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The effect of incline on caloric expenditure measured by a wrist-worn commercial activity monitor

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The Effect of Incline on Caloric Expenditure Measured by a Wrist-Worn Commercial Activity Monitor

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Abstract

Purpose Physical activity monitors have become popular among the general public to monitor steps, floors climbed, active minutes, and energy expenditure (EE). While there is evidence to support that these devices are accurate in counting steps, there is limited and inconclusive research regarding how accurate they are in measuring EE. This study aimed to test the accuracy of a newer commercial physical activity monitor, the Fitbit Charge (FC), in reporting EE compared to a research-grade accelerometer (GT3X), and indirect calorimetry (IC) while walking on a treadmill with and without incline.

Methods 30 subjects (22 female and 8 male) walked on a treadmill for 4 five-minute stages: 2 mph with 0% grade, 2 mph with 5% grade, 3 mph with 0% grade, and 3 mph with 5% grade. IC was used to measure EE, and subjects wore the FC on their non-dominant wrist and the GT3X on their right hip.

Results Analysis showed significant main effect for device and stage, and a significant interaction effect between device and stage. EE for FC was higher (26.22 ± 5.57, 32.10 ± 4.79, 35.39 ± 6.97, and 36.64 ± 6.64 kcals) compared to IC (14.27 ± 3.51, 19.97 ± 4.05, 21.92 ± 4.04, and 28.37 ± 5.78 kcals) and to the GT3X (8.20 ± 3.81, 10.47 ± 7.99, 27.07 ± 10.77, and 27.89 ± 10.64 kcals) for all stages. EE for GT3X was also significantly ($P < 0.001$) different from IC. FC significantly ($P < 0.001$) overestimated mean total EE (130.36 ± 4.19 kcals) compared to IC (83.79 ± 3.08 kcals) and GT3X (73.25 ± 5.26 kcals).

Conclusion FC overestimates EE regardless of incline compared to EC and GT3X.

Keywords: Fitbit, caloric expenditure, incline treadmill, treadmill walking, physical activity monitors

CHAPTER I

Introduction

A new trend in fitness is activity trackers that are worn throughout the day, and sync wirelessly to a person's smartphone to give real-time feedback of physical activity in free-living. These devices are accelerometers, which quantify the frequency, intensity, and duration of physical activity throughout the day using acceleration on three axes: forward/backward, up/down, and side-to-side [12]. Accelerometers now not only give step counts to quantify physical activity, but also estimate energy expenditure, elevation or steps climbed, intensity of exercise, and track sleep activity [4]. These easy-to-use activity trackers are becoming more and more popular, creating an opportunity for many companies to create their own device. Fitbit, Garmin, Jawbone, Polar and Withings are just a few brands that sell multiple models of physical activity monitors. It is important that these devices be accurate and reliable because these devices are used to promote and increase physical activity of the general public.

Multiple research studies have examined the accuracy of different commercial physical activity monitors in relation to steps, and have found them to be reasonably accurate step counters [2-3, 7-8, 11]. The original Fitbit and Fitbit Ultra were tested for step count accuracy and reliability while subjects walked on a treadmill, jogged and stair-stepped for six minutes each in one study by Noah et al. [8]. Both monitors were found to be accurate and reliable in counting steps during treadmill walking and jogging compared to a research grade Actical device. However, there was a notable difference between the Fitbit Ultra and the Actical device for steps while walking on an inclined treadmill. There were also significant differences between the original Fitbit and the Actical device, as well as between the Fitbit Ultra and the Actical device for jogging. It seemed that the incline of the treadmill as well as speed affected validity of step counts for the original Fitbit and Fitbit Ultra [8].

Three different studies examined the accuracy of the Fitbit One and Fitbit Zip, two hip-worn monitors, and the Fitbit Flex, a wrist-worn monitor [3, 7, 11]. Takacs et al. compared step counts on the Fitbit One to observer counts for walking at various speeds on a treadmill [11]. The second study by Ferguson et al. compared step counts from the Fitbit One and Fitbit Zip to two research-grade accelerometers (BodyMedia SenseWear and the Actigraph GT3X+) in a free-living environment [3]. Lastly, Kooiman et al. used the Fitbit Flex and Fitbit Zip during treadmill walking and free-living activities and compared them to a research-grade accelerometer [7]. All three of these studies found the devices to be reliable and valid for counting steps [3, 7, 11]. Dontje et al. tested the inter-device reliability of step counts for the Fitbit Ultra, a hip-worn device, instead of comparing it to observer counts or a research-grade accelerometer [2]. They also determined step count inter-device reliability for different levels of aggregation (minutes, hours, and days). One subject wore ten Fitbit Ultras at a time on his hip for eight consecutive days. It was concluded that the Fitbit Ultra had good inter-device reliability at the level of minutes, but the best reliability at the level of days [2].

Fitbits and most other commercial physical activity monitors estimate daily energy expenditure. Many people log their caloric intake with their activity tracker smartphone app in order to balance caloric intake and expenditure [4]. It is especially important to those people who are interested in losing or maintaining weight that the energy expenditure feature of these monitors be accurate. In general, commercial physical activity monitors use data from the accelerometer to detect activity mode(s), and then use proprietary software to estimate how many calories are expended [5]. In addition, commercial physical activity monitors also estimate and report basal metabolic rate, which is estimated using age, gender, height, and weight [5].

