D). Subjects lay comfortably on a lounge chair during the 40-minute collection period. The first 20 minutes were intended to allow the subject to reach a resting level. The average energy expenditure over the final 20 minutes was determined to be the RMR.

Treadmill Testing: Treadmill testing was performed on a Quinton motor driven treadmill (model Q55XT, Seattle, WA). Subjects wore two Lifecorder EX activity monitors on the waist, one in the midline of the right thigh and the other in the midline of the left thigh. Expired gases were collected to determine energy expenditure through indirect calorimetry. The last two minutes of each stage were considered to be steady state and were averaged and used for oxygen uptake for that stage. Subjects participated in ten trials of nine speeds (54, 67, 80, 94, 107, 121, 134, 147, 161 $m \cdot min^{-1}$). The researchers identified a transitional speed individualized by subject that could be a fast walk or a slow run. Subjects were asked to perform this speed twice, once as a walk and then again as a run. All walking stages lasted four minutes followed by a two-minute rest period and all running stages were performed for six minutes followed by a two-minute rest period. During the two-minute rest period the investigators gathered step count, net caloric expenditure, and gross caloric expenditure information from the monitors. Steps were tallied using a hand counter and a stopwatch was synchronized with the activity monitors to ensure accurate timing of exercise and rest periods.

Free-Living Testing: Following the laboratory testing, subjects were instructed on proper pedometer placement and were asked to wear the Lifecorder EX for 24 hours. They were asked to note the times when the pedometer was placed on in the morning and removed in the evening. They were also asked to note activities performed during the day on an activity log (see Appendix E). During this 24-hour period, subjects met with the investigator for 30 minutes of monitored exercise on a 400-meter rubberized track. The subjects were randomized into one of three groups and were asked to perform one of the following: 30-minute run, 30-minute walk, or three 10-minute walks. Subjects were allowed to choose their own pace and the researcher timed each lap with a stopwatch to determine average speed. From the Lifecorder EX, the researcher recorded beginning and final steps, activity energy expenditure, and gross energy expenditure to determine the number of steps and caloric expenditure associated with the monitored bout of track exercise.

Statistical Analysis: Statistical analyses were carried out using SPSS Version 13 (SPSS Inc., Chicago, IL). An alpha of $P < 0.05$ was used to denote statistical significance. Values are reported as mean ± standard deviation and presented as percent difference for illustrative purposes. A three-way repeated measures ANOVA (Speed * Device * Gender) was used to compare mean differences in steps and energy expenditure between the Lifecorder EX and criterion measures. Since no gender effect was determined, all subjects were combined and two-way repeated measures ANOVA (Treadmill Speed * Measurement Device) were used to compare mean difference scores for steps taken, net energy expenditure, and gross energy expenditure between the Lifecorder EX and criterion measures. Paired T-Tests were used to determine if differences existed in descriptive characteristics by gender, accelerometer reported resting metabolic rate compared to indirect calorimetry, and accelerometer reported total energy expenditure compared to indirect calorimetry. A Chi Square analysis was used to determine if the

Lifecorder EX correctly categorized walking as moderate and running as vigorous.

Results

All participants in this study were healthy, recreationally active individuals. Participant characteristics are reported in Table 1. Males were significantly taller, heavier, and leaner than females. There was no gender difference in age or body mass index.

Table 2 presents the mean data scores for steps, net energy expenditure, and gross energy expenditure for each treadmill speed tested and mean percent error for these tests are presented in Table 3 and Figure 1. Since no differences were found between measures taken on the left versus right hip, all data reported are means of the right hip measures. The accelerometer underestimated steps taken at the two slowest speeds by 8.39% and 1.73% (54 and 67 m•min^{-1}, respectively). The device correctly displayed mean step counts compared to actual steps taken at speeds ≥ 80 m•min^{-1}. Both net and gross caloric expenditure were significantly overestimated by the device at all tested speeds except walking at 134 m•min^{-1}.

The Lifecorder EX overestimated total net energy expenditure during the entire treadmill session by 19.71% and total gross energy expenditure by 17.45%, yet it underestimated mean resting metabolic rate for the entire group by 11.36% (194.22 kcals•day^{-1}).

