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Accuracy of Commercial Fitness Trackers During High-Intensity Functional Training

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ACCURACY OF COMMERCIAL FITNESS TRACKERS DURING HIGH-INTENSITY FUNCTIONAL TRAINING

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Commercially available fitness trackers have been found to accurately measure steps and caloric expenditure during walking and running activities. Circuit-style, high-intensity functional training (HIFT) has become increasingly popular because it is inexpensive and effective in improving muscular strength and cardiovascular fitness. **PURPOSE**: To evaluate the accuracy of five accelerometers (ActiGraph GT3X, Nike Fuelband, Fitbit One, Fitbit Charge HR, and Jawbone UP Move) in estimating energy expenditure while performing an acute bout of HIFT. **METHODS**: Participants (n = 47) underwent baseline testing and at least 48 hours later, each participant completed the main test: a 15-minute workout consisting of 12 repetitions each of 7 different exercises; performed circuit-style by completing as many rounds as possible. During the main test, each participant wore the Cosmed $K4b^2$ portable metabolic analyzer (PMA) and five different accelerometers. **RESULTS**: Four of the five fitness trackers reported lower (p <0.01) total caloric expenditure values compared to the PMA during the acute bout of HIFT. The waist-mounted device (ActiGraph, 182.55 ± 37.93 kcals) most closely mimicked caloric expenditure compared to the PMA (Cosmed, 144.99 ± 37.13 kcals) as indicated by an insignificant p value (0.056). Systematic differences between the activity monitors were calculated using an Intraclass Correlation (ICC) with an ICC = -0.032. The ICC of F (46,235) = 0.812 (p = 0.799) was not significant at the predetermined 0.05

alpha level. A Repeated Measures ANOVA showed that when compared to the Cosmed, all activity monitors were significantly different at the 0.05 alpha level. The Fitbit One and the Fitbit Charge HR were the only two activity monitors that are not significantly different from one another ($p = 0.985$). The range of error based on mean absolute percentage errors (MAPE) was lowest for the ActiGraph (15.1%) and highest for the Fitbit Charge HR (22.1%). **CONCLUSION**: The wrist- and hip-mounted fitness trackers do not accurately assess energy expenditure during HIFT exercise.

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Chapter 1 - Introduction

Commercial fitness trackers, also sometimes referred to as accelerometers, are small devices that are typically worn on the wrist or on the waist and are capable of measuring the daily caloric expenditure, steps taken, energy expenditure, possible sleep patterns, and heart rate (Kooiman et al., 2015; Tucker, Bhammar, Sawyer, Buman, & Gaesser, 2015). These monitors are developed so that consumers can track daily physical activity levels, as well as recognize the amount sedentary time they accumulate for a given time period. Over the last decade, commercial fitness devices (objective method of monitoring physical activity) have been readily available for purchase, and are becoming increasingly popular ways to assess energy expenditure among free-living conditions (Kooiman et al., 2015; Nilsson, Ekelund, Yngve, & Sjostrom, 2002; Cartrine Tudor-Locke, 2002). The fitness tracker industry is making quite a bit of money with these different trackers available on the market. This industry is set to triple its sales from $2 billion in 2014 to almost $5.4 billion in 2018 (Lamkin, 2015). Therefore, it is important to determine the accuracy of these fitness trackers in order for consumers and fitness professionals to be knowledgeable about the true capacities of the activity monitors they are purchasing and/or recommending.

Fitness trackers estimate energy expenditure using regression equations that are generated by researchers (Crouter, Horton, & Bassett, 2012). These regression equations have been developed to estimate the amount of energy expended over a given time frame and are based counts per minute (movement) in order to estimate physical activity intensity (Crouter, Clowers, & Bassett, 2006). For example, lifestyle regression equations more accurately estimate physical activity energy expenditure (PAEE) for moderate intensity exercises, however they tend to overestimate the energy expenditure of sedentary and light activities, while underestimating the energy expenditure of vigorous activities (Bassett et al., 2000). Additionally, consistent movement patterns during activities such as walking and running lead to a more accurate estimate of PAEE than irregular movement patterns such as those involving free-living movements (uphill walking, lifting objects, squatting down, standing up from a seated position, etc.) (Crouter, Churilla, & Bassett, 2006).

Typically, self-reported questionnaires, logs, interviews, and journals have been used to assess physical activity (Lyden, Kozey, Staudenmeyer, & Freedson, 2011; Sallis & Saelens, 2000; Cartrine Tudor-Locke, 2002). However, this is problematic as individuals have a tendency to over report favorable outcomes and under report unfavorable outcomes (Caeser, 2012). People tend to overestimate their physical activity levels when self-report measurements are used (Sallis & Saelens, 2000). Therefore, the amount of energy expended from each individual is most likely being overestimated as well. In addition to issues with overestimation using self-reported measures, these tools are time–consuming and burdensome for the individuals as they have to keep track the amount of exercise they partake in on a daily basis (walking, gardening, running, calisthenics, etc.); and these logs do not take into account the intensity of the physical activity (Caeser, 2012; Cartrine Tudor-Locke, 2002).

According to the World Wide Survey of Fitness Trends for 2015, body weight training (BWRT) and high-intensity interval training (HIIT) have become increasingly popular modes of exercise (Thompson, 2014). This includes exercises such as push-ups, air squats, sit-ups, and lunges. BWRT and HIIT have become very popular because they are inexpensive, require minimal equipment, and are effective (Thompson, 2014). One particular type of HIIT, high-intensity functional training (HIFT), is a high-intensity circuit-style training method in which only an individual's body weight is utilized (Heinrich, Patel, O'Neal, & Heinrich, 2014). This mode of exercise can be done anywhere; while also removing common exercise barriers such as weather, access to exercise facilities, and safety of surroundings. There are few studies that investigate HIFT and its benefits, however one study reported that a high-intensity, circuit-style training modality elicited cardiovascular responses similar to sprint intervals in college-aged men and women (Gist, Freese, & Cureton, 2014). HIFT is a relatively new modality that warrants further investigation into its risks and benefits. Because HIFT is becoming an increasingly useful mode of exercise, and the use of commercial fitness trackers have become extremely popular, understanding the accuracy of commercial fitness trackers during this mode of exercise is important. People may experience significant physiological benefits from HIFT training, but if their fitness trackers do not pick up on the caloric expenditure and/or step counts, they may discontinue the exercise and perceive it as not helping them achieve their fitness goals. To our knowledge no previous study has investigated the accuracy of popular, commercial activity trackers in assessing total energy expenditure (TEE) during a HIFT session.

Statement of the Problem

Commercially available fitness trackers are advertised as having the capacity to assess a variety of physiological measures, including TEE. High-intensity interval training exercise, such as HIFT circuits, are a popular mode of exercise training. HIFT exercises include functional movements performed daily (e.g. stair climbing, squatting, and lunging). Given the popularity of commercially available fitness trackers and the popularity of HIFT, there is a need to evaluate the effectiveness of these devices in regards to calculating TEE during HIFT.

Statement of the Purpose

The purpose of this study is to determine the accuracy/validity of four commercially available fitness trackers (Nike Fuelband, Fitbit One, Fitbit Charge HR, and Jawbone UP Move) in assessing TEE during an acute bout of HIFT.

It is hypothesized that these commercial fitness trackers will underestimate the total amount of energy that is being expended based upon the types of exercises being performed (e.g. body weight squats and sit-ups). This hypothesis will be assessed by the research question:

Do commercially available fitness trackers accurately assess total energy expenditure (TEE) during a high-intensity, circuit-style, functional training (HIFT) bout of exercise?

Significance of the Study

This study will advance knowledge in the field of Exercise Science and Kinesiology by helping technicians, clinicians, consumers, and other health care providers better understand the accuracy and functionality of the fitness equipment they are purchasing and/or recommending to their clients/patients. This study will compare the latest commercially available fitness trackers (Nike Fuelband, Fitbit One, Fitbit Charge HR, and Jawbone UP Move) to two criterion measures: 1) The ActiGraph GXT3 (a well-validated accelerometer used extensively for assessing PAEE for research purposes) and 2) The Cosmed $K4b^2$ (portable metabolic analyzer which uses indirect calorimetry to accurately assess TEE). With this information, we will be able to determine whether or not the commercial fitness trackers are accurate in calculating TEE during HIFT, which is one of the most popular modes of exercise today. This study is unique in that the exercises being performed do not involve running/walking, therefore we will be able to determine if they can correctly calculate energy expenditure based upon exercises that are completed (e.g. sit-ups and body weight squats). This study will benefit those who are interested in using a fitness tracker to help self-monitor their daily physical activity levels.

