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Validating The Adidas miCoach And Nike+ Sport Kit For Estimating Pace, Distance And Energy Expenditure During Over-Ground Exercise

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Dedication

I dedicate this to my parents,
Gregory and Diane Porta,
without whom my academic achievements would not be possible.

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by

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Abstract

There is currently no known published research validating the Adidas miCoach or Nike+ Sport Kit personal training systems for outdoor, over-ground walking and running. To validate these devices for estimating pace ($min \cdot km^{-1}$), distance (km) and energy expenditure (EE) ($kcal \cdot min^{-1}$) during outdoor over-ground walking and running for two different sensor configurations, 6 male and 8 female participants with moderate endurance training (Mean ± SE Age: 28.21 ± 2.27 y; Body Mass: 60.93 ± 2.97 kg; Height: 167.43 ± 2.09 cm; Percent Body Fat: 14.93 ± 1.94% (N=16); and VO_{2max}: 54.44 ± 1.47 $mL \cdot kg^{-1} \cdot min^{-1}$) completed this study. The protocol consisted of walking at 53.6, 80.4 and 107.2 $m \cdot min^{-1}$ and running at 134.0, 160.8, 187.6 and 214.0 $m \cdot min^{-1}$ on an outdoor, 400 meter track, while wearing a portable metabolic measurement unit (COSMED $K4b^2$). Each sensor was attached on the right (miCoach) and left (Nike+) shoelaces (LC), as well as the midsole (MC) of the shoe. Estimated pace, distance and EE were compared to values determined by criterion methods (AC). Data were analyzed using a MANOVA (pace, distance) or MANCOVA with repeated measures (energy expenditure) to evaluate significant differences. For the miCoach, each subsequent stage elicited a significant change in estimated pace for both the LC and MC ($p \leq 0.001$) except between 53.6 and 80.4 $m \cdot min^{-1}$, and 107.2 and 134.0 $m \cdot min^{-1}$ at the MC. The miCoach LC and MC also demonstrated a significant change for distance ($p=0.019$) and EE ($p=0.032$) with each subsequent speed. For the Nike+, each subsequent stage elicited a significant change in estimated values for pace ($p=0.001$), distance ($p< 0.001$), and EE ($p<0.001$). The miCoach LC and MC pace were significantly different from each other at 80.4 $m \cdot min^{-1}$ ($p=0.021$). There were no other significant differences seen between miCoach LC and MC, or between Nike+ LC and MC for pace; likewise, there were no significant differences between the miCoach LC and MC or Nike+ LC and MC for distance. The miCoach LC and MC EE were significantly different from each other at walking speeds of 53.6 and 80.4 $m \cdot min^{-1}$ ($p \leq 0.012$). There were no other significant differences seen between the miCoach LC and MC, or between the Nike+ LC and MC for EE. For practical purposes, miCoach seems to be useful; however, the Nike+ seems to fall short of the manufacturers' claims. The inability of both the miCoach and Nike+ to correctly estimate pace, distance and EE across the entire range of speeds indicates that these do not appear to be valid assessment instruments for outdoor research purposes.

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Introduction

According to the 2011 physical activity (PA) update by the American College of Sports Medicine, healthy adults aged 18 to 65 years should perform moderate-intensity (M-I) aerobic PA for a minimum of 30 minutes, five days each week, or vigorous-intensity (V-I) aerobic PA for a minimum of 20 minutes, three days per week (Garber et al., 2011). An alternative to these recommendations is to perform a combination of both M-I PA, or brisk walking, at a metabolic equivalent (MET) range of 3.0-6.0, that noticeably accelerates heart rate (HR) and V-I PA, or jogging, at greater than 6.0 METS, causing substantial increase in HR four days per week; twice performing M-I PA for 30 min, and twice performing V-I PA for 20 minutes (Garber et al., 2011). Often people misinterpret these recommendations or do not fully understand PA requirements, believing that their light activities of daily living (ADL) are sufficient to meet M-I PA or that only V-I PA will improve overall health (Garber et al., 2011). However, M-I PA should be accounted for in addition to the light intensity ADL's (e.g. washing dishes, taking out the trash, walking from your car to the store), and can even be separated into more convenient 10-minute periods of M-I PA, provided an accumulated 30 minutes is performed throughout the day (Garber et al., 2011).

In the past, the National Institutes of Health (NIH) had expressed concern over the reliability of PA assessments due to the difficulties of assessing PA under free-living conditions (Schutz, Weinsier, & Hunter, 2001). One method to assist in monitoring PA in the general population is activity monitors such as accelerometers and pedometers, which are being marketed to the average person as motivational and training aids. Physical activity monitors provide an objective method of measuring PA with immediate feedback for the user; however, there appears to be little research on the validity and reliability of a few of these devices. Therefore, the introduction of numerous activity monitors from different manufacturers necessitates the need to validate the use of these monitors; in particular, the Adidas miCoach and Nike+ Sport Kit.

The Adidas miCoach is a three piece training system that utilizes a stride sensor affixed to the shoe, a HR monitor for assessing intensity, and a pacer system worn by the user which telemetrically records stride and HR data, and provides voice feedback through an earphone. The Nike+ Sport Kit, similar to the Adidas miCoach, is a two part device in which a sensor is affixed to the shoe and wirelessly linked through a receiver attached to an Apple iPod Nano (Apple Inc. CA, USA), which stores and tracks data, as well as gives you feedback while allowing you to listen to your own selected music playlist. There was little reported research on the validation of the Adidas miCoach for PA; however, there has been one published conclusion on the validity of the Nike+ Sport Kit (Kane, Simmons, John, Thompson, & Bassett, 2010), as well as the first known published conclusions supporting the shoelaces sensor placement (Conger, Strath, & Bassett, 2005) and similar experimental design to the current study (King, Torres, Potter, Brooks, & Coleman, 2004) that assisted in the development of experimental design for this study. Although the Nike+ has been validated, the similarities to the miCoach for shoelaces and midsole configurations, for intended use, and the ability to perform similar measurements (pace, distance, and EE) provides direct comparison and reduces inter-subject variance through simultaneous investigation, under identical treatment conditions. Therefore, the purpose of the current study was to validate the accuracy of both the Adidas miCoach, and Nike+ Sport Kit to estimate pace ($min \cdot km^{-1}$), distance (km) and energy expenditure (EE) ($kcal \cdot min^{-1}$), in two different sensor configurations during outdoor, over-ground walking and running.

1.1 Specific Aims

1.1.1 Sensor Validation.

To validate the Adidas miCoach and Nike+ sport kit by examining EE, pace, and distance, using indirect calorimetry, pacing strategy and known distance on a 400 meter outdoor, over-ground running track at seven different walking and running speeds.

1.1.2 Sensor Placement.

To validate the Adidas miCoach and Nike+ sport kit for both the midsole and laces configurations by examining the sensor placement in a compatible shoe at seven different walking and running speeds.

