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Graduate Studies

THE ACCURACY OF VARIOUS ACTIVITY TRACKERS IN ESTIMATING STEPS TAKEN AND ENERGY EXPENDITURE

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science, Clinical Exercise Physiology

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THE ACCURACY OF VARIOUS ACTIVITY TRACKERS IN ESTIMATING STEPS TAKEN AND ENERGY EXPENDITURE

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We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science, Clinical Exercise Physiology.

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ABSTRACT

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This study was designed to assess the accuracy of various activity trackers in estimating steps taken and energy expenditure. The activity trackers included the Nike Fuelband, Jawbone UP, BodyMedia FIT Core, Adidas MiCoach, Fitbit Ultra, and the NL-2000i. Only the Nike Fuelband, Jawbone UP, FitBit Ultra, and the NL-2000i recorded steps. Twenty subjects (10 males, 10 females) participated in two, 50-minute activity sessions. The first session consisted of treadmill walking and treadmill running. Each exercise was 20 minutes, with a 10 minute break between. The second session consisted of 20 minutes on an elliptical cross-trainer, a 10-minute break, and the time needed to complete the agility drills. The activity trackers were worn concurrently with a portable metabolic gas analyzer. Steps were recorded using a hand counter. At the end of each mini-session, steps and kcals were recorded by each activity device. The results of the study showed steps to be fairly accurate for all devices, but calories to be less accurate. The accuracy of the devices varied depending on the exercise modality. Based on the results, choosing an activity device should be based on the information looking to be recorded and the type of activity to be performed.

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INTRODUCTION

It is well-known that living a sedentary lifestyle can lead to poor health. In response, the American College of Sports Medicine (ACSM) and the American Heart Association (AHA) published recommended guidelines for physical activity. These guidelines were updated in 2007 by both organizations, and state that healthy individuals should get a minimum of 30 minutes of physical activity per day, five days a week, or 20 minutes of vigorous activity per day three days a week, or a combination of the two. The recommendations also included how to define moderate and vigorous levels of physical activity. Moderate activity is defined as within a metabolic equivalent (MET) range of 3.0-6.0. Vigorous activity is defined to be greater than 6.0 METS (Haskell et al., 2007).

Assessing and monitoring physical activity has become more common over the years. In this era, monitoring has become much easier with the help of items such as pedometers, accelerometers, and other fitness trackers. Pedometers were one of the first devices used by the public as a means to monitor their activity. In 1965, Y. Hatano, a Japanese pedometer manufacturer, came out with the idea that people should accumulate 10,000 steps per day. It is unknown where that number came from, but it has continued to be used as a daily goal to reach. Tudor-Locke and Bassett took the notion of steps per day one step further and created categories to define activity levels. They said that <5000 steps per day could be classified as sedentary, 5000-7499 steps without sports or exercise as low active, 7500-9999 steps as somewhat active, ≥10 000 steps as active, and >12 500 steps as highly active (Tudor-Locke & Bassett, 2004). This was a useful tool, since it helped stratify activity levels based on measured steps. But because pedometers are unable to monitor intensity, it was not possible to incorporate ACSM and AHA guidelines for moderate and vigorous activities. Now, some pedometers (such as the New-Lifestyles NL-2000i) have the ability to monitor intensity.

Numerous studies have been conducted to determine the accuracy of the NL-2000 to monitor steps, with very positive results. The NL-2000 was shown to be within ±3% of steps taken on an outdoor track (Schneider, Crouter, Lukajic, & Bassett, 2003). It has also been tested while exercising on a treadmill and was found to be within ±1% of steps taken at speeds of 80 m/min and above (Crouter, Schneider, Karabulut, & Bassett, 2003). Because of these findings, the NL-2000 has been recommended as a device that can be used in research settings for monitoring steps taken (Schneider, Crouter, & Bassett, 2004). Information about the ability of activity trackers to measure steps taken is limited, although it has been shown that where the tracker is worn can affect results (Barkhuus, 2006).

Another aspect of evaluating physical activity is the estimation of energy expenditure. Using direct and indirect calorimetry can give you data in a laboratory setting, but that is not practical in a free living situation. It has previously been recommended that a pedometer should not be used to measure energy expenditure due to a lack of accuracy (Crouter et al., 2003). Thus, activity trackers incorporating accelerometers, Global Positioning Systems (GPS), inclinometers, and other technology have been developed to improve accuracy. Manufacturers of these devices also claim that they are able to track activities other than just walking and running, such as having the ability to recognize when you take the stairs and monitoring your game of basketball.