When the Lifecorder EX detects movement it categorizes activity as light, moderate, or vigorous using activity units of 1-3, 4-6, and 7-9, respectively. The relationship between these intensity units and mean measured MET cost was determined for the treadmill testing and is presented in Table 4 and Figure 2. The device never

Table 1. Characteristics of Participants (mean ± SD)

	Men (N=10)	Women (N=10)	All Participants (N=20)
Age (y)	24.6 ± 5.32	26.6 ± 5.06	25.6 ± 5.15
Height (m)*	1.79 ± 0.05	1.64 ± 0.06	1.71 ± 0.09
Weight (kg)*	78.67 ± 13.09	59.7 ± 4.9	69.19 ± 13.68
BMI (kg•m^{-2})	24.6 ± 3.98	22.32 ± 2.37	23.46 ± 3.4
Body Fat (%)*	12.88 ± 6.35	22.47 ± 7.33	17.68 ± 8.29
Measured RMR*	1980.19 ± 207.57	1438.85 ± 109.73	1709.5 ± 321.29
Lifecorder BMR*	1716.3 ± 125.99	1314.3 ± 54.47	1515.3 ± 226.83

*Significant difference between gender ($p<0.05$)
BMI = body mass index
RMR = resting metabolic rate
BMR = basal metabolic rate

Table 2. Mean Data Scores

Speed (m•min^{-1})	Observed Steps	Lifecorder Steps	Measured Net Kcals	Lifecorder Net Kcals	Measured Gross Kcals	Lifecorder Gross Kcals
54	385.1	352.8*	7.66	9.05*	12.41	17.65*
67	423.9	416.55*	8.8	11.5*	17.59	20.8*
80	453.45	449.65	10.31	14.6*	19.35	24.1*
94	475.8	472.85	12.18	17.3*	21.37	26.9*
107	503.1	498.8	15.75	20.55*	25.24	29.9*
121w	531.7	527	21.06	23.53*	31.38	33.68*
121r	944.3	945.4	36.64	54.63*	48.49	70*
134w	570.3	558	30.75	29.5	43.4	41
134r	956.1	948.5	46.66	58.6*	61.19	74.95*
147	969.5	961.65	51.19	59.0*	66.03	75.65*
161	978.21	970.74	55.79	59.316*	71.22	76.105*

*Significantly different from criterion ($p< 0.05$)
w = walk
r = run

Table 3. Mean Percent Error

Speed (m•min^{-1})	% Error Steps	% Error Net Kcals	% Error Gross Kcals
54	-8.39*	18.15*	42.22*
67	-1.73*	30.68*	18.25*
80	-0.84	41.61*	24.55*
94	-0.62	42.04*	25.88*
107	-0.85	30.48*	18.46*
121w	-0.88	11.73*	7.35*
121r	0.12	49.08*	44.37*
134w	-2.16	-4.05	-5.53
134r	-0.79	25.59*	22.49*
147	-0.81	15.26*	14.57*
161	-0.76	6.32*	6.86*