Currently, there is only limited energy expenditure research on older models of Fitbits, such as the Fitbit Classic and Fitbit Ultra [8, 10]; and only one study that has evaluated energy expenditure of newer models like the Fitbit Flex [1]. Sasaki et al. compared the Fitbit Classic worn on the hip to the portable Oxycon Mobile portable metabolic system for walking and running trials on a treadmill and simulated free-living activities [10]. They found that the Fitbit Classic significantly underestimated energy expenditure for treadmill walking with grade compared to the Oxycon Mobile portable metabolic system. However, for the other free-living activities, the Fitbit was not significantly different from the Oxycon Mobile system [10]. Noah et al. compared the Fitbit Ultra and the original Fitbit, both hip-worn devices, to an indirect calorimetry device (the K4b^2 Cosmed) as subjects performed bouts of walking with an incline, walking without an incline, jogging, or stair stepping [8]. They found that both the Fitbit Ultra and the original Fitbit underestimated energy expenditure when compared to indirect calorimetry for all four activities [8].

Other researchers compared the estimation of energy expenditure of the Fitbit Flex, a wrist-worn device, and a research grade accelerometer Actigraph GT3X+ to the Oxycon Mobile portable metabolic system during sedentary activity, aerobic activity, and resistance exercise [1]. The results showed that the Fitbit Flex provided "reasonably accurate" estimates of energy expenditures at an individual level, but showed larger error at the individual activity level, especially for resistance exercise [1]. For self-selected aerobic activity, the Fitbit Flex overestimated energy expenditure [1].

Despite the increasing number of studies examining the accuracy of commercial fitness devices, some areas of research remain unclear. The studies that do exist differ in what the devices are being compared to, where the devices are worn, and what types of activities are being performed. As a result, the conclusions have varied. It is important to note some studies found the accuracy of the estimation of energy expenditure to be dependent on the type of activity being performed [1, 3, 8, 10]. Specifically, the two studies by Noah et al. and Sasaki et al. noted differences in incline affect the accuracy of the estimated energy expenditure [8, 10]. According to the Fitbit website, the devices all have an altimeter sensor which detects changes in barometric pressure, and therefore altitude changes [6]. The sensor in the Fitbits only detects changes of at least 10 feet at a time [6]. They also mention that Fitbits do not register elevation changes when on an inclined treadmill because one's body position does not change by at least 10 feet [6]. Therefore, the Fitbits do not detect changes in incline when walking or running on a treadmill, which effects energy expenditure estimations.

With more and more commercial physical activity monitors on the market, and the popularity of these devices growing, it is important to the general public to know which of these devices are accurate. It is especially important to those trying to monitor their caloric intake and expenditure with these devices to know which one will give them the most reliable information, and therefore help them the most in reaching weight loss or weight maintenance goals. If there is a difference in the accuracy of these devices' estimations because of incline, that is of interest to many people that exercise on treadmills with inclines. Further studies need to compare physical activity monitors in exercise settings to indirect calorimetry, which is the most accurate at measuring energy expenditure.

Purpose

There has been limited research published about how accurate commercial physical activity monitors, especially newer models, are in estimating caloric expenditure while exercising. What has been published shows that performing exercise on an incline may cause a discrepancy in the accuracy of commercial physical activity monitors when compared to indirect calorimetry and the Oxycon Mobile portable metabolic system. The Fitbit Charge is a newer activity tracker model and has yet to be validated in this way. The purpose of this study was to further investigate the effect of incline on the accuracy of the estimated energy expenditure from the Fitbit Charge in comparison to indirect calorimetry and a research grade accelerometer.

We hypothesized that when compared to indirect calorimetry and the research grade Actigraph GX3T+ monitor, the Fitbit Charge would underestimate energy expenditure while walking and running on a treadmill at 5% grade; however, it would be accurate at estimating energy expenditure while walking and running on a treadmill at 0% grade.

CHAPTER II

Methodology

Subjects:

Our study had a total of 30 participants. Recruitment of subjects took place on the campus of James Madison University. Subjects were recruited using word of mouth and campus-wide email. A brief description of what was required of each subject and an overview of the study was provided. Subjects were required to be at least 18 years old. Subjects with limitations to vigorous exercise due to orthopedic injury were excluded. In addition, subjects with a previous diagnosis of cardiovascular, pulmonary, or metabolic disease were also excluded.

Pretest:

Subjects first read and signed the Informed Consent. Following obtained consent, they completed the Physical Activity Readiness Questionnaire to identify any reason the subject should not be allowed to participate in any moderate-to-vigorous physical activity.

Body Composition:

Dual-Energy X-ray Absorptiometry (DEXA) was used to measure percent body fat and percent lean mass. Body weight was then measured on a physician's scale to the nearest 0.1 pound and a portable stadiometer was used to measure height to the nearest 0.1-inch and centimeter. Subjects lay in a supine position while a full body scan was performed using the DEXA unit (GE Lunar).

Submaximal Exercise Protocol:

Subjects completed a graded submaximal exercise protocol on a treadmill. Each subject wore one Actigraph GT3X+ research-grade accelerometer on their right hip. They also wore a

Fitbit Charge on their non-dominant wrist. Energy expenditure was measured through indirect calorimetry (Parvo Medics TrueOne 2400).