The accuracy of measuring energy expenditure (EE) has been shown to vary from study to study. In one study, Balogun, Martin, and Clandenin (1989) found an overestimation of EE by accelerometers during level treadmill walking. In another study, Crouter, Churilla, and Basset (2006) found that the three accelerometers they tested overestimated EE during both walking and in sedentary activities. These devices were also shown to underestimate EE during other forms of activity, such as basketball, racquetball, and fast running. GPS-based monitors have also been shown to be inaccurate, generally over-predicting EE in walking and running. GPS monitors appear to not be suited for slower walking, but provide more accurate results during fast walking and running (McKenzie, Manning, & Heil, 2006). King, Torres, Potter, Brooks, and Coleman (2004) conducted a study on the Sensewear Armband (SP2) by BodyMedia. The SP2 uses non-invasive sensors to measure different physical parameters, such as heat flux, and an accelerometer. The SP2 was tested for the accuracy of measuring EE in normal activities of daily living and was shown to overestimate EE during sit-stand variations and walking.

There are new activity trackers regularly coming onto the market; however, there appears to be very little published research on the validity of these devices. Thus, the purpose of this study was to evaluate the accuracy of five activity trackers currently on the market to estimate energy expenditure and steps taken. The five activity trackers used in the present study were the Nike Fuelband, Fitbit Ultra, Jawbone UP, BodyMedia FitCore, and the Adidas MiCoach. First, the activity trackers were compared to hand counted steps to measure steps taken. Second, they were compared to a portable metabolic gas analyzer to estimate EE.

METHODS

Subjects

This study included 20 apparently healthy volunteers (10 men and 10 women) between the ages of 18-44 years. All subjects were required to complete the Physical Activity Readiness Questionnaire (PAR-Q) to confirm their ability to safely participate in physical activity. The protocol was approved by the Institutional Review Board for the Protection of Human Subjects and all subjects provided written informed consent.

Procedures

This study was divided into two parts: measuring of energy expenditure and measuring of steps taken. The protocol was the same for both studies and was done concurrently. The activity trackers tested were Nike Fuelband, BodyMedia FIT Core, Adidas MiCoach, Fitbit Ultra, and Jawbone UP. Along with wearing these activity trackers, subjects wore a portable metabolic analyzer and the NL-2000i pedometer (New-Lifestyles Inc., Lees Summit, MO). Each subject went through a series of different exercises wearing all of these devices concurrently. The sessions consisted of physical activity done on a treadmill, an elliptical cross-trainer, and in a gymnasium. The testing was conducted in two different 50-minute sessions.

The first session included walking and running on a level treadmill. First, the subject walked at a self-selected speed for 20 minutes. The subject then had a 10-minute break before beginning the running portion. The run was 20 minutes at a self-selected running pace. The second session of testing was completed on an elliptical cross-trainer and in a gymnasium. There was a 10-minute break between the elliptical cross-trainer and gymnasium portions. The elliptical cross-trainer is a model that involves using both the arms and the legs. Subjects self-selected their intensity and completed 20 minutes on the elliptical cross-trainer. After the break, subjects completed one session of sports-related exercises in a gymnasium. The first sports-related exercise was agility ladder drills. This consisted of seven different moves, completed twice. The ladder drill was followed by 10 basketball free throws. The second exercise was the "T Drill" and was done for 30 seconds. The T drill was followed by another 10 basketball free throws. Last, subjects performed a basketball half-court lay-up drill for one minute.

After completing each 20-minute bout of exercise, the "calories burned" was recorded from each activity tracker. Steps taken numbers were recorded from the Nike Fuelband, Jawbone UP, Fitbit Ultra, and NL-2000i. The numbers given for "calories burned" were compared to the portable metabolic analyzer energy expenditure ratings. The steps taken for each device were compared to the data collected from direct observation. Direct observation was conducted through hand counting steps of each subject.

STASTICAL ANALYSIS

Standard descriptive statistics were used to characterize the subject population. Two-way repeated measures ANOVA were used to determine differences between activity trackers and gender for both steps and kcals. Significant F ratios were followed by pairwise comparisons using Tukey's post-hoc tests. Alpha was set at $p<0.05$.Pearson Product-Moment Correlations were used to compare actual steps and actual kcals to values from each tracker. All analyses were conducted using the Statistical Package for the Social Sciences (SPSS, Version 20; SPSS Inc., Chicago, IL).