*Significantly different from criterion value ($p < 0.05$)
w = walk
r = run

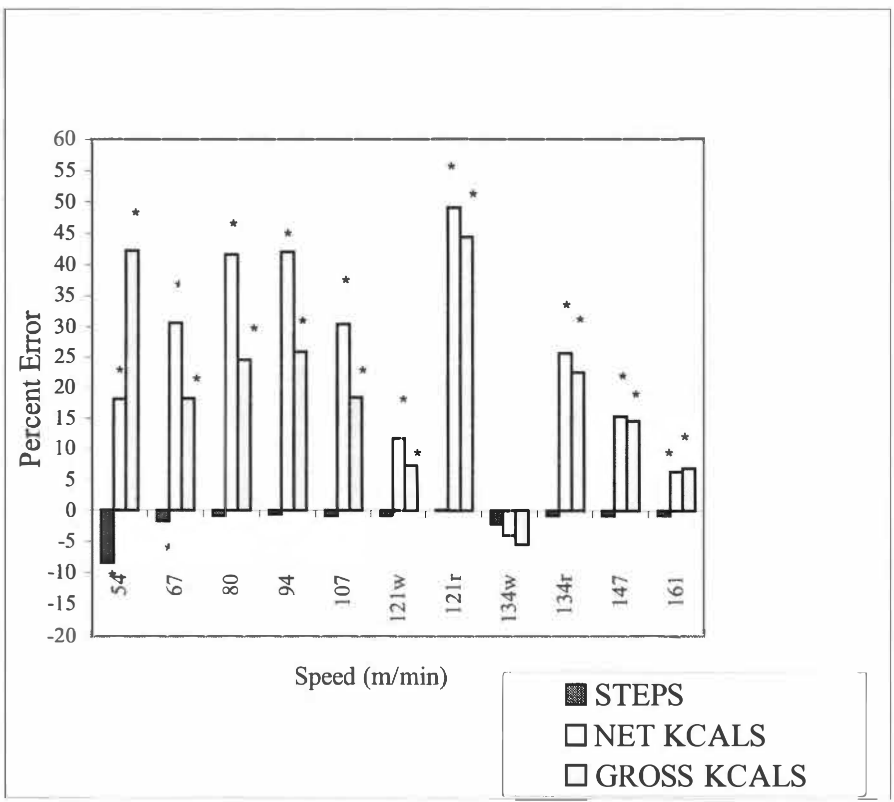


Figure 1. Mean Percent Error by Speed

Table 4. Lifecorder Intensity Units Compared to Measured METS (± SD)

Lifecorder Intensity	Measured MET	Range	Observations
1	NA	NA	0
2	2.72 ± 0.29	2.2-3.2	17
3	3.13 ± 0.41	2.2-4.0	26
4	3.46 ± 0.43	2.8-4.1	24
5	4.52 ± 0.89	3.1-6.3	31
6	5.86 ± 1.47	3.6-8.8	23
7	8.10 ± 0.01	8.0-8.2	3
8	8.24 ± 1.29	5.0-11.5	72
9	8.70 ± 0.17	8.6-8.9	3

Compiled from treadmill testing

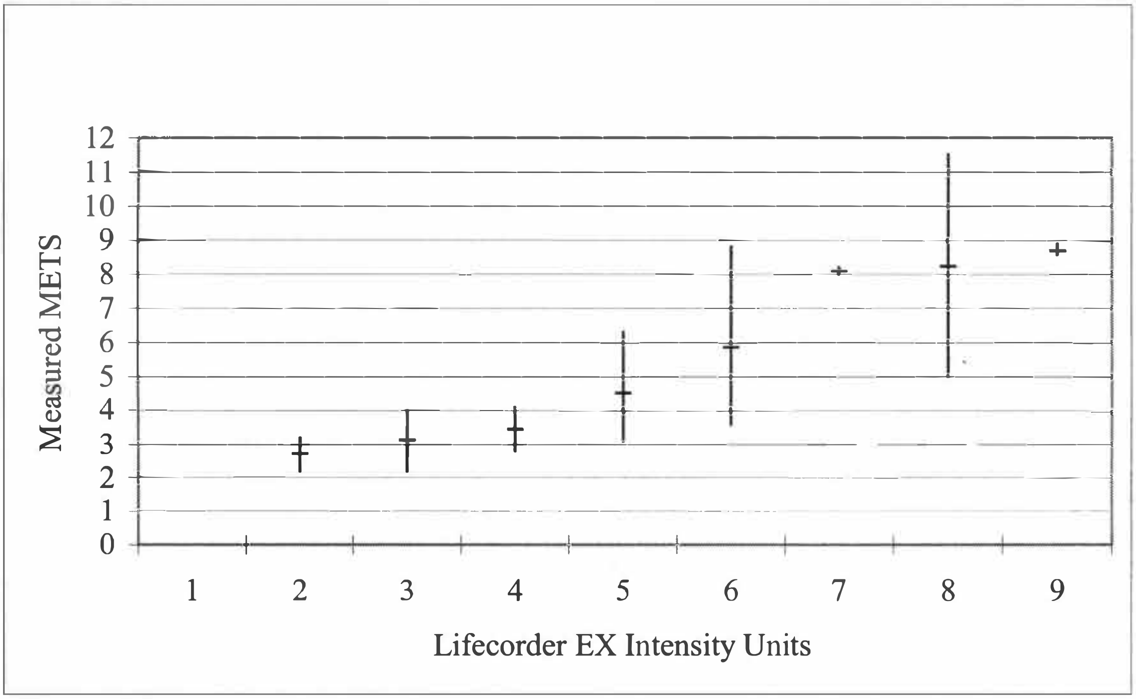


Figure 2. Comparison of Lifecorder Intensity and Measured METS

registered activity as a 1 and rarely registered 7's and 9's. When subjects performed one treadmill speed twice once as a walk and then again as a run, the device produced significantly different intensity values to distinguish a difference between walking and running ($p<0.001$).