Each exercise stage was 5 minutes long. The first two, five-minute stages were in the low intensity range (2.0 mph/0% grade and 2.0 mph/5% grade, respectively); the second two stages were in the moderate intensity range (3.0 mph/0% grade and 3.0 mph/5% grade, respectively). An additional two stages at vigorous intensity were completed (5.0 mph/0% grade, and 5.0 mph/3%) for those subjects able to tolerate these intensities. After the final 5-minute exercise bout, the subjects walked at a slower pace for 3 minutes to cool-down. The entire exercise protocol lasted 20 - 30 minutes. In the event of untoward subject responses during the exercise trial, the test was terminated immediately, in accordance with published guidelines [9].

Data Analysis:

Pearson correlations were employed to examine relationships between the energy expenditure values obtained from the 3 devices. Repeated measures ANOVA was employed for comparisons on energy expenditure, with device and exercise stage as within-subject factors. Post-hoc comparisons were made utilizing t-tests with Bonferroni correction factor. Data analysis was conducted using SPSS statistical package (Version 24, IBM Corp, Armonk, NY). Statistical significance was set *a priori* at $P < 0.05$.

CHAPTER III

Manuscript

The Effect of Incline on Caloric Expenditure Measured by a Wrist-Worn Commercial Activity Monitor

Abstract

Purpose Physical activity monitors have become popular among the general public to monitor steps, floors climbed, active minutes, and energy expenditure (EE). While there is evidence to support that these devices are accurate in counting steps, there is limited and inconclusive research regarding how accurate they are in measuring EE. This study aimed to test the accuracy of a newer commercial physical activity monitor, the Fitbit Charge (FC), in reporting EE compared to a research-grade accelerometer (GT3X), and indirect calorimetry (IC) while walking on a treadmill with and without incline.

Methods 30 subjects (22 female and 8 male) walked on a treadmill for 4 five-minute stages: 2 mph with 0% grade, 2 mph with 5% grade, 3 mph with 0% grade, and 3 mph with 5% grade. IC was used to measure EE, and subjects wore the FC on their non-dominant wrist and the GT3X on their right hip.

Results Analysis showed significant main effect for device and stage, and a significant interaction effect between device and stage. EE for FC was higher (26.22 ± 5.57, 32.10 ± 4.79, 35.39 ± 6.97, and 36.64 ± 6.64 kcals) compared to IC (14.27 ± 3.51, 19.97 ± 4.05, 21.92 ± 4.04, and 28.37 ± 5.78 kcals) and to the GT3X (8.20 ± 3.81, 10.47 ± 7.99, 27.07 ± 10.77, and 27.89 ± 10.64 kcals) for all stages. EE for GT3X was also significantly ($P < 0.001$) different from IC. FC significantly ($P < 0.001$) overestimated mean total EE (130.36 ± 4.19 kcals) compared to IC (83.79 ± 3.08 kcals) and GT3X (73.25 ± 5.26 kcals).

Conclusion FC overestimates EE regardless of incline compared to EC and GT3X.

Keywords: Fitbit, caloric expenditure, incline treadmill, treadmill walking, physical activity monitors

Introduction

A new trend in fitness is activity trackers that are worn throughout the day, and sync wirelessly to a person's smartphone to give real-time feedback of daily physical activity. These devices are accelerometers, which quantify the frequency, intensity, and duration of physical activity throughout the day using acceleration on three axes: forward/backward, up/down, and side-to-side [13]. Fitbit is one brand that continues to release newer models of physical activity monitors, adding more features each time. These devices not only give step counts to quantify physical activity, but also estimate energy expenditure, elevation or steps climbed, intensity of exercise, and track sleep [4]. It is important that these popular devices be accurate and reliable because they are used to promote and increase physical activity of the general public, and assist in achieving health and wellness goals.

Multiple research studies have examined the accuracy of some Fitbit models in relation to steps, and have found them to be reasonably accurate step counters [2-3, 8-9, 12]. However, little current research exists investigating the accuracy of the caloric expenditure reported by commercial activity monitors. Many people log their caloric intake with their activity tracker smartphone app in order to balance caloric intake and expenditure [4]. It is especially important to those people who are interested in losing or maintaining weight that the energy expenditure feature of these monitors be accurate. In general, commercial physical activity monitors use data from the accelerometer to detect activity mode(s), and then use proprietary software to estimate how many calories are expended [6]. In addition, commercial activity monitors also estimate and report one's basal metabolic rate, which is estimated using age, gender, height, and weight [6].

Currently, there is very limited energy expenditure research on older models of Fitbits, such as the Fitbit Classic and Fitbit Ultra [9, 11]; and only one study that has evaluated energy expenditure of newer models like the Fitbit Flex [1]. Sasaki et al. compared the Fitbit Classic worn on the hip to the portable Oxycon Mobile portable metabolic system for walking and running trials on a treadmill and simulated free-living activities [11]. They found that the Fitbit Classic significantly underestimated energy expenditure for treadmill walking with and without grade compared to the Oxycon Mobile portable metabolic system. However, for the other free-living activities, the Fitbit was not significantly different from the Oxycon Mobile system [11].

Noah et al. compared the Fitbit Ultra and the original Fitbit, both hip-worn devices, to an indirect calorimetry device (the $K4b^2$ Cosmed) as subjects performed bouts of walking with an incline, walking without an incline, jogging, or stair stepping [9]. They found that both the Fitbit Ultra and the original Fitbit underestimated energy expenditure when compared to indirect calorimetry for all four activities [9].

Other researchers compared the estimation of energy expenditure of the Fitbit Flex, a wrist-worn device, and a research grade accelerometer Actigraph GT3X+ to the Oxycon Mobile portable metabolic system during sedentary activity, aerobic activity, and resistance exercise [1]. The results showed that the Fitbit Flex provided "reasonably accurate" estimates of energy expenditures at an individual level, but showed larger error at the individual activity level, especially for resistance exercise [1]. For self-selected aerobic activity, the Fitbit Flex overestimated energy expenditure [1].