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Indoor Manuscript

ACCURACY OF THE ADIDAS miCOACH and NIKE+ SPORT KIT TO ESTIMATE PACE, DISTANCE, AND ENERGY EXPENDITURE DURING TREADMILL WALKING AND RUNNING

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Abstract

The Adidas miCoach and Nike+ Sport Kit were developed as a personal training system to estimate pace, distance and energy expenditure (EE), but have yet to be validated. To validate these devices for estimating pace (min·km^{-1}), distance (km) and EE (kcal·min^{-1}) during treadmill walking and running for two different sensor configurations, 9 male and 9 female participants with moderate endurance training (Mean ± SE Age: 28.83 ± 1.90 y; Height: 168.72 ± 1.86 cm; Body Mass: 62.19 ± 2.58 kg; Percentage Body Fat: 14.17 ± 0.17 %; and VO_{2max}: 54.36 ± 1.15 mL·kg^{-1}·min^{-1}) completed this study. The protocol consisted of walking at 53.6, 80.4 and 107.2 m·min^{-1} and running at 134.0, 160.8, 187.6 and 214.0 m·min^{-1} on a calibrated motor-driven treadmill while wearing a portable metabolic measurement unit (COSMED $K4b^2$). Each sensor was attached on the right (miCoach) or left (Nike+) shoelaces (LC) as well as the midsole (MC) of the shoe. Estimated pace, distance and EE were compared to values determined by criterion methods (AC). Data were analyzed using a MANOVA (pace, distance) or MANCOVA with repeated measures (energy expenditure) to evaluate significant differences. For both the miCoach and Nike+, each subsequent stage elicited a significant change in estimated values for pace ($p<0.016$), distance ($p\leq0.001$), and EE ($p\leq0.006$). The miCoach MC significantly underestimated pace at 134.0 and 160.8 m·min^{-1} compared to AC pace ($p\leq0.042$). The Nike+ LC and MC both significantly overestimated pace at 53.6 m·min^{-1} ($p<0.001$) and 80.4 m·min^{-1} ($p\leq0.027$), and significantly underestimated pace at 160.8 m·min^{-1} ($p\leq0.053$), 187.6 m·min^{-1} ($p<0.001$) and 214.0 m·min^{-1} ($p<0.001$) compared to AC pace. The miCoach MC significantly underestimated AC distance at 160.8 m·min^{-1} ($p=0.027$). The Nike+ LC and MC both significantly overestimated walking distance at 53.6 m·min^{-1} ($p<0.001$) and 80.4 m·min^{-1} ($p\leq0.003$), and significantly underestimating running distance at 187.6 m·min^{-1} ($p\leq0.001$) and 214.0 m·min^{-1} ($p<0.001$) compared to AC distance. The miCoach MC significantly overestimated EE compared to AC EE at 53.6 m·min^{-1} ($p=0.023$), and both the LC and MC significantly overestimated EE values for 80.4 m·min^{-1} ($p\leq0.001$), 107.2 m·min^{-1} ($p\leq0.006$) and 214.0 m·min^{-1} ($p\leq0.048$). The Nike+ LC and MC both significantly underestimated EE at 107.2 m·min^{-1} ($p<0.001$) compared to AC EE. Although there were no significant differences between the MC and LC for either unit, suggesting that configuration is interchangeable, the ability of these units to distinguish across a range of speeds, and at higher intensity stages suggests promise for the development of PA monitors capable of accurately estimating a variety of activities and intensities

2.1 Introduction

The American College of Sports Medicine suggests that engaging in moderate amounts of physical activity (PA) provides significant health benefits (Garber et al., 2011). Since exercise prescription is a critical component of many disease treatments, accurately quantifying the amount of physical activity performed becomes a necessity. The ability to decrease the amount of subjective information retrieved from participants through validated assessments of PA are critical for research. Also, the practical application and growing popularity among the general public to use pedometers and accelerometers as objective PA measures further emphasized the need to evaluate the accuracy of PA monitors.

Two recently introduced commercially available PA monitors are the Adidas miCoach (miCoach) (Adidas AG, Germany) and the Nike+ Sport Kit (Nike+) (Nike Inc, OR, USA). Both devices utilize multi-axial piezoelectric accelerometry and wireless engineering to measure changes in acceleration during dynamic movements. Acceleration information and basic anthropometric measures (height, body mass, gender) are all then manipulated using proprietary algorithms to estimate pace, distance and energy expenditure (EE). Both devices were primarily designed for walking and running and each can be used while held within the midsole of a respective (Adidas or Nike) compatible shoe or while attached to the shoelaces.

Currently, there is no known published research assessing the miCoach and only one known publication evaluating the Nike+ (Kane, Simmons, John, Thompson, and Bassett, 2010). If these devices are capable of accurately estimating PA, they may afford researchers an additional tool for objectively assessing physical activity. Therefore, the purpose of this study was to evaluate the ability of the Adidas miCoach and Nike+ Sport Kit to accurately estimate pace, distance and energy expenditure while located within the midsole or attached to the shoelaces during treadmill walking and running.

2.2 Methods

2.2.1 Instrumentation

The miCoach is comprised of three wirelessly linked components: a pacer unit, a stride sensor, and a heart rate monitor (Figure 2.1.1). The pacer unit attaches to the user by a spring clip and when activated, links to the stride sensor (located at the shoe) and the heart rate monitor (positioned around the chest). As the primary component, the pacer unit is synchronized to a user generated miCoach account created with the web based miCoach manager software for data retrieval and analysis. This is the only way to view data, as there is no visual feedback from the unit; however, there are audio cues which provide feedback and coaching throughout exercise.

Figure 2.1.1. Adidas miCoach

Figure 2.1.2. Nike+ Sport Kit

Nike and Apple (Apple Computers Inc. CA, USA) designed the Nike+ as a two-part wireless device including the shoe sensor integrated with an iPod or iPhone (Figure 2). All iPod Nano generations, the iPod touch (2^{nd} or newer generations), and the iPhone (3GS or newer generations) support the Nike+. The current study used two compatible 6th generation iPod Nanos. Enabling the Nike+ required an attached receiver to the iPod Nano and linking the two components was done as indicated by the manufacturer. Data can be viewed via the iPod interface during activity, and audio feedback is also cued throughout exercise. The data are then synchronized with the user generated Nike account created with web based Nike+ manager software for further data retrieval and analysis.

The COSMED $K4b^2$ (COSMED S.r.l., Italy) is a portable, indirect calorimetry (IC) metabolic measurement system capable of measuring oxygen uptake (VO_2), and other metabolic gases over a fairly wide range of exercise intensities (McLaughlin, King, Howley, Bassett &

Ainsworth, 2001). The COSMED K4b^2 utilizes a bidirectional digital turbine flow meter connected to a facemask (Hans-Rudolph, Kansas City, MO USA) that completely covers the mouth and nose, and is secured with a mesh headpiece to ensure all gases are collected. The device is then worn on the chest while supported with an adjustable manufacturer supplied harness.

2.2.2 Participants

Eighteen volunteers (9 men, 9 women) completed the study (Mean ± SE Age: 28.83 ± 1.90 y; Height: 168.72 ± 1.86 cm; Body Mass: 62.19 ± 2.58 kg; Percentage Body Fat: 14.17 ± 0.17 %; and VO_{2max}: 54.36 ± 1.15 mL·kg^{-1}·min^{-1}). Prior to any data collection, each participant was briefed about the requirements, potential risks and benefits of the study, and provided written consent to participate on a form approved by the University of Texas at El Paso Institutional Review Board. Inclusion criteria for both men and women were a) participation in moderate to vigorous endurance exercise at least 3 days per week, and b) a minimum relative maximal oxygen uptake (VO_{2max}) value of 50 mL·kg^{-1}·min^{-1}. The VO_{2max} criterion was selected to ensure that all participants would be able to complete the validation protocol. Participants reported to the laboratory on two separate occasions separated by a minimum of 48 hours. For each of the two laboratory visits, participants reported for testing having refrained from vigorous physical activity for 24 hours and having not consumed any food, caffeine, or calorie-containing beverages for three hours prior.

2.2.3 Experimental Protocols

The first laboratory visit included the completion of study forms, a health history questionnaire, anthropometric measurements, and the determination of VO_{2max}. Height was measured to the nearest 0.1 cm using a calibrated stadiometer (SECA 225, GMBH & Co., Germany), body mass was measured to within 0.1 kg (TANITA WB-110A, Tanita Corp., Japan), and percentage body fatness was determined by air-displacement plethysmography (BOD POD, Life Measurement, Inc., Concord CA). Each participant then completed a VO_{2max} test on a calibrated motor-driven treadmill (Track Master R32, Full Vision, Inc.). For the VO_{2max} test, ventilation and expired gas fractions were determined using a TrueOne metabolic measurement system (ParvoMedics, Sandy UT) calibrated to the manufacturers specifications (Bassett et al., 2001). The second laboratory visit involved the PA monitor calibration and completion of the validation protocol.