Table 5 presents a comparison of Lifecorder EX activity units and estimated MET cost determined from the track exercise sessions. Estimated average MET cost determined using the ACSM prediction equations (60) was 3.9 for walking (moderate intensity is 3-6 METS) and 12.1 for running (vigorous intensity is > 6 METS). A Chi Square analysis determined that the Lifecorder EX properly categorized the walking activity sessions as moderate intensity (4-6 Lifecorder units) and the running sessions as vigorous intensity (8-9 Lifecorder units). Table 6 highlights the fact that the device is describing physical activity in a manner comparable to ACSM standards. All self-selected walking was of moderate intensity, so the device never registered a 1, 2, or 3 during the track sessions. The device correctly quantified the physical activity being performed. Figure 3 demonstrates the Lifecorder EX's ability to assess and report 24-hour activity intensity and duration.

Discussion

The Lifecorder EX activity monitor has the potential to be a powerful tool for allowing researchers to monitor a subject's physical activity pattern. The device has a large memory storage capacity of up to 200 days of data, which can allow researchers to perform longer duration studies without having to meet subjects frequently to download data. The original model Kenz Lifecorder had a smaller storage capacity of 42 days. All information is saved on the memory chip and can be reviewed through the computer

Table 5. Lifecorder Intensity Units Compared to Mean Estimated METS (± SD)

Lifecorder Intensity	Estimated MET	Range	Observations
1	NA	NA	0
2	NA	NA	0
3	NA	NA	0
4	3.43 ± 0.08	3.3-3.5	3
5	3.81 ± 0.22	3.4-4.4	19
6	4.13 ± 0.28	3.8-4.3	3
7	NA	NA	0
8	12.16 ± 1.50	10.0-14.2	6
9	11.80	NA	1

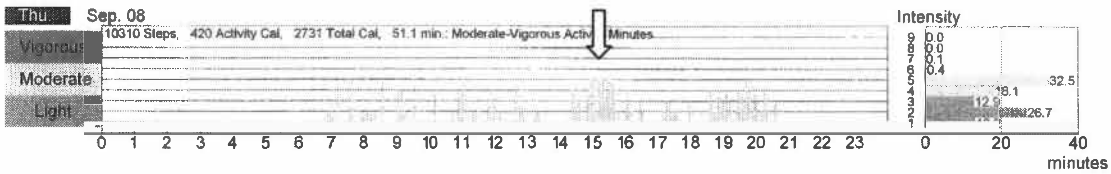
Compiled from self-paced walking and running on a 400-meter track

Table 6. Lifecorder Categories Compared to ACSM Categories

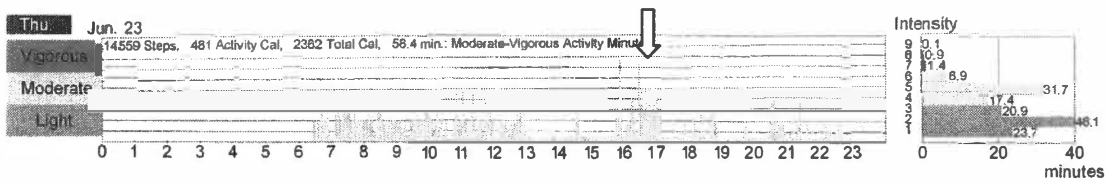
Lifecorder Intensity	ACSM Predicted Intensity		
	Light (1.0-2.9 METS)	Moderate (3.0-5.9 METS)	Vigorous (6.0+ METS)
Light (1-3 units)	0	0	0
Moderate (4-6 units)	0	25	0
Vigorous (7-9 units)	0	0	7