List of Terms

High-Intensity Functional Training (HIFT) – high-intensity, circuit-style training in which only an individuals' body weight is utilized; mimics movements used in daily living activities (Heinrich et al., 2014).

Fitness Tracker – device used to track fitness metrics such as calories burned, steps taken, and distance traveled

Accelerometers – an instrument for measuring acceleration

Triaxial Accelerometer – An accelerometer that is capable of sensing motion in three planes (anterior-posterior, vertical, and medial-lateral)

Portable metabolic analyzer (Cosmed K4b^2) – portable system for pulmonary gas exchange measurement with true breath-by-breath analysis

Maximal Aerobic Capacity – maximum rate at which a human subject can take up oxygen from the air; also known as VO_2 max. It is the highest amount of oxygen a person can consume during maximal exercise of several minutes' duration (Medical Dictionary for the Health Professions and Nursing, 2012; Dictionary of Sport and Exercise Science and Medicine by Churchill Livingston, 2008).

Chapter 2 - Literature Review

This chapter will discuss physical inactivity, physical activity, define total energy expenditure (TEE), and provide an overview of physical activity fitness trackers.

Physical Inactivity

The obesity epidemic poses a significant threat to the overall health of the nation, and its prevalence has increased over the years from 12% in 1991 to 18% in 1998 (Mokdad et al., 1999). Currently, 16% of children are considered overweight, and 34% are at risk of becoming overweight (Wang & Beydoun, 2007). Obesity has many consequences for the individuals being affected such as psychological, health, and social implications. Projections show that if the obesity trend continues along its current path, 80% of all American adults will be considered overweight or obese (Wang, Beydoun, Liang, Caballero, & Kumanyika, 2008). One major factor that has contributed to these metabolic diseases such as obesity is the lack of physical activity (Cartrine Tudor-Locke, 2002). There are many factors that play a role in reducing the time or ability to be active and many factors that have created a more sedentary environment at home and work. One investigation reported that on average, overweight and obese individuals take fewer steps throughout the day than those individuals who are lean (C. Tudor-Locke, Brashear, Johnson, & Katzmarzyk, 2010). As the industrial revolution approached the nation over time and technology advanced, there have been more occupations created where sitting on a computer is considered normal versus getting up and being physical at work such as working assembly lines, farming, and hard physical labor. There are several Americans who dedicate their lives to their work, which ultimately leads them to work from 9:00am to 5:00pm with very little room to exercise or be active. This issue goes hand in hand with college students. Those individuals who work in a white collar job setting may be unaware of the lack of physical activity being performed daily due to their job environment. Many students who attend universities have a great deal of responsibility with classes, course work, occupations, etc., that they are unable to find time to workout during the day or simply be recreationally physically active.

Physical Activity

Physical activity is movement involving the musculature of the body resulting in energy expenditure above the resting baseline values (Caspersen, Powell, & Christenson, 1985). Physical activity is a multi-dimensional behavior that is characterized by mode, intensity, frequency, and duration. These variables put together categorize physical activity energy expenditure (PAEE). Physical activity, whether it be walking, running, anaerobic, or aerobic exercising, has been known to help reverse the effects of major diseases such as obesity, diabetes, cardiovascular disease, hypertension, etc. (Kumahara et al., 2004). It is well known that physical activity affords many health-related benefits, however physical activity/exercise can tend to be overlooked by the lack of motivation, time, capability, or gym space.

The use of fitness trackers and pedometers, devices used to track steps taken, are highly associated with increases in the amount of physical activity that is performed by an individual. Setting a step goal ranging from 2,000-10,000 steps, depending on the individual, seems to be a motivational factor for increasing the amount of daily physical activity (Bravata et al., 2007). These devices are becoming a popular motivational tool and not just solely being used to estimate energy expenditure. For those individuals who just want to walk more, these devices are a great way to track steps and distance traveled. On the other hand, for those avid gym goers, these activity monitors may help them gage their amount of physical activity for any given day. Fitness trackers help gage the amount of physical activity that is being performed, whether it be walking through the office at work, or performing a high intensity training workout (i.e. if an individual has set a 10,000 step goal and has only achieved 4,000 of those steps, they are well aware that they are below their goal thus far and need to start being more active for that day).

Total Energy Expenditure (TEE)

Total energy expenditure (TEE) takes into consideration resting energy expenditure (REE) as well as physical activity energy expenditure (PAEE). In simpler terms, TEE = PAEE + REE. For those fitness trackers that only take into consideration PAEE, it is necessary to add measured or estimated REE to have comparable results to those fitness trackers that already estimate TEE (Lee, Kim, & Welk, 2014). REE can be measured by using a portable metabolic device or a metabolic cart. If unable to actually measure an individuals' REE, it can be estimated by using equations such as that derived by Mifflin et al. 1990:

For females, REE = 9.99 x weight (kg) + 6.25 x height (cm) – 4.92 x age (years) -161

For males, REE = 9.99 x weight (kg) + 6.25 x height (cm) – 4.92 x age (years) + 5.

For example, the Fitbit activity monitors measure TEE and accounts for both PAEE as well as the energy expended at rest (Caeser, 2012).

Physical Activity Fitness Trackers

Physical activity fitness trackers are devices used to measure the duration/intensity of a workout, as well as estimate the amount of energy expended, steps taken, floors climbed, etc. These devices have become popular among consumers due to their smaller size and their ability to measure different variables. Fitness trackers use algorithms (energy expenditure equations) to estimate energy expenditure; however, when in free-living conditions and while performing non-weight bearing activities, these physical activity monitors tend to underestimate energy expenditure (Dannecker, Sazonova, Melanson, Sazonov, & Browning, 2013). Current physical activity monitors contain small sensors to measure acceleration, gravity, etc. (Caeser, 2012). Micro-electro-mechanical accelerometers (MEMs) are embedded into some physical activity monitors. MEMs allow these fitness trackers to detect human motion in various planes (triaxial and biaxial) without compromising the ability of the monitor to measure acceleration (Caeser, 2012).

Movement

Fitness trackers and pedometers can measure steps and energy expenditure easily based upon movement from one spot to another. For agility drills such as shuffling, pivoting, and anything involving quick steps and fast arm movements, the fitness trackers appear to underestimate the energy expenditure (Stackpool, Porcari, Mikat, Gillette, & Foster, 2014). This is likely due to various, complex movements that are being performed while completing the agility exercises. Small, quick, abnormal steps may not be registering with the fitness trackers and therefore underestimating the energy expenditure. There is typically less major arm movement involved in exercises involving quick steps, which then effects the accuracy of the fitness trackers worn on the wrist and arm (Stackpool et al., 2014). When subjects completed a two session study involving a 50-minute workout session that included a 40-minute treadmill walk with a 10-minute rest period in between for the first session; as well as a 20-minute elliptical workout with agility drills after for the second session, all while wearing commercial fitness devices, it was shown that the energy expenditure reported from the activity monitors were lower than those reported from the portable metabolic analyzer. During the treadmill running, the Fitbit Ultra, Nike Fuelband, and Jawbone UP Move underestimated caloric expenditure when compared to the portable metabolic analyzer; and while performing the agility drills (agility ladder and "T Drill"), the Nike Fuelband underestimated caloric expenditure by 14% with Jawbone UP Move underestimating by 30% when compared to the criterion method. Not only did the activity trackers differ significantly from the portable metabolic analyzer, it is also worth mentioning that the steps were also underestimated with the Nike Fuelband (Stackpool et al., 2014). In a study that looked at accelerometer energy expenditure in different activity settings such as treadmill walking, reclining, typing on a computer, elliptical, biking, and stair climbing, it was reported that the activity monitors showed relatively accurate measurements when compared to the criterion method (Oxycon mobile 5.0). The participants completed 13 different activities for a duration of 69 minutes. The 13 activities were performed for 5 minutes each, with the treadmill activities lasting 3 minutes. The value of kilocalories measured from the portable metabolic analyzer (Oxycon mobile 5.0) was 356.9 ± 67.6 kilocalories, and the estimates from the eight accelerometers used in the study ranged from 271.1 ± 53.8 kilocalories (Basis B1 Band) to 370.1 ± 51.5 kilocalories (Jawbone UP Move). Mean absolute percentage error (MAPE) measures error in a device (fitness trackers in this case) when compared to the criterion method and is expressed as a percentage. It is another method to assess the error in the fitness trackers compared to a criterion method.