2.2.4 Sensor Placement

All Adidas and Nike compatible shoes are designed with the sensor cavity located under the insole of the left shoe. For this study, each participant was provided with correctly fitted compatible shoes (Men's Nike Air Pegasus 27). To allow for simultaneous direct comparison of the miCoach and Nike+, a sensor compartment was meticulously created in the insole of the right shoe to the exact dimensions of the left shoe. A total of 4 sensors (2 miCoach and 2 Nike+) were used during each validation protocol. The miCoach sensors were positioned on the right and the Nike+ positioned on the left. One unit was positioned in the respective midsole configuration (MC), while the second unit was placed in the laces configuration (LC) of the same shoe. The miCoach was attached to the LC using a manufacturer provided lace-clip, while the Nike+ was affixed with a commercially available neoprene pouch (Grantwood Technology, LLC). Each sensor unit was accompanied by its own pacer unit or iPod, respectively. The miCoach pacer unit and iPod were then wirelessly linked to their sensors for data acquisition and positioned on the participant's harness. To ensure that the data from each of the four sensors represented the same collection interval, all units were synchronized to within one second of each other, the COSMED $K4b^2$, and a Sportline 470 (Sportline, Inc. CA, USA) universal stopwatch to ensure all data were time-matched.

2.2.5 Calibration

Prior to use, both the miCoach and Nike+ require a simple calibration procedure in order to properly estimate stride length and rate for internal calculations. The miCoach system telemetrically connects the pacer unit to the stride sensor. In order to ensure connection, the stride sensor must be activated by tapping the shoe on the ground. The manufacturer then suggests calibrating the miCoach by completing a "self-paced, half-mile run." Therefore, calibration was completed at 134.0 $m \cdot min^{-1}$ for 0.8 km. Treadmill speed was verified using a calibrated tachometer (DT-107A, Shimpo Instruments, IL, USA) prior to the start of all trails, for each stage.

There is no user interface on the miCoach pacer unit requiring data to be downloaded to the miCoach support website, containing proprietary miCoach Manager Software, where anthropometric data were input and actual distance (800 meters) was specified for analysis. The Nike+ allows multiple workout options: calorie burning goal, distance goal, time goal, and open-ended. Using the open-ended workout option, the anthropometric measurements for height, weight and gender were input into the iPod user interface. The manufacturers suggest calibrating the Nike+ by completing a “self-paced, quarter-mile walk” and a “self-paced, half-mile run.” Therefore calibration was completed at 80.4 $m \cdot min^{-1}$ for 0.4 km and 134.0 $m \cdot min^{-1}$ for 0.8 km. It was assumed that the software for both the miCoach and Nike+ adjusted the estimated values to correspond with the actual distance traveled during the calibration procedure and based upon acceleration dynamics.

The COSMED $K4b^2$ was allowed a recommended 45-minute preparation period before the unit was calibrated using gases of known concentration and a three-liter calibration syringe as per the manufacturer’s specifications. A flexible rubber facemask (Hans-Rudolph, MO, USA) was fitted to each participants face, completely covering the mouth and nose to ensure all gases were collected. The harness was adjusted around the waist and over the shoulders to minimize movement of the device during exercise. Participants were allowed to remove or adjust the facemask between exercise stages as needed. To ensure data from each of the four sensors and the COSMED $K4b^2$ represented the same collection interval, as well as time matching of data recorded by all instruments within one second of each other, each individual trial started on an exact minute.

2.2.6 Sensor Validation Protocol

The validation trial consisted of seven ordered 10-minute stages of treadmill walking and running in an indoor, climate controlled laboratory. The grade was maintained at 0% throughout the entirety of the test. The seven stages were separated into walking stages (53.6, 80.4, and 107.2 $m \cdot min^{-1}$) and running stages (134.0, 160.8, 187.6 and 214.0 $m \cdot min^{-1}$), completed in ascending order. Participants were allowed a 10-minute rest period between each stage if needed. During each stage, pace ($min \cdot km^{-1}$), distance (km) and EE ($kcal \cdot min^{-1}$) were measured by each PA monitor, respectively.

2.2.7 Data Management

Data from the COSMED $K4b^2$ were downloaded from the machine into the associated computer interface, converted to a Microsoft Excel spreadsheet and analyzed manually to average the last seven minutes of each stage. This ensures only steady-state exercise was included in the determination of actual EE, which used COSMED $K4b^2$ VO_2 values to calculate kilocalories (kcal), using the following equation: kcal = VO_2 ($L \cdot min^{-1}$) x 4.825 ($kcal \cdot L^{-1}$ O_2) (Knoebel, 1984). Treadmill speed for each stage was measured at minutes 2 and 8 using a calibrated tachometer (DT-107A, Shimpo Instruments, IL USA) and the average was recorded to determine pace. Actual distance was then calculated from speed measurements and duration (10 minutes).

Data from both miCoach pacer units, as well as both iPods were also downloaded to the associated computer interfaces and analyzed by their respective proprietary equations for each unit. The miCoach computer interface required the user to input height (cm), weight (kg) and gender and contained the ability to "crop" the data to ensure only the specific test period was analyzed. The Nike+ computer interface also had this feature, necessitating the same information in order to correctly analyze the data. Data were then recorded manually from each respective website and integrated into a separate comprehensive spreadsheet, along with the recorded actual criterion (AC) values of pace, distance traveled and EE for analysis.

2.2.8 Statistical Analysis

Statistics were analyzed by utilizing the software package SPSS Version 22.0 (SPSS, Chicago, IL). Two participants had missing data for the 187.6 and 214.0 $m \cdot min^{-1}$ stages. Therefore, to avoid the loss of participants due to incomplete data sets, Missing Value Analysis using the expectation-maximization (EM) method, was employed to replace the missing values. The International Business Machines (IBM) EM analysis was used to estimate the means, correlations and covariance, assuming a likelihood distribution (IBM, 2011). The determined missing data were input based on the conditional expectation of the "missing" data, assuming maximal likelihood estimates of the conditional parameters as though the missing data had been filled in as functions of the log-likelihood (IBM, 2011). A comparison of means and standard deviations indicated that the method used to replace the missing values did not affect the statistical results.

For the two devices, seven stage and three configurations (2 x 7 x 3) model, multiple Multivariate ANOVAs with repeated measures and a separate Multivariate ANCOVA with repeated measures for EE were conducted using estimated marginal means to determine specific areas of significance. The MANOVA's were conducted to observe any significant differences among descriptive data (age, height, body mass, body fat percentage and VO_{2max}), as well as, between estimated pace ($min \cdot km^{-1}$) and distance (km) with that of AC measurements of pace and distance for both sensor configurations (LC, MC) and between monitors (miCoach, Nike+). Additionally, the MANOVA was conducted to observe if there was any significant main effect for sex. The MANCOVA was then conducted to observe any significant differences between estimated EE ($kcal \cdot min^{-1}$) and actual measured EE for both sensor configurations. Body mass served as a covariate because EE is dependent on body mass during weighted activity. Significance was set at an alpha level < 0.05.

Table 2.1.1 Mean (± SE) descriptive characteristics for men (N = 9) and women (N = 9).

N = 18	Age (y)	Height (cm)	Body Mass (kg)	Body Fat* (%)	VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)
Men	26.11 ± 2.41	174.67 ± 1.66	70.49 ± 2.73	9.40 ± 1.46	56.42 ± 1.17
Women	31.56 ± 2.77	162.78 ± 1.76†	53.90 ± 1.89†	18.94 ± 1.76†	52.29 ± 1.80
Combined	28.83 ± 1.90	168.72 ± 1.86	62.19 ± 2.58	14.17 ± 0.17	54.36 ± 1.15

*N=16 for percentage body fat. †Significantly different from men ($p \le 0.001$).

2.3 Results

Descriptive characteristics of the study participants are shown in Table 2.1.1. In general, men had a significantly greater stature and body mass ($p<0.001$), women had a greater body fat percentage ($p\leq0.001$), while age and VO_{2max} were similar. Initial analysis of the data revealed no significant main effect of gender on estimated pace or distance. As anticipated, a significant main effect of gender was observed for EE ($p<0.001$) leading to the inclusion of body mass as a covariate for the EE analysis model.