Compiled from field testing on a 400-meter track
Numbers indicate the number of observations in each category

a. Three 10-minute walks



b. One 30-minute walk



c. One 30-minute run

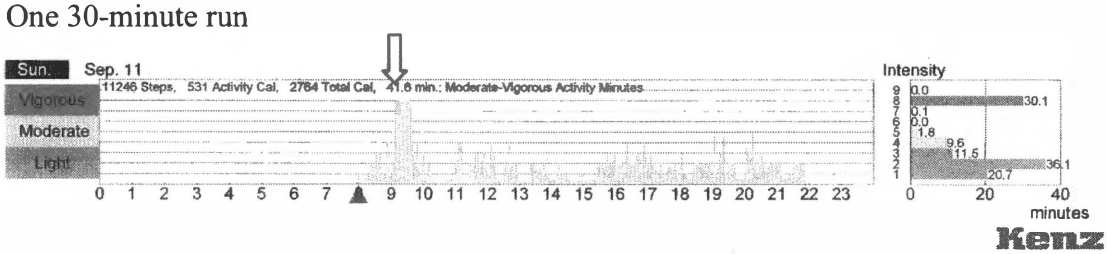


Figure 3. Lifecorder Activity Summary

software program. Other new features of this device include the ability to program an individual's characteristics and analysis parameters into the device through the software and options that include setting goals for steps, energy expenditure, and minutes of moderate-vigorous activity. The parameters of moderate activity intensity can be adjusted to include lighter or heavier activity levels. Another interesting option allows the researcher to set a "key lock." This function locks the display on the accelerometer to prevent subjects from being able to see their accumulated activity. In the past, a pedometer would be sealed, now the software makes it simple. A final new option is the "measurement stand-by" mode. The researcher is able to program when the device should begin measuring. This prevents unnecessary measurement before an observation period or during shipping.

The Lifecorder EX functions as both a pedometer and accelerometer, therefore it is able to quantify the intensity of physical activity as well as counting steps. The digital display offers immediate feedback similar to a pedometer and it possesses a USB port for downloading to a personal computer like an accelerometer. The software program then allows the researcher to create daily or weekly reports summarizing the subject's activity pattern. Steps, energy expenditure, minutes spent in light, moderate, and vigorous activity, and a 24-hour summary of activity intensity can be viewed.

The activity monitor reported steps accurately at $\geq$ 80 m•min^{-1}. Although the device offered a statistically significant underestimation of steps at 54 and 67 m•min^{-1}, it was reporting 92.0% and 98.9% of steps taken at these two speeds, respectively. This trend has been seen in the past with other activity monitors (3, 12, 30, 33). It is thought that walking at such slow speeds does not always create enough of a vertical acceleration at the hip to register a step. Therefore these devices may not give an accurate portrayal of physical activity in individuals with a slow, shuffling gait (33).

The Lifecorder EX underestimated resting metabolic rate by 11.4% (194.2 kcals•day^{-1}) in this study. These results are similar to errors seen in other resting metabolic rate formulas. Kumahara et al. (28) found the Kenz Lifecorder, which uses the same formula as the Lifecorder EX, to underestimate resting metabolic rate by approximately 7% when compared to measured sleeping metabolic rate. The current study used a resting metabolic rate averaged over a 40-minute rest period, while the former study used an average over an 8-hour sleeping measure. Also, this formula was created based on a Japanese population. Kumahara's subjects were Japanese, while none of the subjects in the present study were of Japanese decent.

Thompson et al (50) found that the Cunningham equation predicted resting metabolic rate within 158 and 103 kcals•day^{-1} for athletic males and females, respectively. Frankenfield et al. (14) found that the Mifflin equation was within 10% of measured resting metabolic rate for a population of obese and nonobese subjects and Garrell and colleagues (16) reported that the Harris Benedict equation tended to overestimate resting metabolic rate by 10-15% and the WHO equation was within 10% of measured rate in all subjects tested. This device appears to offer estimates of resting metabolic rate similar to existing equations. An option for researchers to enter true measured resting metabolic rate could be beneficial.