MAPE is calculated by dividing the average of absolute differences between the fitness trackers and the criterion method by the criterion method value, and finally multiplying it by 100 to generate a percentage. The Fitbit One recorded a MAPE of 10.4% with the Nike Fuelband recording a 13.3% MAPE (Lee, Kim, and Welk, 2014). The underestimation of lifestyle activities results from not taking into consideration the added energy expenditure from arm movement, uphill walking, stair climbing, and carrying objects (Bassett et al., 2000).

In a previous study involving 21 participants, there was a series of three routines used in the protocol. One routine involved sedentary/walking movements, routine two consisted of household/yard work activities, while the last routine involved conditioning/sports exercises (17 total exercises combined). The Nike Fuelband overestimated the energy expenditure for more than half of the 17 total exercises, and underestimated for three of them. During the household activities involving a great amount of arm movement, the Nike Fuelband overestimated energy expenditure (sweeping; Nike Fuelband, 4.7 ± 0.4 vs. Cosmed, 3.0 ± 0.8). However, during the elliptical exercise, the Nike Fuelband was significantly different than the Cosmed (Caeser, 2012).

Body Placement

Body placement of these commercial fitness trackers is also an area of question. Accelerometer output is dependent upon where the accelerometer is placed on the individual's body, and sensor capabilities of the monitor (Caeser, 2012). Several different fitness trackers exist that allow an individual to wear them on their wrist, around their waist/arm, clipped onto their belt loop, or clipped directly onto their pants/shorts. There is not a significant amount of research that discusses which placement on the body is most accurate. For those exercises that require full body movements, it has been suggested to place the accelerometer as close to the center of mass as possible to maximize accuracy (Caeser, 2012; Crouter, Schneider, Karabulut, & Bassett, 2003).

Chapter 3 - Methods

Participants

This study included 47 total participants [male (*n* = 22) and female (*n* = 25)] between the ages of 18-59 recruited in the Bowling Green, KY area. Flyers were posted on the Western Kentucky University campus as well as emailed Western Kentucky University students, faculty, and staff. Each participant was given an informed consent form that has been approved by the University Institutional Research Board (IRB) (ID: 802720-1) which included potential risks, benefits, and detailed study procedures. Demographic characteristics of the 47 participants are located in Table 2. Participants were recreationally active individuals. Recreationally active is defined as regular exercise such as aerobic or weight training activities 2 to 5 days per week and not participating in college athletics (Pescatello & American College of Sports, 2014). Participants were instructed to continue their typical daily activities, diet, and sleep regimens.

Equipment

Cosmed K4b^2. The Cosmed K4b^2 (Cosmed, Rome, Italy) is a small portable metabolic analyzer using indirect calorimetry and is capable of assessing a variety of variables. For the present study, caloric expenditure and oxygen consumption (VO_2) were primary outcomes of interest. The Cosmed K4b^2 portable metabolic analyzer with the battery pack and the harness weigh about 1.5 kg (3.3 lbs) (Crouter, Clowers, et al., 2006). Before each test was conducted, the Cosmed K4b^2 was calibrated and operated according to the manufacturer's instructions. All study team members were trained on the proper use of the equipment.

ActiGraph GT3X. The ActiGraph (ActiGraph, Pensacola, FL) is a small accelerometer typically used for research purposes and has been used in many previous studies to assess physical activity (Lee et al., 2014). The ActiGraph can be worn on the hip, wrist, ankle, and on the waist. Several studies have utilized the ActiGraph on the waist (Crouter, Churilla, et al., 2006; Lee et al., 2014), as it is closest to the individual's center of gravity. It's a triaxial device and can measure human motion in three planes (horizontal, vertical, and diagonal) (Lee et al., 2014). This accelerometer can detect both static and dynamic acceleration. MEMs-based physical activity monitors have been developed to measure physical activity, and have become the most widely used accelerometers to assess physical activity (Caeser, 2012). ActiGraph is one of the most widely used accelerometer for research, and because it is so popular, there have been several regression equations made available to use in the software when analyzing the data (Crouter, Churilla, et al., 2006). Freedson et al., generated one equation in particular that works fairly well when used during treadmill walking or jogging (Freedson, Melanson, & Sirard, 1998). Hendelmen et al. 2000 and Swartz et al. 2000 generated regression equations that apply to moderate-intensity lifestyle activities. These activities in these studies included playing golf, dusting, vacuuming, lawn mowing, recreational activities, and conditioning (Hendelman, Miller, Baggett, Debold, & Freedson, 2000; Swartz et al., 2000).

Nike Fuelband. The Nike Fuelband (Nike Inc., Beaverton, OR) is a triaxial accelerometer that is worn specifically on the wrist. This device assesses steps taken, distance progressed, and calories burned. Data can be synchronized to the Nike+ Connect software (website) by attaching the device to the USB cord provided, which will be connected to the computer; or by uploading the data to a cellular device that uses iOS software (iPhone) via Bluetooth. Data can be shown on the Nike Fuelband itself by a multitude of LED lights that rotate about the band displaying the different measurements the Fuelband has to offer. By clicking the button on the band, the different measurements will be displayed (steps and calories).

Jawbone UP Move. The Jawbone UP Move (Jawbone, San Francisco, CA) is a triaxial accelerometer that can be attached in a small band and worn on the wrist, or clipped onto the waistband of pants/shorts. Jawbone UP Move can assess physical activity patterns throughout the day as well as assess sleep patterns. There is not a screen on this device to display any data visibly. Data can be synchronized by using a cellular device with iOS software (iPhone) and the UP by Jawbone app via Bluetooth.

Fitbit One. The Fitbit One (Fitbit Inc., San Francisco, CA) is a triaxial accelerometer that can measure different variables such as steps taken, calories burned, floors climbed, sleep patterns, and distance traveled. This device is worn on the waistband of pants/shorts. There is a small screen that displays the features and can be rotated through by clicking the button. Data can be synchronized via Bluetooth on a cellular device with the Fitbit app; or on a desktop computer using wifi and a wireless dongle that is plugged into the USB port of the computer and the Fitbit Connect software.

Fitbit Charge HR. The Fitbit Charge HR (Fitbit Inc., San Francisco, Ca) is a triaxial accelerometer that can measure different variables such as steps taken, calories burned, distance traveled, heart rate via plethysmography, and floors climbed. This device is specifically worn on the wrist and can be purchased in three different sizes: small, medium, and large. Data can be synchronized via Bluetooth on a cellular device with the Fitbit app; or on a desktop computer using wifi and a wireless dongle that is plugged into the USB port of the computer and the Fitbit Connect software.

Protocol

The protocol consists of two different data collection sessions. Session one, the participants underwent baseline measurements such as blood pressure, heart rate, body composition, and waist/hip/thigh circumferences. In addition to baseline measures, participants performed a maximal oxygen consumption test using the ParvoMedics TrueOne metabolic cart and a treadmill using the Bruce protocol. Session two, the participants returned to the Biomechanics/Exercise Physiology lab and performed an acute bout of a HIFT workout while wearing the Cosmed $K4B^2$ and each of the activity monitors. The HIFT intervention/data analysis took place in the laboratories. The participants visited the Exercise Physiology lab during two separate sessions, which are described below.