Despite the increasing number of studies examining the accuracy of commercial fitness devices, some areas of research remain unclear. It is important to note some studies found the accuracy of the estimation of energy expenditure to be dependent on the type of activity being performed [1, 3, 9, 11]. Specifically, the two studies by Noah et al. and Sasaki et al. noted differences in incline affect the accuracy of the estimated energy expenditure [9, 11]. According to the Fitbit website, the devices all have an altimeter sensor which detects changes in barometric pressure, and therefore altitude changes [7]. The sensor in the Fitbits only detects changes of at least 10 feet at a time [7]. They also mention that Fitbits do not register elevation changes when on an inclined treadmill because one's body position does not change by at least 10 feet [7]. Therefore, the Fitbits do not detect changes in incline when walking or running on a treadmill, which effects energy expenditure estimations.

With more and more commercial physical activity monitors on the market, and the popularity of these devices growing, it is important to the general public to know which of these devices are accurate. If there is a difference in the accuracy of these devices' estimations because of incline, that is of interest to many people that exercise on treadmills with inclines and/or run up hills in their community. There has been limited research published about how accurate commercial physical activity monitors, especially newer models, are in estimating caloric expenditure while exercising. What has been published shows that performing exercise on an incline may cause a discrepancy in the accuracy of commercial physical activity monitors when compared to indirect calorimetry and the Oxycon Mobile portable metabolic system. The Fitbit Charge (FC) is a newer activity tracker model and has yet to be validated in this way. The purpose of this study was to further investigate the effect of incline on the accuracy of the estimated energy expenditure from the FC in comparison to indirect calorimetry (IC) and a research grade accelerometer (GT3X).

Methods

Subjects:

Our study had a total of 30 participants, 22 females and 8 males (Table 1). Subject characteristics included an average age of 25.8 years, height of 168.1 cm, weight of 69.5 kg, BMI of 24.5, and percent body fat of 28.07% (Table 1). Recruitment of subjects took place on the campus of James Madison University. Subjects were recruited using word of mouth and campus-wide email. A brief description of what was required of each subject and an overview of the study was provided. Subjects were required to be at least 18 years old. Subjects with limitations to vigorous exercise due to orthopedic injury were excluded. In addition, subjects with a previous diagnosis of cardiovascular, pulmonary, or metabolic disease were also excluded.

Body Composition:

Dual-Energy X-ray Absorptiometry (DEXA) was used measure percent body fat and percent lean mass. Body weight was then measured on a physician's scale to the nearest 0.1 pound and a portable stadiometer was used to measure height to the nearest 0.1-inch and centimeter. Subjects lay in a supine position while a full body scan was performed using the DEXA unite (GE Lunar).

Submaximal Exercise Protocol:

Subjects completed a graded submaximal exercise protocol on a treadmill. Each subject wore one GT3X+ on their right hip. They also wore a FC on their non-dominant wrist. Energy expenditure was measured through IC (Parvo Medics TrueOne 2400).

Each exercise stage was 5 minutes long. The first two, five-minute stages were in the low intensity range (2.0 mph/0% grade and 2.0 mph/5% grade, respectively); the second two stages were in the moderate intensity range (3.0 mph/0% grade and 3.0 mph/5% grade, respectively). After the final 5-minute exercise bout, the subjects walked at a slower pace for 3 minutes to cool-down. The entire exercise protocol lasted 20 - 30 minutes. In the event of untoward subject responses during the exercise trial, the test was terminated immediately, in accordance with published guidelines [10].

Data Analysis:

Pearson correlations were employed to examine relationships between the energy expenditure values obtained from the 3 devices. Repeated measures ANOVA was employed for comparisons on energy expenditure, with device and exercise stage as within-subject factors. Post-hoc comparisons were made utilizing t-tests with Bonferroni correction factor. Data analysis was conducted using SPSS statistical package (Version 24, IBM Corp, Armonk, NY). Statistical significance was set *a priori* at $P < 0.05$.

Results

Significant correlations were found for total EE between IC and GT3X ($r=0.756$, $P < 0.001$), IC and FC ($r=0.750$, $P < 0.001$), and GT3X and FC ($r=0.816$, $P < 0.001$) (Figures 1-3). There was a significant interaction effect of device and exercise stage on EE ($P < 0.001$), as well as significant main effects for device ($P < 0.001$) and exercise stage ($P < 0.001$) on EE (Table 2).

Further analysis of each stage revealed that the FC was significantly higher than IC and the GT3X for all 4 stages in measuring mean EE (Table 2). The GT3X was significantly lower than IC for stages 1 and 2, but higher for stage 3 (Table 2). For stage 4 there was no mean difference between the GT3X and IC (Table 2). FC also significantly ($P < 0.001$) overestimated mean total EE compared to IC and GT3X (Figure 4).

Discussion

The results from the current study reveal significant differences in EE between the FC and the other two devices for each stage of the exercise protocol. While the overestimation of the FC is evident, the effect that incline has on this estimation is unclear. The FC significantly overestimated EE regardless of incline, which was applied in stages 2 and 4. Furthermore, the FC also significantly overestimated mean total EE compared to both IC and the GT3X. These results do not support the hypothesis that the FC would underestimate EE when walking on a treadmill with grade and would be accurate when walking on treadmill without grade. There was no significant difference between estimations of EE for stages with incline (stages 1 and 3) and without incline (stages 2 and 4) (Table 2). Thus, it appears that incline doesn't have an effect on the estimation of EE by the FC, though the device consistently overestimates EE while walking on a treadmill compared to IC and the GT3X.