RESULTS

Twenty apparently healthy men (10) and women (10) between 18-44 years of age completed the study. Descriptive characteristics of the subjects in the study are presented in Table 1.

Table 1. Descriptive characteristics of the subjects in the study (n=20).

	Males (n=10)	Females (n= 10)
Age (years)	21.5±1.35	22.5±1.27
Height (in)	71.8±2.70	64.9±3.41
Weight (kg)	80.9±8.31	63.0±7.64

Values represent mean ± standard deviation.

The first thing done was to compare steps recorded by the various activity trackers during treadmill walking, treadmill running, elliptical exercise, and the agility test to the actual steps taken during each activity. Step values are presented in Table 2 and the correlations between actual and recorded steps for each device are presented in Table 3. Each test was performed at a self-selected workload. During treadmill walking, the only significant difference was for the Nike Fuelband, which underestimated actual steps by 6%. The correlation between actual steps and Nike Fuelband steps was R=.55, showing a moderate correlation.

During treadmill running, both the Fitbit Ultra and the NL-2000i significantly underestimated actual steps by 6% and 10%, respectively. The correlation between the Fitbit Ultra and actual steps was moderate (R=.44), however, the correlation for the NL-2000i was extremely low (R=-.19).

For elliptical exercise, the only significant difference was for the NL-2000i, which under predicted actual steps by 6%. However, the correlation between actual and predicted steps was still fairly strong (R=.70).

Results for the agility test found that all of the activity trackers underestimated actual steps, except for the Jawbone UP. The underestimation was 34% for the Nike Fuelband, 20% for the Fitbit Ultra, and 17% for the NL-2000i, respectively. Even more worrisome, the correlation for all of the activity trackers were relatively poor, ranging from R=.17 to R=.49.

Table 2. Comparison of steps taken measured using hand counting compared to steps taken from the activity devices.

Devices	Treadmill Walking	Treadmill Running	Elliptical	Agility
Actual	2425±177.9	3182±173.9	2631±371.5	805±51.9
Jawbone UP	2403±176.6	3186±171.5	2627±359.0	783±110.1
Nike Fuelband	2273±154.8*	3169±171.2	2580±458.7	533±70.4*
Fitbit Ultra	2425±177.2	2990±313.0*	2630±370.6	645±90.0*
NL-2000i	2425±178.0	2869±247.1*	2477±471.1*	671±106.9*

Values represent means ± standard deviation.
*Significantly different than actual steps (p<.05).

Table 3. Correlation of steps taken between actual steps taken and steps recorded from activity devices.

Devices	Treadmill Walking	Treadmill Running	Elliptical	Agility
Jawbone UP	.98	.99	.99	.34
Nike Fuelband	.55	.98	.97	.17
Fitbit Ultra	.99	.44	.99	.49
NL-2000i	.99	-.19	.70	.44

The next step in data analysis was to compare the treadmill walking, treadmill running, elliptical, and the agility caloric expenditure values recorded by the activity devices to the actual caloric expenditure (kcals) measured by the portable metabolic gas analyzer. Those results are presented in Table 4 and the correlations between activity trackers and measured kcals are presented in Table 5. The number of subjects in the study varied slightly for each modality due to technical difficulties. Also, the Adidas MiCoach did not record data on the elliptical, thus that column is left blank.

During treadmill walking, the Adidas MiCoach was the only device which was significantly different from the measured kcals. Recorded kcals were over predicted by 34% using that tracker. The best correlation between measured and predicted kcals was for the Jawbone Up (R=.87).

For treadmill running, the Jawbone Up (+20%), the Nike Fuelband (+15%), and the Body Media FIT Core (-13%) were significantly different than measured kcals. Overall, the correlations for all of the activity trackers were moderate to good, ranging from R=.63 to R=.81.

Analysis of the data for elliptical exercise found that the Nike Fuelband and the Body Medit FIT Core significantly underestimated measured caloric expenditure by 27% and 20%, respectively. Correlations for all of the activity trackers were relatively low, with there being virtually no correlation between measured and predicted kcals for the Nike Fuelband (R=.08).