Mean (± SE) pace, distance, and EE values estimated by the miCoach and Nike+, and AC values for each stage are presented in Table 2.1.2. For both the miCoach and Nike+, each subsequent stage elicited a significant change in estimated and actual values for pace ($p<0.016$), distance ($p\leq0.001$), and EE ($p\leq 0.006$). In comparison, there were no significant differences between configurations for either the miCoach or Nike+.

2.3.1 Pace

The miCoach LC estimated pace values were similar to AC pace for each of the walking and running stages. However, the miCoach MC significantly underestimated pace at 134.0 and 160.8 m·min^{-1} compared to AC pace ($p\leq 0.042$). The Nike+ LC and MC both significantly overestimated pace at 53.6 m·min^{-1} ($p<0.001$) and 80.4 m·min^{-1} ($p\leq0.027$), and significantly underestimated pace at 160.8 m·min^{-1} ($p\leq0.053$), 187.6 m·min^{-1} ($p<0.001$) and 214.0 m·min^{-1} ($p<0.001$) compared to AC pace. Additionally, significant differences in estimated pace were observed between the miCoach and Nike+ for the LC and MC at 53.6 m·min^{-1} ($p<0.001$) and 214.0 m·min^{-1} ($p\leq0.032$), as well as for the MC at 107.2 m·min^{-1} ($p=0.051$) (Table 2.1.2).

2.3.2 Distance

The miCoach LC estimated distance values were similar to AC distance for each walking and running stage. However, the miCoach MC significantly underestimated AC distance at 160.8 m·min^{-1} ($p=0.027$). The Nike+ LC and MC both significantly overestimated walking distance at 53.6 m·min^{-1} ($p<0.001$) and 80.4 m·min^{-1} ($p\leq0.003$), and significantly underestimating running distance at 187.6 m·min^{-1} ($p\leq0.001$) and 214.0 m·min^{-1} ($p<0.001$) compared to AC distance.

Additionally, significant differences in estimated distance were observed between the miCoach and Nike+ for the LC and MC at 53.6 $m \cdot min^{-1}$ ($p<0.001$) and 214.0 $m \cdot min^{-1}$ ($p \leq 0.034$), as well as the MC at 107.2 $m \cdot min^{-1}$ ($p=0.034$) (Table 2.1.2).

2.3.3 Energy Expenditure

The miCoach MC significantly overestimated EE compared to AC EE at 53.6 $m \cdot min^{-1}$ ($p=0.023$), and both the LC and MC significantly overestimated EE values at 80.4 $m \cdot min^{-1}$ ($p \leq 0.001$), 107.2 $m \cdot min^{-1}$ ($p \leq 0.006$) and 214.0 $m \cdot min^{-1}$ ($p \leq 0.048$). The Nike+ LC and MC both significantly underestimated EE at 107.2 $m \cdot min^{-1}$ ($p<0.001$) compared to AC but were similar for all other stages. Additionally, significant differences in estimated EE were observed between the miCoach and Nike+ for the MC at 53.6 $m \cdot min^{-1}$ ($p<0.001$) and both the LC and MC at 80.4 $m \cdot min^{-1}$ ($p<0.001$), 107.2 $m \cdot min^{-1}$ ($p<0.001$), 187.6 $m \cdot min^{-1}$ ($p \leq 0.029$) and 214.0 $m \cdot min^{-1}$ ($p \leq 0.002$) (Table 2.1.2).

Table 2.1.2 Treadmill Mean (± SE) pace, distance and energy expenditure for each exercise stage of the validation protocol estimated by the Adidas miCoach and the Nike+ Sport Kit, and Actual Criterion.

	SPEED (m·min^{-1})						
VARIABLE	53.6	80.4	107.2	134.0	160.8	187.6	214.0
Pace (min·km^{-1})							
miCoach							
LC*	19.04 ± 0.81	12.67 ± 0.47	9.76 ± 0.31	7.94 ± 0.27	6.67 ± 0.22	5.68 ± 0.19	4.88 ± 0.17
MC*	17.82 ± 0.74	11.66 ± 0.41	8.80 ± 0.30	8.05 ± 0.23†	6.73 ± 0.18†	5.67 ± 0.16	4.85 ± 0.14
Nike+							
LC*	14.33 ± 0.39†‡	11.37 ± 0.33†	9.69 ± 0.35	7.44 ± 0.15	6.57 ± 0.12†	5.97 ± 0.11†	5.54 ± 0.10†‡
MC*	14.38 ± 0.29†‡	11.15 ± 0.19†	9.73 ± 0.27‡	7.39 ± 0.15	6.53 ± 0.13†	5.89 ± 0.11†	5.47 ± 0.15†‡
Actual*	18.61 ± 0.07	12.33 ± 0.01	9.25 ± 0.01	7.41 ± 0.01	6.20 ± 0.01	5.33 ± 0.01	4.65 ± 0.01
Distance (km)							
miCoach							
LC*	0.54 ± 0.02	0.80 ± 0.03	1.04 ± 0.03	1.28 ± 0.04	1.52 ± 0.04	1.78 ± 0.05	2.08 ± 0.06
MC*	0.57 ± 0.02	0.86 ± 0.03	1.15 ± 0.04	1.25 ± 0.04	1.50 ± 0.04†	1.78 ± 0.05	2.08 ± 0.06
Nike+							
LC*	0.71 ± 0.02†‡	0.89 ± 0.02†	1.05 ± 0.03	1.35 ± 0.03	1.53 ± 0.03	1.69 ± 0.04†	1.82 ± 0.04†‡
MC*	0.70 ± 0.01†‡	0.90 ± 0.01†	1.04 ± 0.03‡	1.36 ± 0.03	1.54 ± 0.03	1.71 ± 0.04†	1.85 ± 0.05†‡
Actual*	0.54 ± 0.00	0.81 ± 0.00	1.08 ± 0.00	1.35 ± 0.00	1.61 ± 0.00	1.88 ± 0.00	2.15 ± 0.00
Energy Expenditure (kcal·min^{-1})							
miCoach							
LC*	3.67 ± 0.18	5.47 ± 0.22†	7.08 ± 0.24†	8.76 ± 0.32	10.45 ± 0.38	12.30 ± 0.42	14.27 ± 0.53†
MC*	4.00 ± 0.15†	6.08 ± 0.20†	7.96 ± 0.26†	8.62 ± 0.26	10.45 ± 0.32	12.29 ± 0.37	14.33 ± 0.43†
Nike+							
LC*	3.18 ± 0.07	4.00 ± 0.09‡	4.72 ± 0.13†‡	8.63 ± 0.21	9.83 ± 0.21	10.84 ± 0.24‡	11.63 ± 0.24‡
MC*	3.17 ± 0.06‡	4.06 ± 0.07‡	4.68 ± 0.11†‡	8.69 ± 0.21	9.91 ± 0.22	10.99 ± 0.24‡	11.84 ± 0.32‡
Actual*	3.31 ± 0.12	4.30 ± 0.14	6.14 ± 0.19	8.96 ± 0.34	10.20 ± 0.35	11.59 ± 0.35	12.74 ± 0.34

Midsole configuration (MC) and Laces Configuration (LC). *Significant difference between each stage ($p \leq 0.016$); †Significantly different from Actual ($p \leq 0.053$); and ‡Significantly different from Adidas miCoach ($p \leq 0.051$).

2.4 Discussion

The purpose of this study was to evaluate the ability of the Adidas miCoach and the Nike+ Sport Kit to accurately estimate pace, distance and EE while located within the midsole or attached to the shoelaces during treadmill walking and running. Validity was investigated by comparing the miCoach and Nike+ estimates of pace, distance, and EE with that of the actual, criterion measurements of pace, distance, and EE. This study is the first known to evaluate the Adidas miCoach, and only the second to assess the Nike+ Sport Kit. The miCoach and the Nike+ recorded similar values when positioned in the LC or MC, suggesting that either configuration can be used without affecting estimated pace, distance, or EE values.