Previous literature has shown equivocal findings when studying the accuracy of Fitbit devices for caloric expenditure. Most findings conflict with the results of this current study. Sasaki et al. found the Fitbit Classic to underestimate caloric expenditure when walking with an incline and jogging without incline on a treadmill compared to an indirect calorimeter [10]. Two other older Fitbit models, the Fitbit Ultra and Fitbit original, were also found to underestimate

EE when compared to another indirect calorimetry device ($K4b^2$ Cosmed) for treadmill walking with an incline, walking without incline, jogging, and stair-stepping [8]. In contrast, we found the FC to overestimate EE [8]. It is of note, however, that the FC is a wrist-worn device and the Fitbit Ultra and Fitbit original are both worn on the hip [8]. However, Bai et al., found the Fitbit Flex, a wrist-worn device, overestimated EE for a 20-minute bout of aerobic exercise compared to IC [1]. However, the subjects in that study chose whether they walked, jogged, or ran and they were allowed to self-select treadmill speeds. Unfortunately, it did not specify the treadmill speeds that were chosen or whether or not the subjects used incline.

There appears to be a pattern in the literature that the hip-worn devices underestimate caloric expenditure during various forms physical activity whereas the wrist-worn devices overestimate this measurement. This pattern suggests a possible effect of device placement on accuracy of reported EE. Hildebrand et al. compared the EE output from two different accelerometers for multiple forms of physical activity when placed on the hip and the wrist. Two significant main effects were found: first, there was a significant main effect for placement with the wrist placement resulting in higher output of EE than the hip placement. Second, there was a significant interaction effect between placement and activity, with the wrist placement of both accelerometers resulting in higher EE output for more intense activities, but similar or lower EE output for sedentary activities compared to hip placement of the accelerometers. In the present study, the FC, worn on the wrist was compared to the GT3X, which was worn on the hip. It could be possible that the different placement of these devices used in the present study affected the difference in reporting EE. While Hildebrand et al. and the present study both found the wrist-worn devices to produce higher, less accurate EE estimations, consumers may continue to prefer this placement of physical activity monitors because of their comfort, style, and convenience. Regardless, the general public should note this effect of placement when using or selecting commercial physical activity monitors.

Another interesting finding is that speed of treadmill walking may impact the validity of EE estimation for the FC. In stages 1 and 2 the subjects walked at a pace of 2 mph, and in stages 3 and 4 they walked at 3 mph. The results suggest that the FC was more accurate at estimating EE compared to IC and the GT3X in stages 3 and 4, which required subjects to walk at a faster pace (Figure 1). If there is a decrease in the ability of the FC to give accurate EE data at a lower walking speed, this could decrease the popularity of the device for many consumers who walk for physical activity, especially the older population.

Previous literature is sparse concerning the relationship between walking speed and EE, and the research that does exist only applies to hip-worn devices, making it difficult to compare results to the current study of a wrist-worn device. Sasaki et al. examined the Fitbit Classic, a hip-worn device, while walking, running, and performing free-living activities and found it to be less accurate while walking at 3 and 4 mph, but more accurate while jogging at 5.5 mph [10]. These results are interesting because they would support the current hypothesis that the devices are more accurate at higher speeds, however the Fitbit Classic is hip-worn device, and it underestimated EE unlike the FC, a wrist-worn device, that overestimated EE. Additionally, Noah et al. found the Fitbit Ultra and Fitbit original, both hip-worn devices, to significantly underestimate EE for walking with and without incline and jogging, though the devices were more accurate at the jogging speed [8]. However, none of the above studies purposefully examined the effect of speed on estimation of EE. Specific examination of the relationship between various treadmill walking and running speeds and estimated EE of other wrist-worn physical activity monitors such as the FC is warranted.

In summary, there was a significant effect of device across each of the four stages in estimating EE, with the FC overestimating compared to IC regardless of incline. Additionally, the FC significantly overestimated total EE compared to both IC and the GT3X. These findings do not support the hypothesis that FC would underestimate EE while walking on a treadmill with incline and that the FC would be accurate in estimating EE while walking on a treadmill without incline. The current study also didn't support the majority of previous literature that found older models of Fitbits to either underestimate or be reasonably accurate in estimating EE. However, the over- and underestimation of EE by physical activity monitors from study to study may be explained by the placement of device. Further study is needed to examine a possible relationship between accuracy of EE of the FC and speed of treadmill that was suggested from this current study's findings.

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Table 1. Descriptive statistics of subjects.

	All *n* = 30	Males *n* = 8	Females *n* = 22
Age (years)	25.80 ± 8.07	27.25 ± 7.78	25.27 ± 8.29
Height (cm)	168.05 ± 8.53	177.27 ± 7.18	164.70 ± 6.25
Weight (kg)	69.46 ± 13.29	83.99 ± 12.24	64.17 ± 9.18
BMI	24.51 ± 3.53	26.76 ± 3.25	23.69 ± 3.33
Percent Body Fat	28.07 ± 8.04	19.80 ± 7.82	31.08 ± 5.78

Mean ± SD. BMI = Body Mass Index

Table 2. Mean energy expenditure (EE) for each stage reported by FC, IC, and GT3X.