Session One: Initial assessment

In session one, each participant reported to the Exercise Science Lab after an 8 hour overnight fast. The participants were asked to fill out an informed consent, health history questionnaire, self-efficacy questionnaire, physical activity enjoyment questionnaire, and a physical activity readiness questionnaire (PAR-Q). Resting measurements were taken including: resting blood pressure, heart rate, waist and hip circumferences, and body composition via skinfold calipers (Lange skinfold calipers, Beta Technology, Santa Cruz, CA). Height and weight were measured using a stadiometer and digital scale in order to calculate body mass index (BMI). The participants completed a maximal aerobic capacity test based on the Bruce treadmill protocol using the open-circuit spirometry (breathing in ambient air) ParvoMedics TrueOne 2400 maximal oxygen consumption system. Learning and practicing proper movement execution of the high-intensity functional training exercises that will be used for the main test day served as a warm-up for the maximal aerobic capacity treadmill test.

Blood pressure (BP) in mmHg was measured using a manual blood pressure cuff when subjects are in the lab. An appropriately sized cuff was placed around the subjects left arm, over the brachial artery, just above the cubital fossa of the elbow. Pressure was increased to 200 mmHg, then decreased slowly to receive and accurate measurement. The participants' body weight (kg) and height (cm) were determined using a Detect-Medic Scale and attached stadiometer (Detecto Scales Inc., New York). Subjects were asked to remove their shoes and wore a t-shirt and shorts. Once height and weight are obtained body mass index (BMI) was then calculated.

The participants' body composition was measured using calibrated Lange skinfold calipers. The objective is to measure subcutaneous fat to determine body fat. Waist, hip, and thigh circumference measurements were taken by using a standard tape measure. Along with body composition measurements, the participants’ circumferences were measured using a calibrated tension tape measure. Circumference measurements were taken so that the tape measure was on the participants’ skin and not over clothing to assure accuracy while measuring.

Maximum aerobic capacity testing was conducted on a standard treadmill using the Bruce protocol in the Exercise Physiology lab. The ParvoMedics True One metabolic cart (Sandy, Utah) was used during the maximum aerobic capacity test to measure the exchange of gases every 30 seconds throughout the assessment until the participant reached volitional fatigue in order to assess maximal aerobic fitness. Volitional fatigue is defined as the point at which the subject can no longer continue running at the current pace. At this point, the treadmill was stopped immediately.

A rating of perceived exertion scale (RPE) was used to determine a subjective level exertion during the maximal aerobic testing. This scale was based on a numerical system (OMNI-RPE scale) with the numbers being 0-10, 0 being zero exertion and 10 being maximal exertion. Prior to maximal aerobic test, the subjects received standard instructions on RPE scaling procedures.

Session Two: Acute Exercise Bout

The portable metabolic analyzer by Cosmed (Albano Laxiale, Italy) was worn by each participant during the HIFT session in order to track intensity and record the amount of energy being expended and to determine how hard the participant was working based on their VO_2 value. Each participant was scheduled to report to the Exercise Science Lab 48-72 hours after session one. After arriving at the lab, research technicians led the participant through a five-minute warm-up on the treadmill at a self-selected pace. Once the participant was properly warmed up, the portable metabolic analyzer and the activity monitors were fitted to the participant. After the equipment was properly secured, technicians set the timer for the 15-minute exercise bout. The HIFT circuit protocol that the participant performed is described in Table 1. Modifications to the exercises were made if the participants were unable to complete the given exercise. For example, many participants were unable to complete pull-ups, therefore we allowed them to use rings in order to complete an inverted row. Similarly, for push-ups, if a participant was unable to complete a push-up with correct technique, they were able to use the bench and do an incline push-up. The modifications were used if the participant was unable to perform the exercises. The Fitness Trackers that were used during the HIFT workout included two wrist-mounted (Fitbit Charge HR, left wrist; and Nike Fuelband, right wrist), two hip-mounted (Fitbit One, left hip; and Jawbone UP, right hip), and one waist-mounted (ActiGraph GT3X, right side near the midaxillary line) device.

Throughout the duration of the workout, the participants were cheered on by the technicians and encouraged to push themselves as hard as they possibly could for the entire 15-minute duration. All participants received the same amount and type of feedback to ensure feedback did not influence results. To assess the perceived rating of exertion, participants reported RPE (using the OMNI-RPE scale from 0-10) at minute 7:30, 15:00, and then again 15 minutes post exercise (three RPE values total). Post-exercise, participants were asked to estimate the amount of calories they thought they expended during that 15-minute workout in order to assess their perception of the amount of calories they burned compared to the energy expenditure determined by the Cosmed.

Data was collected and analyzed via the Cosmed and software compatible for the various physical activity fitness trackers. Breath-by-breath data was collected using the Cosmed and analyzed by using the $K4b^2$ software. Once the 15-minute workout was completed, the total number of kilocalories was used to represent the amount of energy expended during the HIFT workout using the Cosmed as the “criterion measurement” to compare all fitness trackers to. The total number of kilocalories was used to determine the amount of total energy expended (TEE) during the HIFT workout.

Chapter 4 – Manuscript

Introduction

According to the World Wide Survey of Fitness Trends for 2015, body weight resistance training (BWRT) and high-intensity interval training (HIIT) have become increasingly popular modes of exercise (Thompson, 2014). This includes exercises such as push-ups, air squats, sit-ups, and lunges. Thompson (2014) believes BWRT and HIIT are most popular because it is inexpensive, requires minimal equipment, and is effective. One particular type of HIIT is, high-intensity functional training (HIFT), which is a high-intensity, circuit-style training method in which only an individual's body weight is utilized (Heinrich et al., 2014). This mode of exercise can be done anywhere; while also removing common exercise barriers such as weather, access to exercise facilities, and safety of surroundings. There are few studies that investigate HIFT and its benefits, however one study reported that a high-intensity circuit-style training modality elicited cardiovascular responses similar to sprint intervals in college-aged men and women (Gist et al., 2014). HIFT is a relatively new modality that warrants further investigation into its risks and benefits. Because HIFT is becoming an increasingly useful mode of exercise, and the use of commercial fitness bands has become extremely popular, understanding the accuracy of commercial fitness bands during this mode of exercise is important. People may experience significant physiological benefits from HIFT training, but if their fitness trackers do not pick up on the caloric expenditure and/or step counts, they may discontinue the exercise and perceive it as not helping them achieve their fitness goals. To our knowledge no previous study has investigated the accuracy of popular, commercial fitness trackers in assessing TEE during a HIFT session.

Commercial fitness trackers, also sometimes referred to as accelerometers, are small devices that are typically worn on the wrist or on the waist and are capable of measuring the daily caloric expenditure, steps taken, energy expenditure, possible sleep patterns, and heart rate (Kooiman et al., 2015; Tucker et al., 2015). These monitors are developed so that consumers can track daily physical activity levels, as well as recognize the amount of sedentary time they accumulate for a given time period. The use of activity trackers is highly associated with increases in the amount of physical activity that is performed by an individual. Setting a step goal ranging from 2,000-10,000 steps, depending on the individual, seems to be a motivational factor for increasing the amount of daily physical activity (Bravata et al., 2007). Fitness trackers help gauge the amount of physical activity that is being performed, whether it is walking through the office at work, or performing a high intensity training workout (i.e. if an individual has set a 10,000 step goal and has only achieved 4,000 of those steps, they are well aware that they are below their goal thus far and need to start being more active for that day).

Typically, self-reported questionnaires, logs, interviews, and journals are used to assess physical activity (Lyden et al., 2011; Sallis & Saelens, 2000; Cartrine Tudor-Locke, 2002). However, this is problematic as individuals have a tendency to over-report favorable outcomes and under-report unfavorable outcomes (Caeser, 2012). People tend to overestimate their physical activity levels when self-report measurements are used (Sallis & Saelens, 2000). Therefore, the amount of energy expended from each individual is most likely being overestimated as well.