For agility, actual kcals were significantly underestimated by all of the activity trackers. The underestimations were 30% for the Jawbone Up, 14% for the Nike Fuelband, 17% for the Fitbit Ultra, 60% for the Adidas MiCoach, and 18% for the Body Media FIT Core. Correlations between the activity trackers and measured kcals were fair to moderate, ranging from R=.47-R=.67

Table 4. Comparison of caloric expenditure measured using the portable metabolic gas analyzer compared to kcal values obtained from the activity devices.

Devices	Treadmill Walking (n=19)	Treadmill Running (n=18)	Elliptical (n=20)	Agility (n=20)
Actual	109±19.6	240±47.3	161±25.6	90±20.7
Jawbone UP	123±25.2	288±63.6*	161±74.1	63±23.5*
Nike Fuelband	107±24.2	275±56.4*	118±38.0*	77±18.0*
Fitbit Ultra	111±22.8	230±50.5	154±34.1	75±19.2*
Adidas MiCoach	146±18.2*	261±52.4	-	36±6.8*
BodyMedia FIT Core	112±16.2	210±37.2	129±19.5*	74±19.2*

Values represent means ± standard deviation.
*Significantly different than portable metabolic gas analyzer Kcals (p<.05).

Table 5. Correlation of kcals between the portable metabolic gas analyzer and the kcals recorded by the activity devices.

Devices	Treadmill Walking (n=19)	Treadmill Running (n=18)	Elliptical (n=20)	Agility (n=20)
Jawbone UP	.87	.69	.40	.57
Nike Fuelband	.49	.72	.08	.47
Fitbit Ultra	.24	.63	.41	.67
Adidas MiCoach	.55	.81	-	.65
BodyMedia FIT Core	.68	.73	.47	.56

DISCUSSION

The purpose of this study was to assess the ability of various activity trackers to accurately measure steps taken and energy expenditure (EE). The results of this study found that the accuracy of the device depends on the type of exercise being done. For steps taken, the activity trackers were generally pretty good. The activity trackers that were significantly different than actual steps recorded were no more than 10% off for treadmill walking, treadmill running, and elliptical exercise. During the agility drills there was a larger underestimation, but this is likely due to different types and more complex movements. Movements used during the drills included shuffling, pivoting, quick steps, sliding, and jump stops. Crouter, Schneider, Karabulut, and Bassett (2003) noted that there could be inaccuracies with recording of steps with frail elderly or others with a shuffle gait. Steps taken during the ladder, T-drill, and the basketball layup drill included forward, back, and side-to-side motions. The smaller or quicker steps taken may not always register on the activity trackers. The smaller steps also appeared to lead to less arm movement, which would then affect the accuracy of the activity trackers that were worn on the arms or wrists. Shuffling side-to-side may also only register half the steps. When shuffling, there is a predominant first step, so the push off of the opposite foot may not actually register. Also, the basketball portion included dribbling a basketball. This could have affected steps recorded due to the change of arm movement. These more complex movements are much different than your just forward motion of walking.

For estimating energy expenditure, the devices were a little less accurate. The recording of EE is a more complex process and involves incorporating data measured by the device into a regression equation within the devices' software. This is likely why we see more variance in recordings. The difference between measured and predicted kcals ranged from 13-60%, with devices over predicting and some devices under predicting. None of the devices were accurate across all the activities for recording kcals, so picking an activity device to record kcals may not be the best option.

The NL-2000i was shown to be accurate in assessing steps taken while walking by other studies. Schneider, Crouter, Lukajic, and Bassett (2003) found the pedometer to be within ±3% of the actual steps taken on a 400 m track. Crouter et al. (2003) found the pedometer to be within ±1% of actual steps on the treadmill. This supports the data recorded in the present study which also found the NL-2000i to be accurate in measuring steps taken during treadmill walking. Steeves, Tyo, Connolly, Gregory, Stark, and Bassett (2011) assessed the accuracy of three pedometers (Omron HJ-303, Sportline Traq, and Yamax SW200) in their ability to measure steps during walking, running, elliptical, front-back-side-side stepping (FBSS), stair climbing/descending, and ballroom dancing. Significant differences were found between all three pedometers, especially for the FBSS stepping and ballroom dancing. Although the NL-2000i was not used in the previous study, the current study's pedometer was also unable to accurately measure steps taken during the agility portion.