	FC	IC	GT3X
Stage 1 *2.0 mph, 0% grade*	26.22 ± 5.57*	14.27 ± 3.51	8.20 ± 3.81$^{\Phi}$
Stage 2 *2.0 mph, 5% grade*	32.10 ± 4.79*	19.97 ± 4.05	10.47 ± 7.99$^{\Phi}$
Stage 3 *3.0 mph, 0% grade*	35.39 ± 6.97*	21.92 ± 4.04	27.07 ± 10.77$^{\Phi}$
Stage 4 *3.0 mph, 5% grade*	36.64 ± 6.64*	28.37 ± 5.78	27.89 ± 10.64

Mean ± SD. FC = Fitbit Charge; IC = Indirect Calorimetry; GT3X = Actigraph
* = $P < 0.05$ compared to IC and GT3X
Φ = $P < 0.05$ compared to IC

Figure 1. Correlation of total energy expenditure (EE) for indirect calorimetry (IC) versus research-grade accelerometer (GT3X).

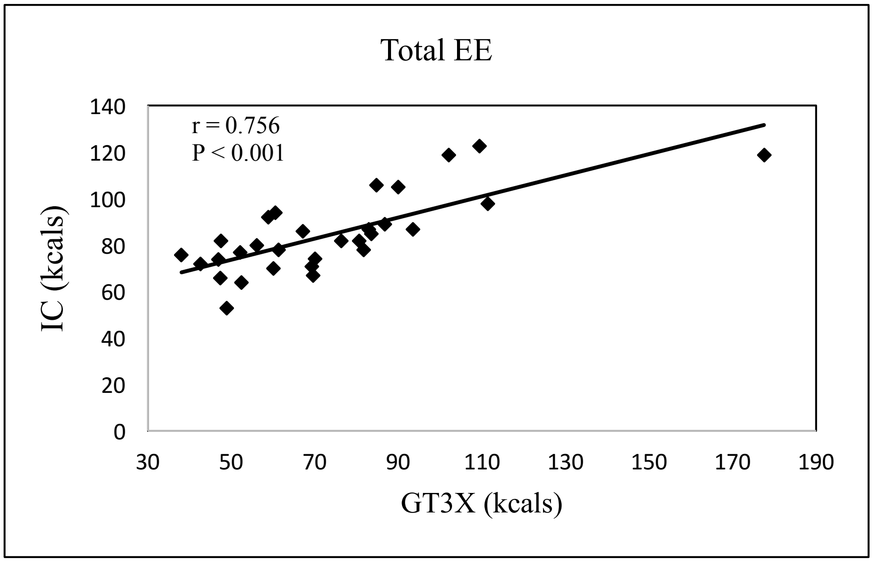


Figure 2. Correlation of total energy expenditure (EE) for indirect calorimetry (IC) versus Fitbit Charge (FC).

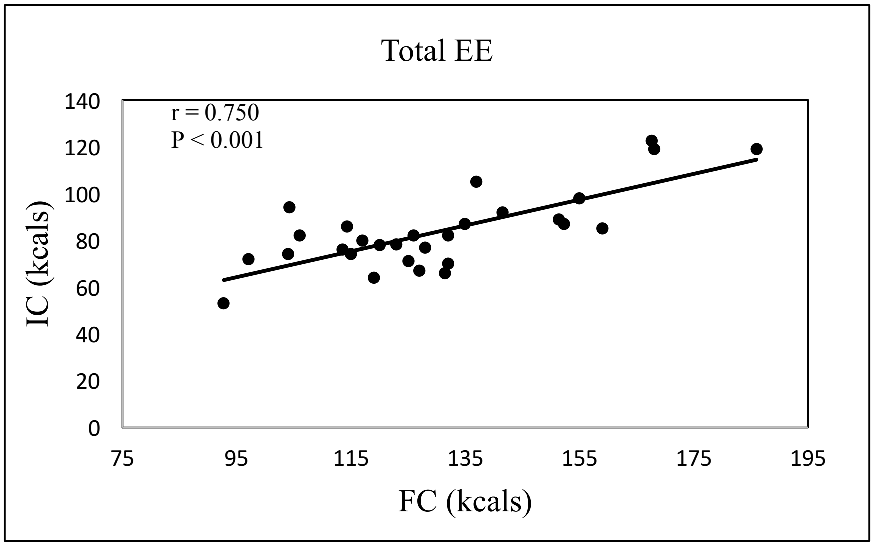


Figure 3. Correlation of total energy expenditure (EE) for research-grade accelerometer (GT3X) versus Fitbit Charge (FC).