Commercially available fitness trackers such as the Nike Fuelband, Fitbit devices, and Jawbone devices are becoming increasingly popular in the fitness industry. This industry is set to triple its sales from $2 billion in 2014 to almost $5.4 billion in 2018 (Lamkin, 2015). Therefore, it is important to determine the accuracy of these fitness trackers in order for consumers and fitness professionals to be knowledgeable about the true capacities of the activity monitors they are purchasing and/or recommending. It is important to determine whether or not these fitness trackers are measuring exactly what they are claiming to measure. Fitness trackers estimate energy expenditure; however, the calculations are based on regression equations. These regression equations have been developed to estimate the amount of energy expended over a given time frame and are based counts per minute (movement) in order to estimate physical activity intensity (Crouter, Clowers, et al., 2006). For example, lifestyle regression equations more accurately estimate physical activity energy expenditure (PAEE) for moderate intensity exercises, however they tend to overestimate the energy expenditure of sedentary and light activities, while underestimating the energy expenditure of vigorous activities (Bassett et al., 2000). Additionally, consistent movement patterns during activities such as walking and running lead to a more accurate estimate of PAEE than irregular movement patterns such as those involving free-living movements (uphill walking, lifting objects, squatting down, standing up from a seated position, etc.) (Crouter, Churilla, et al., 2006). Fitness trackers and pedometers should be able to measure steps and energy expenditure easily based upon movement from one spot to another. For agility drills such as shuffling, pivoting, or anything involving quick steps and fast arm movements, the fitness trackers appear to underestimate the energy expenditure (Stackpool et al., 2014). This is likely due to various, complex movements that are being performed while completing the agility exercises. Small, quick, abnormal steps may not be registering with the fitness trackers and therefore underestimating the energy expenditure. There is typically less major arm movement involved in exercises involving quick steps, which then effects the accuracy of the fitness trackers worn on the wrist and arm (Stackpool et al., 2014).

The purpose of this study was to determine the accuracy/validity of four commercially available fitness trackers during an acute bout of circuit-style high-intensity functional training (HIFT). Based on the previously mentioned studies, the hypothesis is that fitness trackers will underestimate the amount of energy that is being expended based upon the types of exercises being performed (e.g. body weight squats and sit-ups).

Methods

Participants

This study included 47 total participants [male (*n* = 22) and female (*n* = 25)] between the ages of 18-59 recruited in the Bowling Green, KY area. Flyers were posted on the Western Kentucky University campus as well as sent to a master email list of Western Kentucky University students, faculty, and staff. Each participant was given an informed consent form that has been approved by the University Institutional Research Board (IRB) which included potential risk, benefits, and instructions. It was assumed that all participants would continue to partake in their usual daily activities, as well as adhere to their everyday dietary and sleep habits.

Instruments

Cosmed K4b². The Cosmed K4b^2 (Cosmed, Rome, Italy) is a small portable metabolic analyzer using indirect calorimetry and is capable of assessing a variety of variables. For the present study, caloric expenditure and oxygen consumption (VO_2) were primary outcomes of interest. The Cosmed K4b^2 portable metabolic analyzer with the battery pack and the harness weigh about 1.5 kg (3.3 lbs) (Crouter, Clowers, et al., 2006). Before each test was conducted, the Cosmed K4b^2 was calibrated and operated according to the manufacturer's instructions. All study team members were trained on the proper use of the equipment.

ActiGraph GT3X. The ActiGraph (ActiGraph, Pensacola, FL) is a small accelerometer typically used for research purposes and has been used in many previous studies to assess physical activity (Lee et al., 2014). The ActiGraph can be worn on the hip, wrist, ankle, and on the waist. Several studies have utilized the ActiGraph on the waist (Crouter, Churilla, et al., 2006; Lee et al., 2014), as it is closest to the individual's center of gravity. It's a triaxial device and can measure human motion in three planes (horizontal, vertical, and diagonal) (Lee et al., 2014). This accelerometer can detect both static and dynamic acceleration. MEMs-based physical activity monitors have been developed to measure physical activity, and have become the most widely used accelerometers to assess physical activity (Caeser, 2012). ActiGraph is one of the most widely used accelerometer for research, and because it is so popular, there have been several regression equations made available to use in the software when analyzing the data (Crouter, Churilla, et al., 2006). Freedson et al., generated one equation in particular that works fairly well when used during treadmill walking or jogging (Freedson et al., 1998). Hendelmen et al. 2000 and Swartz et al. 2000 generated regression equations that apply to moderate-intensity lifestyle activities. These activities in these studies included playing golf, dusting, vacuuming, lawn mowing, recreational activities, and conditioning (Hendelman et al., 2000; Swartz et al., 2000).

Nike Fuelband. The Nike Fuelband (Nike Inc., Beaverton, OR) is a triaxial accelerometer that is worn specifically on the wrist. For this study, it was worn on the participants' right wrist. This device assesses steps taken, distance progressed, and calories burned. Data can be synchronized to the Nike+ Connect software (website) by attaching the device to the USB cord provided, which will be connected to the computer; or by uploading the data to a cellular device that uses iOS software (iPhone) via Bluetooth. Data can be shown on the Nike Fuelband itself by a multitude of LED lights that rotate about the band displaying the different measurements the Fuelband has to offer. By clicking the button on the band, the different measurements will be displayed (steps and calories).

Jawbone UP Move. The Jawbone UP Move (Jawbone, San Francisco, CA) is a triaxial accelerometer that can be attached in a small band and worn on the wrist, or clipped onto the waistband of pants/shorts. Jawbone UP Move can assess physical activity patterns throughout the day as well as assess sleep patterns. There is not a screen on this device to display any data visibly. Data can be synchronized by using a cellular device with iOS software (iPhone) and the UP by Jawbone app via Bluetooth.

Fitbit One. The Fitbit One (Fitbit Inc., San Francisco, CA) is a triaxial accelerometer that assesses steps taken, calories burned, floors climbed, sleep patterns, and distance traveled. This device is worn on the waistband of pants/shorts. There is a small screen that displays the features and can be rotated through by clicking the button.

To record data for this study, at the beginning of the exercise bout the button would be pressed until vibration, initializing the start of the exercise bout. When finished, the same button was held down until vibration indicating the exercise bout was successful recorded as active minutes. Data can be synchronized via Bluetooth on a cellular device with the Fitbit app; or on a desktop computer using wifi and a wireless dongle that is plugged into the USB port of the computer and the Fitbit Connect software.

Fitbit Charge HR. The Fitbit Charge HR (Fitbit Inc., San Francisco, Ca) is a triaxial accelerometer that can measure different variables such as steps taken, calories burned, distance traveled, heart rate via plethysmography, and floors climbed. This device is specifically worn on the wrist and can be purchased in three different sizes: small, medium, and large. Data can be synchronized via Bluetooth on a cellular device with the Fitbit app; or on a desktop computer using wifi and a wireless dongle that is plugged into the USB port of the computer and the Fitbit Connect software.

Protocol

Session One: Initial assessment

The protocol consisted of two different data collection sessions. For session one, participants reported to the Exercise Physiology Lab after an 8 hour overnight fast, typically in the morning. An informed consent, health history questionnaire, and a Physical Activity Readiness Questionnaire (PAR-Q) were completed and baseline measurements were taken (resting blood pressure, resting heart rate, waist and hip circumference, and skin fold body composition) for each participant height and weight measurements were used to calculate body mass index (BMI). Participants were then instructed in the high-intensity functional movement exercises (See Table 2) and given time to practice the exercises, which served as a warm-up for the maximal aerobic capacity (VO_2 max) test. VO_2 max testing was completed using the Bruce treadmill protocol (Pescatello & American College of Sports, 2014) and the ParvoMedics TrueOne 2400 (Sandy, UT) oxygen consumption system. Learning and practicing proper movement execution of the high-intensity functional training exercises that will be used for the main test day served as a warm-up for the maximal aerobic capacity treadmill test.

Session Two: Acute Exercise Bout

The Cosmed K4b^2 portable metabolic analyzer (Albano Laxiale, Italy) was worn by each participant during the HIFT session in order to track intensity and record the amount of energy being expended and to determine how hard the participant was working based on their VO_2 value. Each participant was scheduled to report to the laboratory 48-72 hours after completing session one. After arriving at the lab, research technicians led the participant through a five-minute warm-up on the treadmill at a self-selected pace. Once the participant was properly warmed up, the portable metabolic analyzer and the activity monitors were fitted to the participant.