There is limited data assessing the accuracy of activity trackers for measuring steps taken, however a number of studies have found that caloric expenditure is either underestimated or overestimated, depending upon the activity. For instance, Balogun, Martin, and Clandenin (1989) found the Caltrac accelerometer to overestimate EE. The difference between the Caltrac and the Beckman Horizon metabolic cart ranged from 13.3-52.9%. They suggested that a different regression equation needed to be created to improve the accuracy of the device. Crouter, Churilla, and Basset (2006) studied three different accelerometers: the Actigraph, Actical, and AMP-331. They found that the Actigraph and Actical both overestimated EE during walking. All three accelerometers underestimated EE during vigorous activities (such as basketball and fast running). They also found that the algorithms created for these devices did not work across a wide range of physical activity levels (light, moderate, and vigorous), meaning, if a device was accurate during light activity, it would not necessarily be accurate during vigorous activity. Light activity was classified as being sedentary, such as lying down and sitting. This supports our findings, since some activity devices were shown to be more accurate for one type of activity and not another. It also supports the underestimation of EE during vigorous activities, such as the present study's agility portion, which also included basketball activities. All activity devices in the current study underestimated EE during the agility portion by 14-60%.

Previous research on the BodyMedia Sensewear Pro II (SP 2) found that it overestimated EE when subjects walked on a level treadmill (Fruin & Rankin, 2004). King, Torres, Potter, Brooks, and Coleman (2004) found that the SP 2 underestimated EE at all treadmill speeds. In the current study, there was no significant difference between measured and predicted EE when using the BodyMedia FIT Core activity tracker. This suggests that BodyMedia may have updated the arm band or used a different algorithm in the FIT Core activity tracker compared to the SP 2.

The Jawbone UP was first released in 2011, but due to technical difficulties, it was recalled. The new Jawbone UP band performed fairly well in the current study. It was accurate with steps taken across all activities and was fairly accurate with kcals. The kcals were only significantly different during treadmill running (+20%) and the agility portion (-14%) of study. There were also no technical difficulties while operating the new Jawbone UP, thus the technological issues appear to be solved.

Several factors could have affected the results of the current study. One factor could be where the activity trackers were worn on the body. Instructions were provided for each device on where to wear the activity trackers. Some of the activity trackers had multiple locations where you could wear them. It is possible where the devices were worn in the current study could have affected recordings.

Another factor that could have influenced the results was the biomechanics of the individual participants. Activity trackers worn on the arms may have been affected by the different arm movement of subjects. Thus, subjects with limited arm movements may have had fewer recorded steps or calories. Arm movement was especially low during the agility portion. While performing the agility ladder, some subjects had little to no arm movement. Reminding subjects to use their arms while walking and performing the agility ladder may lead to more steps and/or calories to be recorded.

Finally, future studies may want to incorporate a wider variety of activities. The current study exercised at one self-selected pace per piece of equipment, with each modality being conducted at a steady state. The treadmill walking speeds ranged from 3.0-4.2 mph, which is a fairly limited range of walking speed. The treadmill running speeds ranged from 5.0-8.5 mph, which is a little broader range. Future studies may want to incorporate multiple speeds and inclines for each device. Fruin and Rankin (2004) found differences in measured energy expenditure when comparing 0% to 5% grade. Testing the same activity trackers at different inclines may lead to the same results.

In summary, when choosing an activity device, it is important to think about the information you want to track. If looking at steps taken, the Jawbone UP appears to be the best activity device to choose. If you are more concerned about calories, there were a wide variety of results, depending upon what type of activity was being performed. Further research needs to be conducted to investigate the accuracy of these activity trackers.

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APPENDIX A

PAR-Q

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____________________

SIGNATURE ____________________ DATE ____________________

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) ____________________ WITNESS ____________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

1:12

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APPENDIX B

INFORMED CONSENT

INFORMED CONSENT

THE ACCURACY OF VARIOUS ACTIVITY TRACKERS IN ESTIMATING ENERGY EXPENDITURE AND STEPS TAKEN

I, ___________________________________, volunteer to participate in a research study being conducted at the University of Wisconsin-La Crosse.