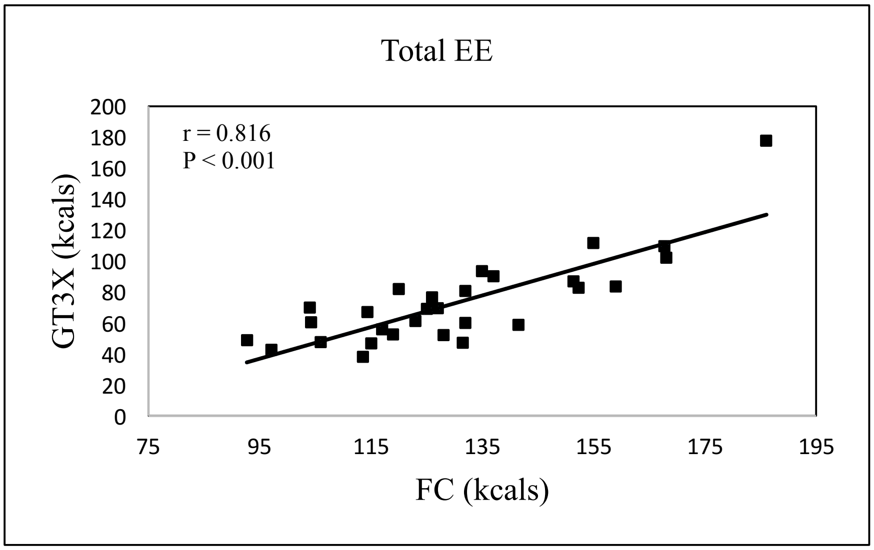
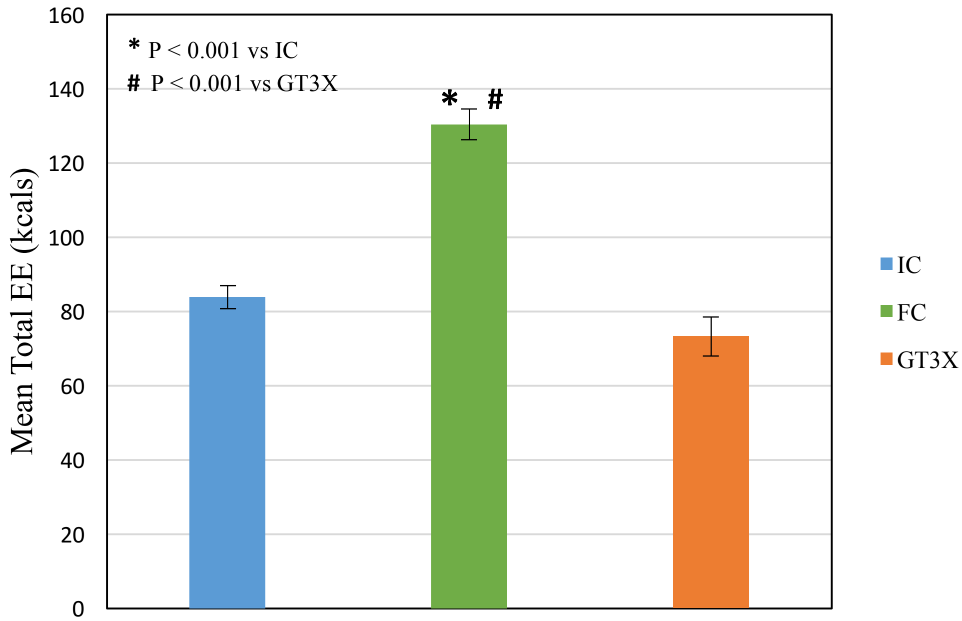


Figure 4. Mean total energy expenditure (EE) reported by the three devices: Fitbit Charge (FC), indirect calorimetry (IC), and research-grade accelerometer (GT3X).



Appendix A

Email Recruitment Statement

Physical Activity Research at James Madison University

Do you own a Fitbit device or other similar wearable activity tracker? Do you wonder just how accurate they are? Researchers at James Madison University's Department of Kinesiology are conducting a study to assess the accuracy of commercially available physical activity and sleep monitors. We are looking for:

- Individuals 18 years and older
- Not currently smoking
- Are without significant heart, lung or metabolic disease
- Have no serious orthopedic or bone problems that prevent vigorous exercise

The study would require subjects to wear 3 activity trackers, 2 on the hip and 1 on the wrist, for 7 consecutive days while they are awake and during sleep. In addition, subjects will undergo body composition assessment, undergo a maximal treadmill exercise test, and a sub-maximal treadmill exercise trial over the course of 2 visits to the James Madison University Human Performance Laboratory. Subjects will receive a comprehensive report on their health status including body composition (% body fat), cardiorespiratory fitness, physical activity levels, and sleep quality. If you are interested in volunteering, please email the research staff at jmucpam@gmail.com

Appendix B

Informed Consent

James Madison University
Department of Kinesiology
Informed Consent

Purpose

You are being asked to volunteer for a research study conducted by Dr. Trent Hargens from James Madison University entitled, "The validity of commercially available physical activity monitors"

The goal of this study is to examine whether physical activity monitors that consumers can buy (the Fitbit Charge, the Fitbit Flex, or Garmin Vivofit) give the person accurate data when it comes to steps taken, energy expended (calories), and intensity of physical activity.

Experimental Procedures

You will be asked to visit the Human Performance Laboratory (HPL) in Godwin Hall 2 times over the course of about 8 – 10 days. Your total time commitment for participation in this study will be about 2 and a half hours (not counting the time you will be wearing devices while not at the HPL). You will be asked to wear 2 devices for a period of 7 days, one of which will be worn on your right hip, the other one will be worn on the wrist of the hand that you do not write with. These two devices will be worn during the day, as well as during the night when you sleep. The purpose of these two devices is to measure your physical activity level and sleep quality.

Visit 1

Upon completion of this informed consent, you will be asked to complete a short health history questionnaire providing information about your health and lifestyle characteristics. This will also help us to make sure you do not have any factors that may disqualify you from participation. You will then be asked to complete 2 additional questionnaires, one that asks about your ability to participate in physical activity, and one that asks about your current level of physical activity participation. Each of these questionnaires should take about 5 minutes to complete.