The Lifecorder EX showed a tendency to overestimate caloric expenditure during walking and running, which is in agreement with previous studies of activity monitors (2, 8, 19). Other studies have shown accelerometers to underestimate 24 hour energy expenditure compared to indirect calorimetry using a metabolic chamber (9, 10, 28). This can be expected since all activities, ambulatory or seated, are measured and hip-mounted activity monitors are unable to distinguish upper body movement, which would cause an underestimation of total energy expenditure. The design of the present study only collected data through indirect calorimetry during treadmill exercise. Upper body movement was limited since the subjects only performed walking and running. One would still expect gross energy expenditure estimates during the entire bout of treadmill exercise to be underestimated since the device underestimated resting metabolic rate. According to Kumahara and colleagues (28), total energy expenditure (TEE) is calculated using basal metabolic rate (BMR), the thermic effect of food ($(1/10)_{TEE}$), physical activity energy expenditure (EE_{ACT}), and energy expended through minor activity ($EE_{Minor\ Act}$) through the following formula:

$$TEE = BMR + (1/10)_{TEE} + EE_{ACT} + EE_{Minor\ Act.}$$

Since the subjects in the present study were fasted, the thermic effect of food factor calculation used by the monitor would cause an overestimation of total energy expenditure. However, the overestimation of activity energy expenditure (EE_{Act}) cannot be explained by this theory since the thermic effect of food is not considered in the net calorie calculation based on the formula: $EE_{Act} = Ka \cdot W$, where Ka is a privately owned factor related to activity intensity and W is subject weight (28).

While it was obvious that the intensity units offered by the Lifecorder EX were not equivalent to MET units, in general, the device properly categorized activity as light, moderate, or vigorous during treadmill activity (see Table 5) and as moderate or vigorous during track exercise (see Table 6). The Lifecorder EX was able to distinguish a difference between walking and running at the same speed. Subjects performed one speed twice (either 121 or 134 $m \bullet min^{-1}$), once as a walk and then again as a run. The device gave a higher intensity unit for running than for walking at the same speed. The device offered a different intensity unit for each walking speed, but was unable to clearly discriminate between different running speeds, which is in agreement with previous studies (7, 19). The device most often reported an intensity unit of 8 for running and rarely reported a 7, regardless of running speed. Overall, the Lifecorder EX appears to be useful in describing the type of activity performed over the course of a day. Although it cannot discriminate between different running velocities, it can adequately identify if the individual is running or walking.

A possible advantage of the software available with this device is that the researcher can change the parameters for moderate intensity from 4-6 to a lower level of 3 or a higher level of 7. This might be beneficial when working with individuals of differing fitness levels. As is discussed in the newest ACSM Guidelines for Exercise Testing and Prescription (60), descriptive terms such as light, moderate, and vigorous should not have an absolute MET value associated with them due to individuals varying levels of fitness. The Lifecorder EX's option to change the activity categorization could possibly be beneficial in this regard.

The Lifecorder EX appears to be a good device for identifying general physical activity trends since it can quantify activity as number of steps taken or minutes spent in light, moderate, and vigorous intensity activity. This device could also be used as a motivational tool since goals of steps, caloric expenditure, or activity minutes can be set. Researchers should take into consideration the errors found in resting metabolic rate estimation, caloric expenditure, and step count at very slow speeds. Also, for researchers interested in assessing exercise intensity and duration, it should to be known that the device averages intensity over a two-minute interval. Therefore, one must take care to see that a rest period and activity period do not get averaged to produce a misrepresentation of what truly occurred. Future research could attempt to understand the errors in energy expenditure estimation, expand on the Lifecorder EX's usefulness in field-testing, and perform studies using a more diverse population to see if measures are affected by variations in age, body composition, or fitness level. Overall, this device appears to be a potentially useful tool for assessing daily physical activity.

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Appendices

Appendix A

Informed Consent Form

Informed Consent Form

Validation of Measures by the LIFECORDER EX Activity Monitor

Investigator: Scott A. Schmidt
Address: The University of Tennessee
Department of Exercise, Sport and Leisure Studies
1914 Andy Holt Ave.
Knoxville, TN 37996
Telephone: (865) 974-8768

Purpose

You are invited to participate in a research study. The purpose of this study is to determine whether the LIFECORDER EX activity monitor offers accurate measurement in a number of featured functions. This activity monitor is worn on the waistband like a standard pedometer. If you give your consent, you will be asked to perform the testing protocol below. You will report to the laboratory following an overnight fast and will limit physical activity on the morning of the test. On a second occasion you will wear the pedometer for 24 hours and meet at Tom Black Track during a mutually scheduled time to perform 30 minutes of monitored exercise. The total time commitment will be approximately 2 hours and 30 minutes plus the 24-hour period of normal daily activity.