Purpose and Procedures

- The purpose of this study is to evaluate the ability of five activity trackers currently on the market to accurately measure energy expenditure and steps taken.
- My participation in this study will consist of three separate sessions.
- During each session, I will be required to wear all of the activity trackers, along with a portable metabolic analyzer and a pedometer. I will also be video-taped during each activity so that my steps can be verified.
- The first session will involve walking and running on a treadmill at a self-selected speed. The walking portion will be 20 minutes followed by a 10 minute break. The running portion will be 20 minutes following the break.
- The second session will be conducted on an elliptical cross-trainer and in a gymnasium. The elliptical cross-trainer segment will be 20 minutes at an intensity of my choosing, followed by a 10 minute break. Following the break, there will be a 20-minute sports-related drill session conducted. The first activity will be seven agility ladder drills, repeated twice. The second exercise will be the "T Drill." Last, the subjects will perform a basketball full-court lay-up drill. Between each drill, subjects will shoot 10 free throws.
- Total time requirement for the entire study will be about 2 hours.
- Testing will take place in Mitchell Hall on the UW-L campus.
- Research assistants will be conducting the research under the direction of Dr. John Porcari, a Professor in the Department of Exercise and Sport Science.

Potential Risks

- I may experience some overall muscle fatigue and shortness of breath as a result of the workouts used in the current study.
- The risk of serious or life-threatening complications is very low in apparently healthy adults.

- The test will be stopped immediately upon the development of any complications.
- There will be persons trained in CPR, Advanced Cardiac Life Support (ACLS), and first aid available for every testing session.

Benefits of Participation

- There are no directly anticipated benefits to me from participating in this study.
- The information gathered in this study about the accuracy of the various activity trackers may be beneficial for the general public and better knowledge about the use of activity trackers may help improve exercise compliance.

Rights and Confidentiality

- My participation in this study is voluntary.
- I may choose to discontinue my involvement in this study at any time without penalty.
- The results of this study have the potential of being published or presented at professional meetings, but only group data or data blinded to individual identity will be presented.

I have read the information provided on this consent form. I have been informed of the purpose of this study, the procedures, and the expectations of myself as well as the testers, and of the potential risks and benefits that may be associated with volunteering for this study. I have asked any and all questions that concerned me and received clear answers so as to fully understand all aspects of this study.

Questions regarding study procedures may be directed to Caitlin Stackpool (218-780-2944), the principal investigator, or the study advisor Dr. John Porcari, Department of Exercise and Sport Science, UW-L (608-785-8684). Questions in regards to the protection of human subjects may be addressed to the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects at (608-785-8124) or (irb@uwlax.edu).

Subject: ______________________________ Date: _____________________

Investigator: _________________________ Date: _____________________

APPENDIX C

REVIEW OF LITERATURE

Review of the Literature

The purpose of this paper is to review the literature concerning assessment and measurement of physical activity, the use of pedometers, and the transition into the use of activity trackers.

Assessment of Physical Activity

Over the years, physical activity has been shown to provide health benefits such as preventing weight gain, decreasing the risk of chronic disease and disability, and increasing physical fitness (Haskell et al., 2007). In 2007, physical activity guidelines were updated by the American College of Sports Medicine (ACSM) and the American Heart Association (AHA). They stated that to achieve health benefits, people must perform at least 30 minutes of moderate intensity physical activity five times a week, 20 minutes of vigorous activity three days a week, or a combination of the two. It was recommended that activities be in bouts of at least 10 minutes. Moderate activity levels were classified as metabolic equivalents (METs) of 3.0-6.0. Vigorous activity levels were METs greater than 6.0 (Haskell et al., 2007). It is to be noted that MET levels for moderate to vigorous activities are not appropriate for every individual. In 2011, ACSM released another statement encouraging a comprehensive physical activity program consisting of cardiorespiratory, resistance, flexibility, and neuromotor activities, but stating the main goal is to reduce time in sedentary positions (Garber et al., 2011).

During the last 20 years, there has been a dramatic increase in obesity in the United States, ranging from 21-34% of the population. These numbers continue to remain high (CDC, 2012). Physical inactivity is another problem in the United States. It is estimated that 10.1-43.0%. of the population performs no leisure time activity. In areas where there is a high prevalence of inactivity, there are also higher rates of obesity (CDC, 2011). In order to help reduce obesity, physical activity must be increased.

Assessing and monitoring physical activity has become more prevalent over the years. In this era, monitoring has become much easier with the help of items such as online diaries, pedometers, and other activity tracker devices. Monitoring exercise has been proven to be an effective way to adhere to physical activity due to an increased awareness. Burke et al. (2011) studied the use of personal digital assistants (PDA) that recorded diet, exercise, and gave daily feedback compared to using a diary to record the same information. The subjects who used PDAs had a higher amount of weight loss, but there was a high adherence among all subjects who recorded their data. Thus, finding inexpensive ways to help record data and monitor activity may be a start to increasing physical activity and aid in compliance to an exercise program.