You will then have your height and weight measured, and then your body composition will be measured via a Dual-energy x-ray absorptiometer (DEXA). The DEXA scan will allow us to measure your percent body fat and percent lean mass. The DEXA is much like an x-ray machine. The DEXA will scan your entire body slowly, so you will need to lie on a table without moving for almost 10 minutes. You will feel no discomfort with this test.

Upon completion of the DEXA scan, you will be asked to complete a maximal treadmill exercise test. During the test, researchers will monitor your heart rate, blood pressure and your perceived exertion to the workload you will be doing. During the test, you will breathe only through a mouthpiece, with your nose clamped off, so that we can measure the amount of oxygen you use during exercise. The treadmill will start with a very slow speed and little to no grade, and will steadily increase in speed and grade throughout the test, so it will start easy, and become very intense. At the end of the test, it should be a best effort on your part. It may be as hard as any exercise you remember doing. The exercise test will last about 8 – 12 minutes. Prior to your arrival to the HPL that day, you will be asked to refrain from eating for 4 hours prior to your arrival, and to avoid caffeine and alcohol for that time period as well.

At the end of this visit you will be instructed on the proper procedures for wearing the 2 devices that you will then wear for 7 days in a row.

Visit 2

8 to 10 following Visit 1, you will be asked to return to the HPL. The day you return to the HPL you will be asked to not wear the two devices at all. For this visit you will be asked to complete a submaximal treadmill exercise trial while wearing 4 devices to monitor your physical activity and steps, the 3 your previously wore for 7 days, plus an additional 1 on your wrist. You will be asked to walk on the treadmill for a total of 20 minutes, with an additional 10 minutes for those who are able to tolerate treadmill running. The first 10 minutes will be fairly easy (5 minutes with no grade, 5 minutes with some grade), the second 10 minutes will be somewhat hard (5 minutes with no grade, 5 minutes with some grade), and the final 10 minutes (for those able) will be hard (5 minutes with no grade, 5 minutes with some grade). You will be monitored in a similar way as your maximal treadmill test (heart rate, blood pressure, oxygen measurement). You will be asked to again refrain from food, caffeine or alcohol for 4 hours prior to arrival at the HPL.

Risks

There are no risks associated with wearing a accelerometers (the physical activity monitoring devices). Also, there is no risk associated with heart rate, blood pressure, height, and weight. You will not be asked to change any of your personal habits during the course of the study. Measurements with associated risks include: the DEXA scan, the maximal treadmill exercise test, and the submaximal treadmill exercise trial.

The amount of radiation that you will receive in the DEXA scan is less than the amount you will receive during a transatlantic flight, and is equal to about 1/20 of a chest x-ray. If you think that you may be pregnant, please inform the research staff immediately, as the radiation from the DEXA could potentially harm the fetus. If you choose not to complete the DEXA scan, you will not be able to continue with the study.

There is a risk of abnormal changes during the maximal and submaximal treadmill exercise tests. These changes may include abnormal blood pressure, fainting, heart rhythm disorders, stroke, heart attack, and death. The chance of serious heart problems during maximal exercise among adults is very small (less than 1/10,000 maximal exercise tests). Every effort will be made to minimize risks of an abnormal response by reviewing you health history and providing adequate supervision of the exercise test. All staff are certified by the American Heart Association in BLS (Basic Life Support), and all tests will be supervised by an individual certified by the American College of Sports Medicine.

Benefits

Participation may include knowledge about your health status. You will receive information on your percent body fat, an assessment of your sleep quality, an assessment of your physical activity level, and cardiovascular fitness. Indirect benefits of participating in this study will be helping the researchers better understand if commercially available physical activity and sleep monitors are accurate in the data they provide the consumer.

Inquiries

If you have any questions or concerns or you would like to receive a copy of the final aggregate results of this study, please contact Dr. Trent Hargens at hargenta@jmu.edu or (540) 568-5844.

Questions about Your Rights as a Research Subject
Dr. David Cockley
Chair, Institutional Review Board
James Madison University
(540) 568-2834
cocklede@jmu.edu

Confidentiality

All data and results will be kept confidential. You will be assigned an identification number. At no time will your name be identified with your individual data. The researcher retains the right to use and publish non-identifiable data. All paper data will be kept secured in a locked cabinet in a locked office. All electronic data will be kept on a password-protected computer in encrypted file folders. Final aggregate results will be made available to participants upon request.

Freedom of Consent

Your participation is entirely voluntary. You are free to choose not to participate. Should you choose to participate, you can withdraw at any time without consequences of any kind.

I have read this consent form and I understand what is being requested of me as a participant in this study. I freely consent to participate. I have been given satisfactory answers to my questions. The investigator provided me with a copy of this form. I certify that I am at least 18 years of age. By clicking "Yes" to the question below and submitting this confidential online survey, I am consenting to participate in this research.
Do you provide consent to participate in the research study entitled, "The validity of commercially available physical activity monitors"?

______________________________ ______________________________
Name of Subject (Printed) Date

Appendix C

Physical Activity Readiness Questionnaire

Physical Activity Readiness Questionnaire (PAR-Q)

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 your doctor before you start.

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
Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?	○	○
do you feel pain in your chest when you do physical activity?	○	○
In the past month, have you had chest pain when you were not doing physical activity?	○	○
Do you lose your balance because of dizziness or do you ever lose consciousness?	○	○
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?	○	○
Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?	○	○
Do you have diabetes or a thyroid condition?	○	○
Do you know of any other reason why you should not do physical activity?	○	○

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