One of the more important findings of our study is the ability of both units to differentiate between both walking and running speeds across a broad range (53.6 $m \cdot min^{-1}$ to 214.0 $m \cdot min^{-1}$). Despite any over- or under-estimation of values, both the miCoach and Nike+ were capable of distinguishing pace, distance, and EE change associated with each stage. This finding is unique and important considering the number of reports indicating that PA monitors demonstrate a plateau effect at higher intensities (Brage, Wedderkopp, Andersen, & Froberg, 2003; Conger, Strath & Bassett, 2005; Haymes & Byrnes, 1993; John, Tyo & Bassett, 2010; Rowlands, Stone, & Eston, 2007). However, the major findings of these data indicate the miCoach provides estimated pace and distance values more consistent with actual pace and distance than does the Nike+, whereas the Nike+ appears to estimate EE more accurately than does the miCoach during treadmill walking and running.

In addition to the ability to distinguish higher intensity stages, another important finding of this study was the ability of each unit to estimate EE with increasing intensity. According to Conger et al. (2005), some popular accelerometers are less accurate in predicting EE at higher intensities, which is evident in our data at stage 214.0 $m \cdot min^{-1}$ for the miCoach only. The miCoach significantly overestimated AC EE for each walking stage, except 53.6 $m \cdot min^{-1}$ at the LC, and was able to closely estimate AC EE at running stages, except 214.0 $m \cdot min^{-1}$; however, the Nike+ was able to closely estimate AC EE for all stages except walking at 107.2 $m \cdot min^{-1}$.

This is interesting as King, Torres, Potter, Brooks, and Coleman (2004) assessed EE estimated by multiple currently available accelerometers against IC using a treadmill protocol identical to ours (RT3, SenseWear Pro Armband, and Biotrainer-Pro 2) and reported that most monitors significantly overestimated EE at most speeds. Considering that the miCoach was able to differentiate between stages and generally recorded accurate estimates for pace and distance, but was less accurate at estimating EE, our data suggest that the likely cause of the error stems from the proprietary equation for estimating EE.

Despite several reports indicating that many PA monitors poorly estimate EE (Abel et al., 2008; Arvidsson, Slinde, & Larsson, 2009; Conger et al., 2005; King et al., 2004), the Nike+ was generally accurate across the range of treadmill intensities. The ability of the Nike+ to accurately estimate EE despite the significant differences in pace and distance causes confusion as to how the other variables are calculated and limits our ability to recommend potential improvements of the proprietary equations. For example, at 53.6 $m \cdot min^{-1}$ the Nike+ significantly overestimated distance while accurately estimating EE. If we assume that the calculation of EE is at least partially derived from distance, then had the Nike+ distance been accurately estimated the EE would likely have been underestimated. Similarly, an accurate estimation of distance at 214.0 $m \cdot min^{-1}$ would likely result in the overestimation of AC EE. Directionally, but not significantly, the Nike+ underestimated AC EE for all stages irrespective of an under- or overestimation of distance and/or pace. This suggests that the components of the Nike+ proprietary algorithm used for the estimation of pace, distance, and EE are all likely in need of modification. That being said, if a company is going to produce a PA monitor for the general public use, it would be beneficial to conservatively error on the side of underestimation. Significant overestimation in practical application would cause a user to believe they have expended more calories than actually expended. This overestimation over a period of time could lead to frustration of the user, lack of expected results and discontinued use of that particular unit or worse, exercise.

Although there are no known studies for the miCoach, it was interesting to observe that the miCoach LC estimated pace and distance values were similar to the actual values across each of the seven treadmill stages, but was less able to accurately estimate EE at the lowest and highest stages. The miCoach LC underestimated pace by no more than 7.6% and distance by no more than 5.9% (while being essentially correct at 53.6 m·min^{-1}), while overestimating EE by up to 27.4%. The ability of the miCoach to accurately distinguish a broad range of speeds at the LC provides support for the manufacturer's recommendation as the primary configuration. It also infers that the calibration sequence accounts for any excess motion that may be created during higher intensity running on the LC. The miCoach MC was able to report similar estimations as the LC and were similarly significant for the MC; however, the MC estimations were significantly different from AC pace at 134.0 and 160.8 m·min^{-1}, and distance at 160.8 m·min^{-1}. This is interesting because EE showed no significant difference for these stages, despite significant differences in pace and distance. This suggests that each variable is potentially derived from a different proprietary algorithm and that they do not interact across pace, distance or EE.

As for the Nike+, Kane et al. (2010) reported that the device, when placed in the MC, accurately estimated speed at 82.0 m·min^{-1}and at all level running speeds (134.0, 161.0 and 188.0 m·min^{-1}); however, it significantly overestimated the speed of level treadmill walking at 55.0 m·min^{-1} and significantly underestimated the speed at 107.0 m·min^{-1}. Kane et al. (2010) preformed their calibrations outdoors at true "self-selected" speeds, potentially allowing the unit to calibrate over a much broader range of speeds when the data were aggregated, allowing the unit to correctly estimate around those speeds. Although Kane et al. (2010) preformed a similar, but less rigorous protocol as our study, the lack of similarities between the two data for the MC, and the lack of significant difference between the LC and MC in our data, suggest that the proprietary algorithm for this particular unit be revisited and potentially modified in its adjustments from calibrations. This is shown by the ability of the Nike+ to closely estimate at the pace corresponding to “self-paced running” (134.0 $m \cdot min^{-1}$), while being ineffective above and below, despite having a “self-paced walking” (80.4 $m \cdot min^{-1}$) calibration as well.

Finally, significant differences observed for pace, distance, and EE when comparing the miCoach to the Nike+ were similar to those seen during the comparison to AC pace, distance, and EE. Most frequently, significant differences between the miCoach and Nike+ were observed when one unit accurately estimated AC values while the other unit did not. Similar to the discussion above, the inconsistencies between the miCoach and Nike+ are likely attributed to discrepancies in the proprietary algorithms. What may be inferred from these data is that systematic errors exist within the current designs, that each unit may have positive attributes over the other, and that the miCoach and Nike+ are not equivalent PA monitors.

2.4.1 Strengths/Limitations

Strengths of the current study include: the simultaneous comparisons of instruments to each other and to criterion values, consistency of data (minimal variance), and the assessment across a broad range of speeds representing those in which most people are likely to engage during recreational and conditioning exercise. The meticulous attention to detail in creating the cutout in the right shoe for simultaneous comparison of both units in both configurations allows both units to undergo similar forces, rather than have each unit run individually in each configuration. The consistency of the data for AC measurements was closely monitored from ensuring the treadmill belt was calibrated to the correct speed throughout the protocol, as well as the use of the COSMED $K4b^2$ in collecting metabolic gasses to determine energy expenditure. Stages above 214.0 $m \cdot min^{-1}$ become more sprinting, than steady state endurance running, for the average recreational user of this unit; therefore, the use of moderately endurance trained participants, gave us an extra stage in which to test the devices at which the majority of studies do not attempt.

A sensor compartment is prefabricated into the midsole of the compatible shoe models of both manufacturers; the MC is the recommended location for Nike+, however, the manufacturer recommends that the miCoach be used in the LC, providing its own lace-clip. When using pedometers and accelerometers, the question of proper monitor configuration becomes a concern, as well as, how to properly affix the monitor in order to reduce rotational motion (Kavanagh & Menz, 2008), vibration, or movement upon the skin (Bouten, Sauren, Verduin & Janssen, 1997), regardless of configuration. Although configuration has been questioned and manufacturer guidelines are not always void of limitations, these data indicate that the miCoach showed no significant differences between the LC and MC for distance or pace or EE values, and minimal significant differences in the suggested LC when compared to AC pace, distance and EE; while the Nike+ showed no significant difference between configurations, and identical significant differences in both walking and running, for all variables. The ability of both configurations to produce similarly estimated values allows us to infer that there was no effect of configuration on the data.