The fitness trackers that were used during the HIFT workout included two wrist-mounted, two hip-mounted, and one waist-mounted fitness tracker. The fitness trackers worn on the wrist consisted of the Fitbit Charge HR (Fitbit Inc., San Francisco, CA) and the Nike Fuelband (Nike Inc., Beaverton, OR). The fitness trackers worn on the hip consisted of the Fitbit One (Fitbit In., San Francisco, CA) and the Jawbone UP Move (Jawbone, San Francisco, CA). The waist-mounted fitness tracker was the ActiGraph GT3X (ActiGraph, Pensacola, FL). All of these fitness trackers were placed in specific places on the body in order to fit the manufacturers recommendations. Each activity monitor uses different outcome measures to summarize the data. Three of the five fitness trackers used provide estimates of physical activity energy expenditure (PAEE) (PAEE; Nike Fuelband, ActiGraph GT3X, and Jawbone UP Move) rather than total energy expenditure (TEE; PAEE + REE) (TEE; Fitbit One and Fitbit Charge). In order to compare these estimates, it was necessary to add resting energy expenditure (REE) to those three activity monitors that measure PAEE values (expressed in kilocalories per minute (Lee et al., 2014). To find REE for each participant, an equation was used to determine the estimated energy expenditure for the entire day while at rest. Once that value was found, it was broken down to kcals/min instead of kcal/day. The following equations were used to determine REE kcal/day (Mifflin et al., 1990):

For females, REE = 9.99 x weight (kg) + 6.25 x height (cm) – 4.92 x age (years) -161

For males, REE = 9.99 x weight (kg) + 6.25 x height (cm) – 4.92 x age (years) + 5.

After the equipment was properly secured, technicians set the timer for the 15-minute exercise bout. The HIFT circuit protocol that each participant performed is described in Table 1. Modifications to the exercises were made if the participants were unable to complete the given exercise. For example, many participants were unable to complete pull-ups, therefore we allowed them to use rings in order to complete an inverted row. Similarly, for push-ups, if a participant was unable to complete a push-up with correct technique, they were able to use the bench and do an incline push-up. The modifications were used if the participant was unable to perform the exercises. Once the 15-minute workout was completed, the total number of kilocalories was used to represent the amount of energy expended during the HIFT workout using the Cosmed $K4b^2$ as the "criterion measurement" to compare the accuracy of all fitness trackers against. The total number of kilocalories (TEE) was used to determine the amount of total energy expended during the HIFT workout. Throughout the duration of the workout, the participants were encouraged to push themselves as hard as they possibly could for the entire 15-minute duration. Participants reported their rate of perceived exertion (RPE) (using the OMNI-RPE scale from 0-10) at minute 7:30, 15:00, and then again 15 minutes post exercise (three RPE values total).

Following the completion of the exercise session, participants were asked to estimate the amount of calories they thought they expended during that 15-minute workout in order to assess their perception of the amount of calories they burned compared to the energy expenditure determined by the Cosmed K4b^2 portable metabolic analyzer.

Table 1. Exercise Protocol for Main Test Day

Exercise Protocol for Session Two	
Warm-up	Five minutes of treadmill jogging at self-selected pace
HIFT Circuit	Complete as many rounds as possible in 15 minutes of: • 12 air squats • 12 push-ups • 12 sit-ups • 12 lunges • 12 pull-ups • 12 high knees • 12 step-ups

Statistical Analyses

Statistical analyses were conducted using IBM SPSS Statistics software version

23 for Windows (IBM Corporation, Armon, NY, USA). For all analyses, statistical significance was defined as a p level < 0.05. Descriptive analyses were conducted to examine associations and differences with the criterion measurement and the multiple fitness trackers. To assess validity of the different fitness trackers when compared to the Cosmed K4b^2, an Intraclass Correlation Coefficient (ICC) was conducted using the data collected in the HIFT exercise bout. Based upon previous literature involving activity trackers (Crouter, Clowers, et al., 2006; Stackpool et al., 2014), a repeated measures ANOVA was conducted to look at the comparison of means between the fitness trackers and the criterion measure. Pearson Correlations were computed to observe overall group–level associations. Mean absolute percentage errors (MAPE) were also computed to provide an indication of complete measurement error. In other words, MAPE measures error in a device (fitness trackers in this case) when compared to the criterion method and is expressed as a percentage (Lee et al., 2014). It is another method to assess the error in the fitness trackers compared to a criterion method. MAPE is calculated by dividing the average of absolute differences between the fitness trackers and the criterion method by the criterion method value, and finally multiplying it by 100 to generate a percentage. This is a conservative method to estimate error that takes into consideration both the overestimation and underestimation of devices because the absolute value of the error is used for calculating.

Bland-Altman Plots with corresponding 95% limits of agreement and fitted lines were used to visually show the variability in the individual error scores of the fitness trackers. These plots help to identify overestimation and underestimation of the different fitness trackers to compare against the Cosmed K4b^2. The limits of agreement were calculated as the mean difference between devices ± SD (Bland & Altman, 1986). Data points located around zero (slope and intercept of 0) signify a higher accuracy of the fitness trackers, while data points located above the zero signify an underestimation of energy expenditure and data points below the zero indicate an underestimation of energy expenditure (Bland & Altman, 1986).

Results

Participants

Due to some errors occurring while downloading data from the ActiGraph software, four participants' data was excluded from the total number of participants whose data was analyzed (n = 47; females = 25 and males = 22). Descriptive statistics for the population are specified in Table 2. Participants' ages ranged between 18 and 59 years (female = 26.9 ± 11.5; male = 29.5 ± 11.0). The body mass index of the participants ranged between 15.33 and 40.35 kg•m^{-2} (females = 22.79 ± 3.4; males = 24.7 ± 4.4). Height, weight, body fat, and VO_2 max values were significantly different for males and females (see Table 2.)

Table 2. Physical Characteristics of Participants

	Male (n = 22)		Females (n = 25)		Total (n = 47)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Age	29.5 ± 11.0	18.0–52.0	26.9 ± 11.5	18.0-59.0	28.5 ± 11.6	18.0-59.0
Height (cm)	177.7 ± 7.5*	161.5-189.0	164.8 ± 4.6	154.8-175.5	69.4 ± 9.0	154.8-189.0
Weight (kg)	77.8 ± 15.7*	50.0–128.6	61.3 ± 8.9	50.2-86.6	69.4 ± 15.1	50.0-128.6
Body Fat (%)	13.8 ± 7.7*	4.8–30.8	23.6 ± 7.2	7.7-36.0	18.8 ± 8.8	4.8-36.0
BMI (kg • m^2)	24.7 ± 4.4	15.3–33.0	22.79 ± 3.4	18.3-40.3	23.6 ± 4.0	15.3-36.4

VO_2 max (ml•kg•min)	53.0 ± 9.3*	32.0-70.2	41.4 ± 6.7	21.1-50.3	47.8 ± 9.7	21.1-70.2
*. Significantly different from females, p <0.001						

Table 3 provides descriptive statistics (mean ± SD) for the various monitors used, including the criterion measuring device (Cosmed $K4b^2$), during the HIFT exercise bout. The measured value of the criterion measure was 144.99 ± 37.13 kcal, and the estimates from the monitors ranged from a low of 56.04 ± 11.07 kcal (Jawbone UP) to a high of 182.55 ± 37.93 kcal (ActiGraph). Table 4 shows the correlation coefficients (r) between the indirect calorimetry measurements (Cosmed $K4b^2$) and the fitness trackers. The strongest correlation between the Cosmed $K4b^2$ and the fitness trackers were seen with the ActiGraph (r = 0.74). The correlation coefficients for the other monitors ranged from r = 0.15 to 0.70 when compared to the criterion measure (Cosmed $K4b^2$).

Systematic differences between the activity monitors were calculated with an ICC = -0.032. The ICC of F (46,235) = 0.812 (p = 0.799) was not significant at the predetermined 0.05 alpha level. A Repeated Measures ANOVA showed that when compared to the criterion measure, all fitness trackers were significantly different at the 0.05 alpha level. In addition, all fitness tracker measures are significantly different from all other monitors, with the notable exception that the Fitbit Charge HR and the Fitbit One were the only two fitness trackers that are not significantly different from one another (p = 0.985).