Procedures

1. Before any testing begins, you will be asked to fill out a brief Health History Questionnaire and Participant Information form. The Health History Questionnaire will be used to determine your health status and will cover topics such as exercise history, medical conditions, and medication use. The Participant Information form will collect your contact information and also emergency contact information.

2. Height and weight will be measured and then you will be asked to lie comfortably on a lounge chair. Your resting energy expenditure will be determined by wearing a mouthpiece and nose clip, which is attached to an analysis system. Your exhaled gases will be measured for 40 minutes.

3. Your body fat will be determined using the Bod Pod. The Bod Pod is a machine that estimates body composition by comparing body size to body weight. Pressure changes within the Bod Pod are used to estimate body fat percentage. You will enter the machine wearing a swimsuit and sit quietly for 2 one-minute trials. You will be able to breathe normally and see the surrounding environment through the plexiglass window.

4. Next, you will be asked to walk or run at 9 different speeds ranging from a very slow walk to a run at a 10-minute mile pace on a treadmill. A transition speed that you can both walk and run at will be identified and performed. You will wear two LIFECORDER EX monitors on your waist and will be connected to the metabolic analysis system by wearing a mouthpiece and nose clip. You will perform 4 minutes of exercise at walking

speeds and 6 minutes of exercise at running speeds with a 2-minute rest between each of the stages.

5. On a separate occasion you will be asked to wear the pedometer for a period of 24 hours. You will go about your normal daily activities, while wearing the device. The only time you will not wear the device will be while bathing and sleeping. You will also be asked to meet with the investigator for 30 minutes of exercise at Tom Black Track. You will be randomly assigned to perform a 30-minute jog, 30-minute walk, or three 10-minute walks. The activity period will be at a time which is convenient to both you and the investigator.

Potential Risks
There are minor risks involved with participation in this study. This protocol will not be any more risky than your normal training regimen. As with any exercise session, you may feel fatigue and some physical discomfort. Risks involved include muscular soreness, musculoskeletal injuries, dizziness, difficulty in breathing, abnormal blood pressure response, and in rare cases heart attack or death.

Benefits of Participation
Benefits of participation in this study include having your height and weight measured and learning your body mass index, body composition and resting metabolic rate. Knowing your body mass index and body fat percentage is important in that they help you assess your fitness level and can help identify if you are at risk for obesity related diseases. Learning your resting metabolic rate can be useful in designing your exercise and dietary strategies.

Confidentiality
The information obtained from these tests will be treated as privileged and confidential and will consequently not be released to any person without your consent. However, the information will be used in research reports and presentations, but your identity will not be disclosed.

Emergency Medical Treatment
The University of Tennessee does not automatically offer compensation or reimbursement for medical claims. In the unlikely event that physical injury is suffered during the course of this research study, or if you have questions regarding this policy, notify Scott Schmidt at (865) 974-8768.

Contact Information
If you have questions at any time concerning the study or the procedures, (or you experience adverse effects as a result of participating in this study,) you may contact Scott Schmidt at (865) 974-8768. If you have questions about your rights as a participant, contact Research Compliance Services of the Office of Research at (865) 974-3466.

Right to Ask Questions and to Withdraw
You are free to decide whether or not to participate in this study and are free to withdraw from the study at any time. Before you sign this form, please ask questions about any aspects of the study, which are unclear to you.

Consent
By signing, I am indicating that I understand and agree to take part in this research study.

______________________	______________________
Your Signature	Date
______________________	______________________
Researcher's Signature	Date

Appendix B

Health History Questionnaire

HEALTH HISTORY QUESTIONNAIRE

DATE____________________ PARTICIPANT ID:__________

DATE OF BIRTH_________________ AGE_____________________

GENDER_________________

Please answer the following questions. This information will only be used for research purposes and will not be made public. Please answer the following questions based on physical exercise in which you regularly engage. **This should not include daily work activities such as walking from one office to another.**

1. Do you regularly engage in exercise? Yes/No If yes, please describe.

____

____

2. On average, how many times per week do you engage in exercise training?

0_____1_____2_____3_____4_____5_____6_____7_____

3. On average, how long do you exercise each time?

0-19 minutes_____20-40 minutes_____more than 40 minutes_____

4. How long have you been exercising at this level?

Less than 6 months ________
6 – 12 months ________
1 – 2 years ________
3 or more years ________

MEDICAL HISTORY

Past History:
Have you ever been diagnosed with the following conditions? Please check the appropriate column.