Pedometers

Pedometers were one of the first devices used by the public as a means to monitor their activity levels. In 1965, Y. Hatano, a Japanese pedometer manufacturer, came out with the idea that individuals should take 10,000 steps per day. It is unknown where that number came from, but it has gained widespread acceptance and continues to be used as a goal. Although pedometers are an inexpensive tool, they are unable to monitor intensity. This made it difficult to correlate steps taken to the guidelines set by ACSM and AHA for moderate and vigorous activities. Tudor-Locke and Bassett (2004) created indices that were linked to health benefits while using a pedometer. Since you could not measure intensity with the pedometer, they said <5000 steps per day could be classified as sedentary, 5000-7490 steps without sports or exercise as low active, 7500-9999 steps as somewhat active, ≥10,000 steps as active, and >12000 steps as highly active. This was a useful tool since it helped stratify activity levels based on measured steps. Now, some pedometers (such as the New-Lifestyles NL-2000i) have the ability to monitor intensity.

Numerous studies have been done on the NL-2000 to validate its accuracy in measuring steps. The pedometer has been tested using multiple speeds and on various surfaces. Schneider, Crouter, Lukajic, and Bassett (2003) tested the accuracy and reliability of the NL-2000 and compared to nine other pedometers on an outdoor track. Subjects were allowed to walk on the 400 m track at their own pace. The steps were hand tallied to test each of the 10 pedometers. The NL-2000 was found to be within ±3% of the actual steps taken, finding it both reliable and accurate. In another study, the NL-2000 was tested on a treadmill. Results from this study found the NL-2000 to be within ±1% of actual steps taken at speeds of 80 m/min and above. At a slower speed (54 m/min), the NL-2000 was less accurate, but it was still found to be acceptable. Because of the above data, the NL-2000 was recommended as a "good choice" in research settings (Crouter, Schneider, Karabulut, & Bassett, 2003). Schneider, Crouter, and Bassett (2004) also studied the accuracy of the NL-2000 in other settings. This study was set in a free-living environment, and the NL-2000 was once again found to provide accurate estimates of steps taken. However, it should be noted that there could be inaccuracies with frail elderly or others with a shuffle gait (Crouter et al., 2003).

Pedometers have been shown as an effective way to measure steps taken in a day, but their activities are limited to walking and running. Other studies have tried different pedometers to measure steps taken during other activities. Steeves et al. (2011) assessed the accuracy of three different pedometers during walking, running, elliptical, front-back-side-side stepping (FBSS), stair climbing/descending, and ballroom dancing. Significant differences were found between all three pedometers, especially for the FBSS stepping and ballroom dancing. This is probably due to the small, quick steps or sliding motion used during these activities. Another limitation of the pedometers is the inability to accurately estimate energy expenditure (EE) (Crouter et al., 2003). This leads us to need another device to help measure other forms of activity and to better estimate EE.

Activity Trackers

Direct and indirect calorimetry can measure EE in a laboratory, but that is not applicable for a majority of the population. It is expensive and needs qualified people to run the equipment. Thus, in order to accommodate the needs of the public, more economical devices were created. These activity trackers have incorporated accelerometers, pedometers, Global Positioning Systems (GPS), and technological measures to try to estimate EE. They claim to be able to track more activities than just walking and running, unlike the pedometer. For instance, inclinometers have the ability to recognize when you take the stairs, and accelerometers can monitor your movements during a game of basketball. In 1991, the use of accelerometers to assess physical activity under free living conditions looked promising, but there was limited data concerning the reliability (Meijer, Westerterp, Verhoeven, Koper, & Hoor, 1991). The information on the ability of these trackers to measure steps taken is limited. It has also been shown that wearing trackers on limbs, rather than near the core/hip, can lead to bumping and misinterpreting data (Barkhuus, 2006).

The accuracy of activity trackers to measure EE has been shown to vary from study to study. A study by Balogun, Martin, and Clendenin (1989) found that the Caltrac accelerometer overestimated EE. Twenty-five subjects (10 men, 15 women) walked on a level treadmill at four different speeds. Energy expenditure was measured using a Beckman Horizon metabolic cart and compared to the accelerometer data. The difference between the two methods ranged from 13.3%-52.9%, which led to the need to develop a different regression equation. For their device, the researchers warned that due to their findings, the raw estimated EE data of the accelerometer should be used cautiously.