Table 3. Total Estimated Energy Expenditure (kcals)

	Mean ± SD	Minimum	Maximum	*N*
Cosmed**	144.99 ± 37.13	66.7	265.7	47

ActiGraph[a]	182.55 ± 37.93	111.3	302.8	47
Nike Fuelband[a]	125.36 ± 21.52	77.2	205.7	47
Fitbit One	84.17 ± 19.05	52.0	129.0	47
Fitbit Charge HR	80.47 ± 17.31	54.0	128.0	47
Jawbone UP Move[a]	56.04 ± 11.07	38.0	85.6	47

**. Cosmed is the criterion method to compare all other activity monitors to.

[a] Added estimated REE (Mifflin et al., 1990)

Table 4. Pearson Correlations

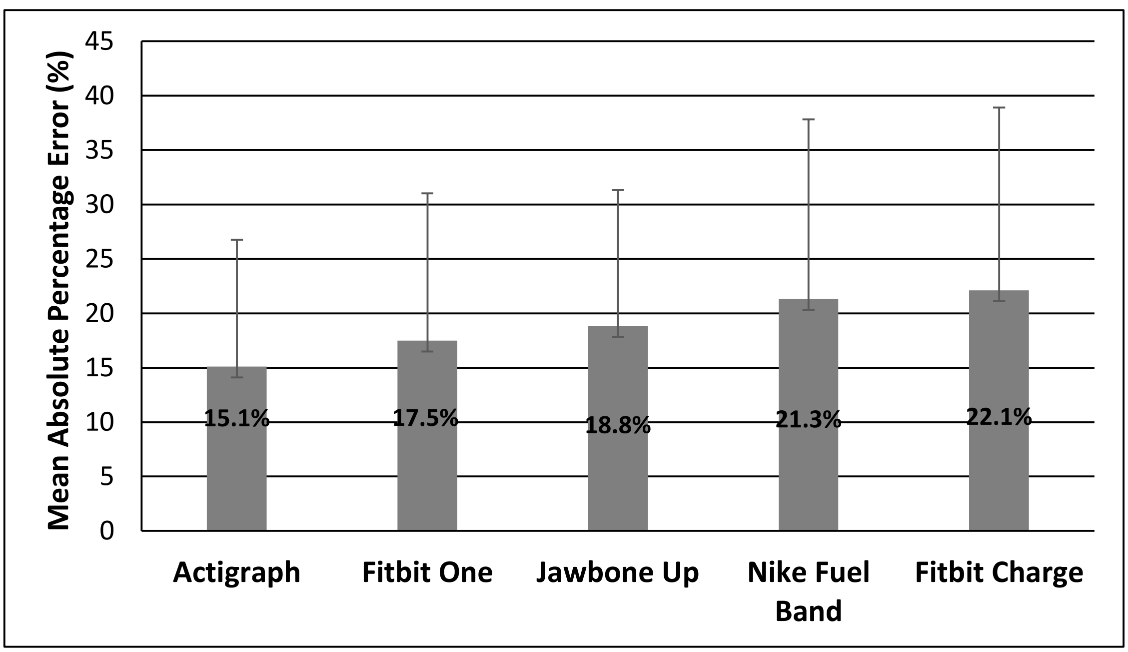
		Cosmed	Nike Fuelband	Fitbit Charge HR	Fitbit One	Jawbone UP	ActiGraph
Cosmed	Pearson Correlation	1	0.319*	0.146	0.514**	0.540**	0.737**
	Sig. (2-tailed)		0.029	0.327	0.000	0.000	0.000
Nike Fuelband	Pearson Correlation		1	0.448**	0.638**	0.482**	0.557**
	Sig. (2-tailed)			0.002	0.000	0.001	0.000
Fitbit Charge HR	Pearson Correlation			1	0.299*	0.382*	0.407**
	Sig. (2-tailed)				0.041	0.008	0.005
Fitbit One	Pearson Correlation				1	0.681**	0.666**
	Sig. (2-tailed)					0.000	0.000
Jawbone UP	Pearson Correlation					1	0.696**
	Sig. (2-tailed)						0.000
ActiGraph	Pearson Correlation						1
	Sig. (2-tailed)						

**. Correlation is significant at the 0.01 level (2-tailed)

*. Correlation is significant at the 0.05 level (2-tailed)

Figure 1 depicts the MAPE for the multiple activity monitors (computed as the average absolute value of errors relative to the Cosmed). The range of errors was least for the ActiGraph (15.1%), followed by the Fitbit One (17.5%) and the Jawbone Up (18.1%); with the highest MAPE value being the Fitbit Charge HR (22.1%).

Bland-Altman plot analyses showed the distribution of error for the estimates. The plots show the differences between the Cosmed and a fitness tracker along the y-axis (Cosmed – fitness tracker1), with the mean of the two methods along the x-axis. The plots (see Fig. 2) showed the narrowest 95% limits of agreement for the ActiGraph (difference = 106.8) with a slightly higher value for the Fitbit One (difference = 124.8). Values were higher for the Nike Fuelband (difference = 146.1), the Fitbit Charge HR (difference = 151.3), and the Jawbone UP Move (difference = 213.4). A tighter grouping of data points around the mean for the ActiGraph, Fuelband, and Fitbit One and less total error were observed when compared with the measured energy expenditure values.



*. Fitbit One and Fitbit Charge HR provide total energy expenditure (REE+AEE)
*. Added estimated resting energy expenditure ActiGraph, Nike Fuelband, and Jawbone UP Move ((Mifflin et al., 1990)

Figure 1. – Mean absolute percentage error (SD) for all monitors with measured REE

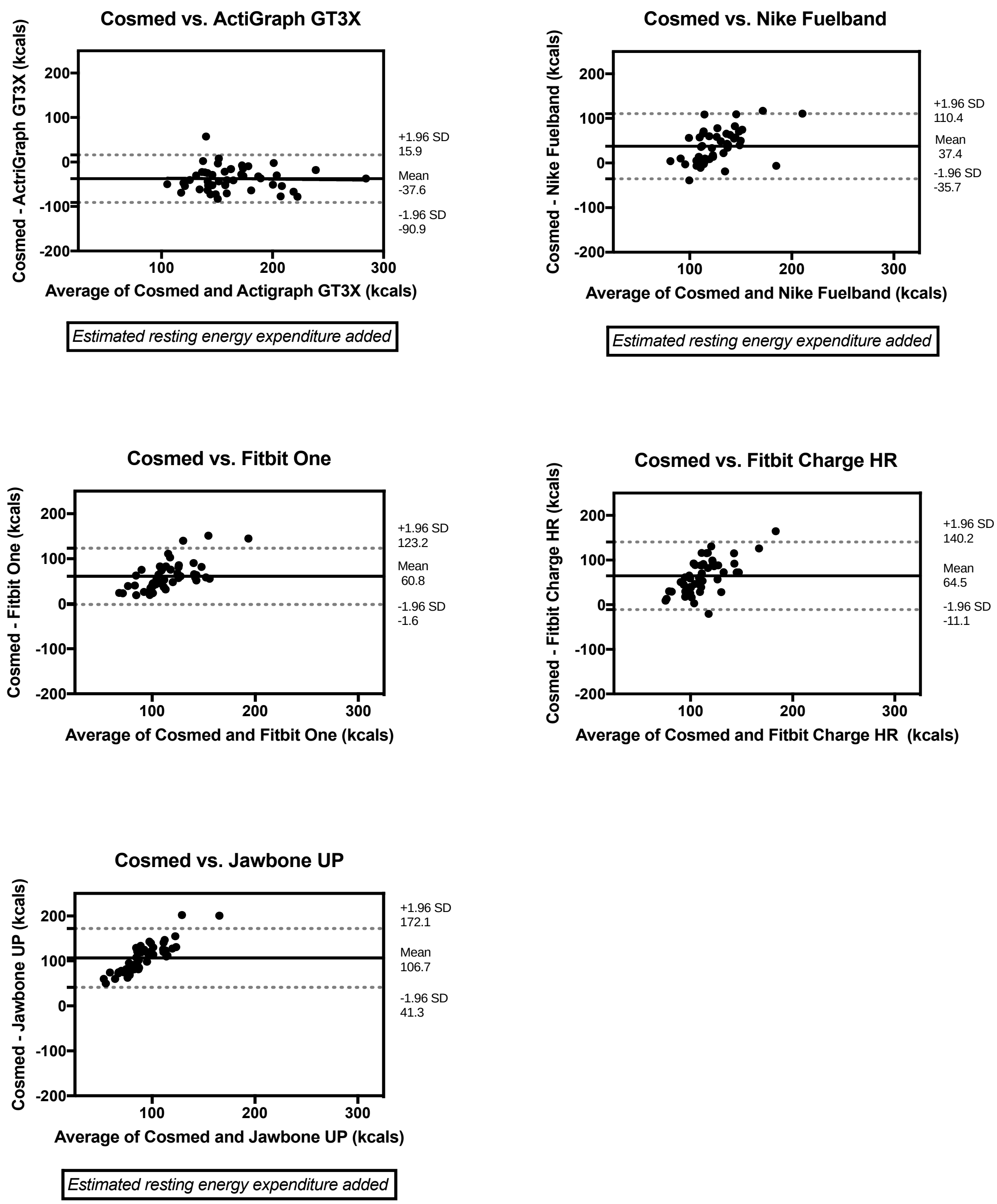


Figure 2. - Bland-Altman plots using estimated resting energy expenditure (REE)