It can be argued that the use of a shoe designed for the Nike+ may have impacted the estimated values derived from the miCoach. At the time of data collection, few Adidas miCoach compatible shoe models were available and it would not be practical to have required the participants to wear two different shoes given the study design. Further, because both manufacturers designed the sensor insert in the midsole of the left shoe, the simultaneous comparison of the monitors would not have been possible. Therefore, we selected a convenient neutral compatible shoe model and modified the right midsole to allow for the simultaneous comparisons. It can also be reasonably argued that the use of the miCoach in the right shoe only and the Nike+ in the left shoe only, may have caused a potential bias to the data. Biomechanical differences in gait between the left and right sides of the body may have affected the accelerometric properties detected by the sensors of a given shoe. However, if the purpose of the calibration procedure is to define the step characteristics, then the calibration procedure should have accounted for these variations, therefore, discrepancies in the data are not likely attributable to differences in step characteristics between the left and right side of the body. This is similarly true for the placement/vibration argument. Based on the ability of both the LC and MC to produce similar estimates allows us to infer that the calibration process accounted for any placement or vibration artifacts.

2.4.2 Future Research

There has been one published finding (Conger et al., 2005), which examined a PA monitor attached to the shoelaces (FitSense FS-1 Speedometer, Wellesley Hills, MA, USA) for estimating distance on an outdoor 400 meter track. While the protocol of the current study is considerably different from Conger et al. (2005), the location was one of the first of its kind to be placed on the shoelaces, and the only known to look at outdoor, over-ground walking and running on a 400 meter track. The unit was able to correctly estimate walking distance but underestimated running distance during outdoor over-ground exercise (two 1600 meter runs). This protocol was done at a “self-selected running speed” averaging 13.1 $km.h^{-1}$ (218.2 $m{\cdot}min^{-1}$); therefore, further investigation should be made for other PA monitors, in particular the miCoach and Nike+, over a variety of speeds to validate PA monitors for their intended recreational use.

Another study, Kane et al. (2010), examined the Nike+ during inclined (5% and 10%) walking at 82.0 $m{\cdot}min^{-1}$. It was reported that the Nike+ was able to closely estimate walking speed at a 5% grade; however, it significantly underestimated walking speed at a 10% grade by 6%, as well as significantly underestimating the caloric cost of walking up a 10% grade by 31%. Further investigation into multiple speeds at multiple inclines is needed to assess the utility of these PA monitors with varying terrain. Furthermore, Bassett, Ainsworth, and Swartz (2000) utilized multiple accelerometers in general categories of activities. The ability to monitor activities of daily living and other general activities could lead to less reliance on self-report and subjective-recall of physical activity for research purposes, as well as better self-monitoring for recreational and conditioning activities.

2.5 Conclusion

The results indicate that the miCoach is a valid tool for estimating pace and distance while the Nike+ is a valid tool for estimating EE, during treadmill walking and running. Neither of these devices would be a preferred device for research purposes as they do not maintain validity across all variables offered by the unit; however, more research is needed to validate the units for their intended use by the recreational user. Although there were no significant differences between the MC and LC for either unit, suggesting that configuration is interchangeable, the ability of these units to distinguish across a range of speeds, and at higher intensity stages suggests promise for the development of PA monitors capable of accurately estimating a variety of activities and intensities

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Outdoor manuscript

ACCURACY OF THE ADIDAS miCOACH and NIKE+ SPORT KIT TO ESTIMATE PACE, DISTANCE, AND ENERGY EXPENDITURE DURING OUTDOOR OVER GROUND WALKING AND RUNNING

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Abstract

There is currently no known published research validating the Adidas miCoach or Nike+ Sport Kit personal training systems for outdoor, over-ground walking and running. To validate these devices for estimating pace ($min \cdot km^{-1}$), distance (km) and energy expenditure (EE) ($kcal \cdot min^{-1}$) during outdoor over-ground walking and running for two different sensor configurations, 6 male and 8 female participants with moderate endurance training (Mean ± SE Age: 28.21 ± 2.27 y; Body Mass: 60.93 ± 2.97 kg; Height: 167.43 ± 2.09 cm; Percent Body Fat: 14.93 ± 1.94% (N=12); and VO_{2max}: 54.44 ± 1.47 $mL \cdot kg^{-1} \cdot min^{-1}$) completed this study. The protocol consisted of walking at 53.6, 80.4 and 107.2 $m \cdot min^{-1}$ and running at 134.0, 160.8, 187.6 and 214.0 $m \cdot min^{-1}$ on an outdoor, 400 meter track, while wearing a portable metabolic measurement unit (COSMED K4 b^2). Each sensor was attached on the right (miCoach) and left (Nike+) shoelaces (LC), as well as the midsole (MC) of the shoe. Estimated pace, distance and EE were compared to values determined by criterion methods (AC). Data were analyzed using a MANOVA (pace, distance) or MANCOVA with repeated measures (EE) to evaluate significant differences. For the miCoach, each subsequent stage elicited a significant change in estimated pace for both the LC and MC ($p \leq 0.001$) except between 53.6 and 80.4 $m \cdot min^{-1}$, and 107.2 and 134.0 $m \cdot min^{-1}$ at the MC. The miCoach LC and MC also demonstrated a significant change for distance ($p=0.019$) and EE ($p=0.032$). For the Nike+, each subsequent stage elicited a significant change in estimated values for pace ($p=0.001$), distance ($p<0.001$), and EE ($p<0.001$). The miCoach LC and MC pace were significantly different from each other at 80.4 $m \cdot min^{-1}$ ($p=0.021$). There were no other significant differences seen between miCoach LC and MC for pace; likewise, there were no significant differences between the miCoach LC and MC or Nike+ LC and MC for distance. The miCoach LC and MC EE were significantly different from each other at walking speeds of 53.6 and 80.4 $m \cdot min^{-1}$ ($p \leq 0.012$). There were no other significant differences seen between the miCoach or Nike+ LC and MC for EE. For practical purposes, miCoach seems to be useful; however, the Nike+ seems to fall short of the manufacturers' claims. The inability of both the miCoach and Nike+ to correctly estimate pace, distance and EE across the entire range of speeds indicates that these do not appear to be valid assessment instruments for outdoor research purposes.

3.1 Introduction

Several reports have attempted the field validation of various physical activity (PA) monitors during activities of daily living or during recreational and conditioning activities among children (Ekelund et al., 2001; Pfeiffer, Mciver, Dowda, Almeida, & Pate, 2006; Puyay, Adolph, Vohra, Zakeri & Butte, 2004) and adults (Bassett et al., 2000; Hendelman, Miller, Baggett, Debold & Freedson, 2000; Leenders, Sherman, Nagaraja & Kien, 2001; Tudor-Locke, Ainsworth, Thompson, & Matthews, 2002). The majority of these types of studies investigated the abilities of multiple accelerometers to quantify the energy cost of activities during both controlled (structured activities), walking and free-living conditions. Despite many efforts to validate several different accelerometers across a variety of activities and intensities, no single valid and reliable PA monitor has emerged that quantifies variables of interest such as energy expenditure (EE).

Two recently introduced, commercially available PA monitors, the Adidas miCoach (miCoach) (Adidas AG, Germany) and the Nike+ Sport Kit (Nike+) (Nike Inc, OR, USA) utilize piezoelectric accelerometry to record dynamic movements. These units, among others, are manufactured to provide estimates of pace, distance and EE. For research purposes, the common work on PA monitors and validation studies have been conducted in laboratory settings, utilizing treadmill walking and running. Our laboratory has previously reported the accuracy of the miCoach and Nike+ during treadmill exercise (King et al., PEND); however, there is currently no known published research assessing the miCoach or Nike+ for outdoor, over-ground walking and running. Therefore, the purpose of this study was to evaluate the ability of the Adidas miCoach and Nike+ Sport Kit to accurately estimate pace, distance and EE while located within the midsole or attached to the shoelaces during outdoor, over-ground walking and running.