	Yes	No	Don't Know
Rheumatic Fever	( )	( )	( )
Heart Murmur	( )	( )	( )
High Blood Pressure	( )	( )	( )
Any heart problem	( )	( )	( )
Lung Disease	( )	( )	( )

	Yes	No	Don't Know
Seizures	( )	( )	( )
Irregular heart beat	( )	( )	( )
Bronchitis	( )	( )	( )
Emphysema	( )	( )	( )
Diabetes	( )	( )	( )
Asthma	( )	( )	( )
Kidney Disease	( )	( )	( )
Liver Disease	( )	( )	( )
Severe Allergies	( )	( )	( )
Orthopedic problems	( )	( )	( )
Hyper- or Hypothyroidism	( )	( )	( )
AIDS	( )	( )	( )

Present Symptom Review:

Have you recently had any of the following symptoms? Please check if so.

Chest Pain	( )	Frequent Urination	( )
Shortness of Breath	( )	Blood in Urine	( )
Heart palpitations	( )	Burning sensations	( )
Leg or ankle swelling	( )	Severe headache	( )
Coughing up blood	( )	Blurred vision	( )
Low blood sugar	( )	Difficulty walking	( )
Feeling faint or dizzy	( )	Weakness in arm	( )
Leg numbness	( )	Significant emotional problem	( )

Are you taking any medications? Yes/No

If yes, please list:____

Appendix C

Participant Information

PARTICIPANT INFORMATION

NAME______________________________ DATE________________________

DATE OF BIRTH_____________________ AGE_________________________

GENDER_____________________

ADDRESS____

____

PHONE NUMBERS (HOME)____________________(WORK)___________________

e-mail address:____

When is the best time to contact you?____

Whom should we notify in case of an emergency?

Name ___________________________

Address ___________________________

Phone # ____________________________

Appendix D

Instructions to Subjects

INSTRUCTIONS FOR METABOLIC RATE TESTING

- 8-12 hour fast- Do not eat or drink anything (except for water) for at least 8 hours (preferably 12 hours) prior to testing.

- Avoid using stimulants such as caffeine and nicotine on the morning of the test.

- Limit physical activity during the 12 hours prior to testing (don't perform vigorous exercise).

- Limit physical activity on the morning of the test.
  Come in straight out of bed, walk slowly to the building, ride the elevator. You need to be as relaxed as possible.

- Bring a swimsuit to wear during the body composition assessment.

- Bring workout clothes and tennis shoes to wear during the treadmill test.

Your appointment will be at ________A.M. on ____________. The total time commitment for the laboratory portion of this study will be approximately 2 hours.

Meet me on the 3rd floor of HPER, outside of the elevator.

If you cannot make your appointment, or have any concerns, please let me know as soon as possible.

Appendix E

Activity Log

Subject #	

Date:	

Time On:	

Time	**Activity**	**Time**	**Activity**
0:00		12:00	
0:30		12:30	
1:00		13:00	
1:30		13:30	
2:00		14:00	
2:30		14:30	
3:00		15:00	
3:30		15:30	
4:00		16:00	
4:30		16:30	
5:00		17:00	
5:30		17:30	
6:00		18:00	
6:30		18:30	
7:00		19:00	
7:30		19:30	
8:00		20:00	
8:30		20:30	
9:00		21:00	
9:30		21:30	
10:00		22:00	
10:30		22:30	
11:00		23:00	
11:30		23:30	

Time Off:	

Notes:

Vita

Scott Andrew Schmidt was born in Saginaw, Michigan on September 23, 1980 to Jerry and Betsy Schmidt. He earned his Bachelor of Science in Exercise Science from the University of Tennessee, Knoxville. He continued his education at the University of Tennessee by pursuing a Master's degree in Exercise Science. While finishing his degree, he worked at two local fitness centers, was a graduate teaching associate in the Physical Education Activity Program at the university, and accepted a position working as an Exercise Physiologist with the Department of Energy in Oak Ridge, Tennessee.