Discussion

The current study examined the accuracy of an assortment of consumer-based, brand name fitness trackers for estimating the energy expended during a HIFT exercise protocol. The results did not provide accurate estimations of energy expenditure of the activity monitors after analyzing the data. With the exception of the ActiGraph GT3X, the remaining four fitness trackers showed inaccurate estimates of the amount of kilocalories expended during the HIFT exercise bout compared to the criterion measure. Although the ActiGraph yielded the most favorable results, it is a research based accelerometer and is a much more expensive device. Because this is a research based accelerometer, it is not surprising that the ActiGraph (182.55 kcal ± 37.93 kcal) shows the most accuracy when compared to the Cosmed (144.99 kcal ± 37.13 kcal). Not only is the device expensive to purchase alone, but the software to analyze the data is also an expensive purchase. The second most accurate activity monitor in this study showed to be the Nike Fuelband (125.36 kcal ± 21.52 kcal). This is an affordable consumer-based fitness tracker that can be purchased commercially in many locations. Of the 5 activity monitors tested, the research based accelerometer (ActiGraph) had the highest correlations with the Cosmed ($r = 0.74$) and the smallest MAPE value (15.1%). The Fitbit monitors had two of the highest MAPE values (Fitbit One = 17.5% and Fitbit Charge HR = 22.1%). In comparison to the study conducted by Lee and colleagues, the ActiGraph recorded similar MAPE values. In the current study, the ActiGraph reported a MAPE value of 15.1% whereas in the study conducted by Lee and colleagues, the ActiGraph reported a MAPE values of 12.6%. When looking at the Fitbit One devices, between the current study and Lee and colleagues' study, the MAPE value had a difference of 7.1% (Lee et al., 2014). According to the repeated measures ANOVA, the Fitbit monitors were not significantly different from one another (p = 0.985), however they were significantly different from the Cosmed. This statement makes sense because the two monitors that are closely related to one another are manufactured by the same company.

The study protocol was designed to replicate functional movements that reflect normal daily behavior, however activity monitors typically have a hard time recognizing these life-style activities (e.g. weight bearing activity, stair climbing, squatting down, and arm movement).

To the best of the authors' knowledge, no previous study has assessed commercially available fitness trackers when preforming a HIFT exercise protocol. The use of fitness trackers to measure energy expenditure is popular among consumers, however depending on the type of exercises being performed (walking, running, BWRT, HIFT, CrossFit, etc.) some fitness trackers may be better than others.

The significance of this study is that it provides information on energy expenditure estimates for HIFT exercises. This could be beneficial in developing new approaches and methods for quantifying physical activity measurements. The participants' fitness level prior to beginning this study is a potential strength of this study, deeming it novel, because all participants were welcome to participate in the study within the age range regardless of prior fitness level. There was no pre-determined fitness level that the participants were required to have, therefore the fitness level of participants may have been a factor influencing the amount of energy expended.

An advantage of consumer fitness trackers is that they are user friendly, offer immediate feedback, and they are less obtrusive than having to keep up with a journal or log, or use a research based accelerometer. However, these fitness devices should only be used as an estimate or reference for caloric expenditure, and not as a dietary intake guide. Future researchers should consider the multiple HIFT exercises when creating energy expenditure equations for these user friendly fitness trackers.

Chapter 5 – Summary of Findings

Discussion

The current study examined the accuracy of an assortment of consumer-based, brand name fitness trackers for estimating the energy expended during a HIFT exercise protocol. The results showed that when performing HIFT, these activity trackers showed to be inaccurate. With the exception of the ActiGraph GT3X, the remaining four fitness trackers showed inaccurate estimates of the amount of kilocalories expended during the HIFT exercise bout compared to the Cosmed $K4b^2$. Although the ActiGraph yielded the most favorable results, it is a research based accelerometer and is a very expensive device. Because this is a research based accelerometer, it is not surprising that the ActiGraph (182.55 kcal $\pm$ 37.93 kcal) shows the most accuracy when compared to the Cosmed (144.99 kcal $\pm$ 37.13 kcal). Not only is the device expensive to purchase alone, but the software to analyze the data is also an expensive purchase. The second most accurate fitness tracker in this study showed to be the Nike Fuelband (125.36 kcal $\pm$ 21.52 kcal). This is an affordable consumer-based accelerometer that can be purchased at Best Buy, Nike, etc. Of the 5 fitness trackers tested, the research based accelerometer (ActiGraph) had the highest correlations with the Cosmed (r = 0.74) and the smallest MAPE value (15.1%). The Fitbit monitors reported two of the highest MAPE values (Fitbit One = 17.5% and Fitbit Charge HR = 22.1%). In comparison to the study conducted by Lee and colleagues, the ActiGraph recorded similar MAPE values. In the current study, the ActiGraph reported a MAPE value of 15.1% whereas in the study conducted by Lee and colleagues, the ActiGraph reported a MAPE values of 12.6%. When looking at the Fitbit One devices, between the current study and Lee and colleagues' study, the MAPE value had a difference of 7.1% (Lee et al., 2014). According to the repeated measures ANOVA, the Fitbit monitors were not significantly different from one another (p = 0.985), however they were significantly different from the Cosmed. This statement makes sense because the two monitors that are closely related to one another are manufactured by the same company.

The study protocol was designed to replicate functional movements that reflect normal daily behavior, however activity monitors typically have a hard time recognizing these life-style activities (e.g. weight bearing activity, stair climbing, squatting down, and arm movement). There is a possibility that some activity monitors overestimated some activities, as well as overestimated some.

To the best of the authors' knowledge, no previous study has assessed commercially available fitness trackers when preforming a HIFT exercise protocol. This study showed that the use of certain commercially available fitness trackers for various modes of exercise are in question. The use of fitness trackers to measure energy expenditure is popular among consumers, however depending on the type of exercises being performed (walking, running, HIFT, BWRT, CrossFit, etc.) these fitness trackers showed to be inaccurate. This study revealed that four commercially available fitness trackers measured significantly lower energy expenditure when compared to the Cosmed. Despite advertisements, these fitness trackers showed to be inaccurate when measuring caloric expenditure during a HIFT circuit. Due to this inaccuracy these fitness trackers should be used as a motivational tool rather than a caloric expenditure measurement tool.

The study provided new knowledge about these physical activity monitors. There are some limitations in that the population was derived of Western Kentucky University Kinesiology students, as well as the university faculty and staff. A strength however is that these participants' fitness level was not predetermined, therefore we can generalize these findings to all ages and body types.

The significance of this study is that it provides information on energy expenditure estimates for HIFT exercises. This could be beneficial in developing new approaches and methods for quantifying physical activity measurements. The participants' fitness level prior to beginning this study based upon their previous training or active lifestyle is a potential limitation because all participants were welcome to participate in the study within the age range. There was no pre-determined fitness level that the participants were required to have, therefore the fitness level of participants may have been a factor influencing the amount of energy expended. Since it was not taken into consideration for this study, it is considered a limiting factor and could be assessed in further research with participants categorized in different fitness levels

An advantage of consumer fitness trackers is that they are user friendly, offer immediate feedback, and they are less obtrusive than having to keep up with a journal or log, or use a research based accelerometer. However, these fitness devices should only be used as an estimate or reference for caloric expenditure, and not as a dietary intake guide. Future researchers should consider the multiple HIFT exercises when creating energy expenditure equations for these user friendly activity monitors.

References

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