3.2 Methods

3.2.1 Instrumentation

The miCoach is comprised of three wirelessly linked components; a pacer unit, a stride sensor, and a heart rate monitor. As the primary component, the pacer unit stores workout information, and is synchronized to a user generated miCoach account created with the web based miCoach manager software that can store and analyzes the data, as well. Nike and Apple (Apple Computers Inc. Cupertino, CA, USA) designed the Nike+ as a two-part, wireless device including a shoe sensor integrated with an iPod or iPhone. The current study used two compatible 6^{th} generation iPod Nanos. Enabling the Nike+ required an attached receiver, connected to the iPod Nano, linking the two components. The iPod can store information, as well as be downloaded to the web based Nike+ manager software. The COSMED $K4b^2$ (COSMED S.r.l., Italy) is a portable indirect calorimetry (IC) metabolic measurement system which monitors concentrations of inspired and expired gasses during activity (McLaughlin, King, Howley, Bassett & Ainsworth, 2001) and utilizes a bidirectional digital turbine flow meter connected to a facemask (Hans-Rudolph, Kansas City, MO USA), fitted to each participants face and secured with a mesh headpiece, completely covering the mouth and nose to ensure all gases are collected. The device is then worn at each subject's chest with an adjustable manufacturer supplied harness.

3.2.2 Participants

Our laboratory previously reported an assessment of the miCoach and Nike+; the participants of the current study were a subgroup of that treadmill exercise evaluation (King et al., PEND). Fourteen volunteers (6 men, 8 women) completed the study (Mean ± SE Age: 28.21 ± 2.27 y; Body Mass: 60.93 ± 2.97 kg; Height: 167.43 ± 2.09 cm; Percentage Body Fat: 14.93 ± 1.94 % (N = 12); and VO_{2max}: 54.44 ± 1.47 $mℓ·kg^{-1}·min^{-1}$). Each participant provided written consent to participate on a form approved by Institutional Review Board of the University of Texas at El Paso following a brief of requirements, potential risks and benefits of the study, and prior to any data collection. To be included in the study, both men and women were required to participate in moderate to vigorous endurance exercise at least 3 days per week. To ensure completion of the validation protocol, all participants were also required to have a minimum relative maximal oxygen uptake (VO_{2max}) value of 50 mL·kg^{-1}·min^{-1}.

3.2.3 Experimental Protocols

Participants were required to report to the laboratory on two separate occasions separated by at least 48 hours, having refrained from vigorous physical activity for 24 hours and having not consumed any food, caffeine, or calorie-containing beverages for three hours prior. The initial laboratory session involved the completion of study forms, a health history questionnaire, and anthropometric measurements followed by a VO_{2max} test. Anthropometric measurements were recorded for body mass, measured within 0.1 kg (TANITA WB-110A, Tanita Corp., Japan); height, measure to the nearest 0.1 cm (SECA 225, GMBH & Co., Germany); and percentage body fatness, determined by air-displacement plethysmography (BOD POD, Life Measurement, Inc., Concord CA). A VO_{2max} test was then completed on a calibrated motor-driven treadmill (Track Master R32, Full Vision, Inc) where ventilation and expired gas fractions were determined using a TrueOne metabolic measurement system (ParvoMedics, Sandy UT), calibrated to the manufacturers specifications (Bassett et al., 2001). The final laboratory session included the PA monitor calibration and validation protocol.

3.2.4 Sensor Placement

For each validation protocol, one miCoach and one Nike+ were placed in the midsole configuration (MC) while a second miCoach and Nike+ were placed in the laces configuration (LC). For this study, the miCoach sensors were located on the right side of the body and the Nike+ sensors were located on the left side of the body. The miCoach was attached to the shoelaces using a lace-clip provided by the manufacturer whereas the Nike+ was attached to the shoelaces using a commercially available neoprene pouch (Grantwood Technology, LLC). Both Adidas and Nike manufacture sensor compatible shoe models with the sensor cavity located under the left shoe insole. Therefore, participants were provided appropriately sized compatible shoes (Men’s Nike Pegasus 27) with the right shoe meticulously modified to create a sensor compartment with the exact dimensions of the left shoe to allow for the simultaneous direct comparison of the miCoach and Nike+.

3.2.5 Calibration

In accordance with the miCoach manufacturer's calibration recommendation, a "self-paced run" for 0.8 km was performed by each participant prior to exercise to define the stride characteristics. The miCoach requires uploading data from the unit to a website containing proprietary software, necessitating the input of anthropometric data, to calibrate each unit. The manufacturer suggested configuration of the miCoach is the LC; however, to assess the effect of sensor location, a second sensor was placed in the cavity created in the right shoe. The manufacturer recommended calibration for the Nike+ is a two part procedure including a 0.4 km "self-paced walk" and a 0.8 km "self-paced run." Using the open-ended workout option, The Nike+ also required anthropometric data for calibration; however, each unit could manually adjust the calibration on the iPod, without a separate web based interface. The manufacturer suggested configuration of the Nike+ sensor is the MC; however, to assess the effect of sensor location, a second sensor was placed in a commercially available neoprene pouch (Grantwood Technology, LLC) secured to the shoelaces of the left shoe. The Nike+ walking calibration was completed first followed by the simultaneous running calibrations of both the miCoach and Nike+.

Ambient conditions (wind speed, humidity, temperature) for the outdoor track environment were recorded prior to and following each trail using a Kestrel 2000 wind meter (Nielsen Kellerman, PA, USA) and Traceable® Humidity/Temperature Pen (Control Company, TX, USA), respectively. Each of the four PA monitors were synchronized to within 1 second of each other, the COSMED $K4b^2$, as well as two separate hand-held Sportline 470 (Sportline, Inc., CA, USA) universal stopwatches to ensure all data were time-matched. Participants were allowed to remove or adjust their facemask between stages, therefore, all data, including start and stop times were recorded manually. Participant speed was monitored manually using a pacing strategy created by timing specific intervals around a standard outdoor 400 meter track. A total of 16 markers were placed at 25 meter intervals and a Sportline 470 Stopwatch, with a countdown timer, was programmed at speed-specific intervals to provide an auditory indication for passing each marker. The researchers also maintained interval times to ensure speed-specific pace was sustained throughout each stage. Actual distance traveled during each stage was then calculated from the total number of markers passed plus the partial distance between markers measured with a certified measuring wheel (DigiRoller Plus II, Calculated Industries, NV, USA).

3.2.6 Sensor Validation Protocol

The validation protocol consisted of seven ordered 10-minute stages of walking and running on an outdoor 400 meter track where both temperature and wind measurements were recorded to monitor climate changes throughout the testing session. The seven ordered stages were separated into walking at 53.6, 80.4, and 107.2 $m \cdot min^{-1}$, and running at 134.0, 160.8, 187.6 and 214.0 $m \cdot min^{-1}$. Participants were allowed up to 10 minutes of rest between each stage. During each stage, pace ($min \cdot km^{-1}$), distance (km) and EE ($kcal \cdot min^{-1}$) were estimated by the miCoach and Nike+.

3.2.7 Data Management and Statistical Analysis

The IC data from the COSMED $K4b^2$ was downloaded to the associated computer interface and converted to a Microsoft Excel spreadsheet. In order to ensure only steady-state exercise was included in the determination of actual criterion (AC) EE, only the last 7 minutes of each stage were analyzed. The COSMED $K4b^2$ oxygen consumption (VO_2) values were used to calculate kilocalories (kcal) using the equation: kcal = VO_2 ($L \cdot min^{-1}$) x 4.825 ($kcal \cdot L^{-1}$ O_2) (Knoebel, 1984). Sensor data from both units were also downloaded to the associated computer interfaces and analyzed by their respective proprietary equations. Both websites require input of participant anthropometric data and allow for “cropping” of data to ensure the analysis of the specific test period. Sensor data, along with the recorded AC measurements of pace, distance and EE were then recorded manually from each respective website and integrated into a separate comprehensive spreadsheet for analysis.