Crouter, Churilla, and Bassett (2006a) measured the accuracy of estimating EE in other accelerometers (the Actigraph, Actical, and AMP-331). Forty-eight subjects (24 men, 24 women) performed activities ranging from sedentary (lying, sitting) to vigorous exercise. The study incorporated three different activity routines consisting of various lifestyle and sports activities. Each activity was performed for 10 minutes with a 1-2 minute break between each activity. Indirect calorimetry was recorded simultaneously. Results found the Actigraph and Actical to overestimate EE during walking and the more sedentary activities. All three accelerometers were shown to underestimate EE in all forms of vigorous activity, such as basketball, racquetball, and fast running. It was also found that the algorithms for these accelerometers did not work across the three (sedentary, moderate, and vigorous) physical activity levels.

Crouter, Clowers, and Bassett (2006b) updated the algorithm for the Actigraph accelerometer by including various activities, representing sedentary/light to vigorous activities. The design of the study was the same as the previous study by Crouter et al. (2006a). They had 24 men and 24 women perform three routines with varying exercise intensity. They also used a metabolic cart to measure EE. Their estimates of EE were within .75 METs of measured values, which were seen as a substantial improvement. Continuing to update algorithms will help make measuring EE more accurate.

Using GPS monitors has also been proven to be inaccurate, as they have been shown to generally over predict EE. In a study done by McKenzie, Manning, and Heil (2006), 13 subjects completed a 2.4 km course at a self-selected walking pace. They wore both a watch and waist GPS and a portable metabolic analyzer. The results showed significantly different results between the GPS estimates of EE and measured EE. It was concluded that GPS monitors appear to not be suited for slower walking, but may be better during fast walking and running (McKenzie et al., 2006).

In 2007, Welk, McClain, Eisenmann, and Wickel (2007) tested the accuracy of the BodyMedia activity tracker, the Sensewear Pro II (SP2), measuring energy expenditure during normal activities of daily living in 30 college-age participants. The SP2 is unique in its ability to incorporate physiological features such as galvanic skin response, heat flux, and skin temperature into its equation. The results of the study showed some differences between measured EE, but the SP2 was found to be more accurate for very sedentary activities, such as lying and sitting. This is probably due to the ability of the device to discriminate between resting and active states.

Conversely, other studies have found the SP2 to be inaccurate in estimating EE. Fruin and Rankin (2004) found the SP2 armband to overestimate EE when walking at 0% grade and underestimate EE when walking at a 5% grade. But, they also found the SP2 to be accurate at resting levels and when riding a cycle ergometer. King, Torres, Potter, Brooks, and Coleman (2004) also looked at the SP2 armband and found an inaccurate measurement of EE when using a treadmill. Ten males and 11 females were to perform three different walking speeds and four different running speeds on a treadmill while measuring EE using the SP2 and through indirect calorimetry. Results of the study showed the SP2 overestimating EE at all treadmill speeds.

Another activity tracker, the Jawbone UP, was first released in 2011, but was taken off the market due to multiple malfunctions. Water problems, a lack of flexibility, an unresponsive vibration motor, and not tracking data were a few of the malfunctions. In 2012, Jawbone released a “new and improved” UP band, which proportionately addressed these problems.

New Activity Trackers

New activity trackers come out every year. Five activity trackers new to the market are the Nike Fuelband, Jawbone UP, Fitbit Ultra, BodyMedia FIT Core, and Adidas MiCoach. The Nike Fuelband incorporates a built-in, three axis accelerometer; the Jawbone UP incorporates a motion sensor; and the Fitbit Ultra uses an accelerometer along with an inclinometer. The BodyMedia FIT Core is very similar to the SP2 discussed previously. It consists of four sensors: a 3-axis accelerometer, galvanic skin response, skin temperature, and heat flux. The Adidas MiCoach comes as a “pacer bundle,” consisting of a heart rate monitor, a stride sensor, and a pacer. At this point in time, there is no data comparing the accuracy of these devices to directly measured EE.

Summary

In conclusion, there is great need for devices that can accurately measure all different types of physical activity. Pedometers have been shown to be relatively accurate in measuring step counts, but inaccurate in measuring energy expenditure. The accuracy of the different forms of activity trackers has been extremely variable in their ability to measure energy expenditure. More research is necessary to find the best devices on the market today, so that the public can make informed decisions.

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