Statistics were analyzed by the software package SPSS Version 22.0 (SPSS, Chicago, IL). Eight different participants had missing data for at least one stage. To avoid the loss of statistical power through the removal of participants with incomplete data sets, the Missing Values Analysis using the expectation-maximization (EM) method was used to replace the missing values. Multiple Multivariate ANOVAs with repeated measures and a separate Multivariate ANCOVA with repeated measures for EE were conducted using estimated marginal means to determine specific areas of significance. Due to EE's dependence on body mass during weighted activity, the MANCOVA was conducted to observe any significant difference between estimated EE and AC EE. Statistics were conducted to observe any significant main effect for sex on configuration, and to observe significant differences among descriptive data, each variable of interest, sensor configurations, and between monitors. Significance was set at an alpha level of < 0.05.

Table 3.1.1 Mean (± SE) descriptive characteristics for men (N = 6) and women (N = 8).

N = 14	Age (y)	Height (m)	Body Mass (kg)	Body Fat* (%)	VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)
Men	22.83 ± 1.99	173.67 ± 2.33	70.30 ± 3.77	9.84 ± 2.24	57.20 ± 1.66
Women	32.25 ± 3.04†	162.75 ± 2.00†	53.90 ± 2.14†	18.66 ± 2.01†	52.38 ± 2.03
Combined	28.21 ± 2.27	167.43 ± 2.09	60.93 ± 2.97	14.98 ± 1.94	54.44 ± 1.47

*N = 12 for percentage body fat. †significantly different from men ($p \leq 0.034$).

3.3 Results

Descriptive characteristics of the study participants are shown in Table 3.1.1. In general, women were significantly older ($p=0.034$) and had a greater body fat percentage ($p \leq 0.016$) while men had a significantly greater stature and body mass ($p \leq 0.002$); although, VO_{2max} were similar. Initial analysis of the data revealed no significant main effect of gender on estimated pace or distance. As anticipated, a significant main effect of gender was observed for EE ($p<0.001$) leading to the inclusion of body mass as a covariate for the EE analysis model.

Mean (± SE) pace, distance, and EE values estimated by the miCoach and Nike+, and AC values for each stage are presented in Table 3.1.2. For the miCoach, each subsequent stage elicited a significant change in estimated pace for both the LC and MC ($p \leq 0.001$) except between 53.6 and 80.4 m·min^{-1}, and 107.2 and 134.0 m·min^{-1} at the MC. The miCoach LC and MC also demonstrated a significant change for distance ($p=0.019$) and EE ($p=0.032$) with each subsequent speed. For the Nike+, each subsequent stage elicited a significant change in estimated and AC values for pace ($p=0.001$), distance ($p<0.001$), and EE ($p<0.001$).

3.3.1 Pace

The miCoach LC and MC estimated pace values were only significantly different from each other at 80.4 m·min^{-1} ($p=0.021$) due to the miCoach MC significantly underestimating AC pace at 80.4 m·min^{-1} ($p=0.023$); both the LC and MC significantly overestimated AC pace at 107.2 m·min^{-1} ($p \leq 0.045$), as well. There were no significant differences between the Nike+ LC and MC for pace. The Nike+ LC and MC both significantly overestimated pace values at walking speeds of 53.6 m.min-1 ($p \leq 0.002$) and 80.4 m·min^{-1} ($p<0.001$) and running speeds of 134.0 m·min^{-1} ($p \leq 0.007$) and 214.0 m·min^{-1} ($p \leq 0.009$); while the Nike+ MC also significantly overestimated paced at 160.8 m·min^{-1} ($p=0.001$). Significant differences in estimated pace were observed between the miCoach and Nike+ LC and MC at 53.6 m·min^{-1} ($p=0.004$), 107.2 m·min^{-1} ($p \leq 0.041$), and 134.0 m·min^{-1} ($p \leq 0.011$), as well as for the LC at 214.0 m·min^{-1} ($p=0.005$) and the MC at 80.4 m·min^{-1} ($p=0.001$). Additionally, the miCoach LC at 53.6, 160.8 and 214.0 m·min^{-1} were within 0.04 min·km^{-1} of AC estimations, while the MC at 134.0, 187.6 and 214.0 m·min^{-1} were within 0.08 min·km^{-1} (Table 3.1.2).

3.3.2 Distance

There were no significant differences between the miCoach LC and MC or Nike+ LC and MC for distance. The miCoach LC and MC overestimated distance values compared to AC for walking at 80.4 m·min^{-1} ($p \leq 0.032$) and 107.2 m·min^{-1} ($p \leq 0.046$). However, the miCoach MC significantly overestimated AC distance at 53.6 m·min^{-1} ($p=0.003$), as well. The Nike+ LC and MC both significantly overestimated AC distance values at 53.6 m·min^{-1} ($p \leq 0.001$), 80.4 m·min^{-1} ($p<0.001$) and 134.0 m·min^{-1} ($p \leq 0.013$), while underestimating at 214.0 m·min^{-1} ($p \leq 0.045$). The Nike+ MC also significantly overestimated distance at 160.8 m·min^{-1} ($p=0.001$). Significant differences in estimated distance were observed between the miCoach and Nike+ for the LC and MC at 134.0 m·min^{-1} ($p<0.007$), as well as at the LC for 53.6 m·min^{-1} ($p=0.012$) and 214.0 m·min^{-1} ($p<0.001$) and at the MC for 107.2 m·min^{-1} ($p=0.004$) and 160.8 m·min^{-1} ($p=0.005$). Additionally, the miCoach LC and MC were able to estimate all running distance within 0.05 km while the Nike+ LC and MC were able to estimate 107.4 and 187.6 m·min^{-1} within 0.03 km (Table 3.1.2).

3.3.3 Energy Expenditure

The miCoach LC and MC were significantly different from each other at walking speeds of 53.6 and 80.4 m·min^{-1} ($p\leq0.012$); there were no other significant differences seen between the miCoach LC and MC, or between the Nike+ LC and MC for EE. The miCoach LC and MC significantly overestimated EE compared to AC for each stage ($p\leq 0.027$). The Nike+ LC and MC both significantly overestimated EE at each running stage ($p\leq 0.030$) compared to AC. The miCoach LC and MC estimated EE values were significantly different from each other at 53.6 m·min^{-1} ($p=0.001$) and 80.4 m·min^{-1} ($p=0.012$). Significant differences in estimated EE were observed between the miCoach and Nike+ for both the LC and MC at 53.6 m·min^{-1} ($p\leq0.009$), 80.4 m·min^{-1} ($p<0.001$), 107.2 m·min^{-1} ($p<0.001$), and 214.0 m·min^{-1} ($p\leq0.019$). Additionally, the miCoach and Nike+ overestimated each running speed, except the Nike+ at 107.2 m·min^{-1}, by a minimum of 11.1% (Table 3.1.2).

Table 3.1.2 Over-ground Mean (± SE) pace, distance and energy expenditure for each exercise stage of the validation protocol estimated by the Adidas miCoach and the Nike+ Sport Kit, and Actual Criterion.

	SPEED ($m \cdot min^{-1}$)						
VARIABLE	53.6	80.4	107.2	134.0	160.8	187.6	214.0
Pace ($min \cdot km^{-1}$)							
miCoach							
LC*	18.81 ± 0.50	11.61 ± 0.35§	8.50 ± 0.28†	7.38 ± 0.16	6.49 ± 0.22	5.28 ± 0.08	4.45 ± 0.06
MC	19.93 ± 1.53	15.04 ± 0.89*†	8.40 ± 0.33†	7.28 ± 0.22*	6.57 ± 0.20*	5.17 ± 0.17*	4.40 ± 0.14*
Nike+							
LC*	15.60 ± 0.71†‡	11.09 ± 0.14†	9.57 ± 0.13‡	6.52 ± 0.17†‡	6.10 ± 0.14	5.21 ± 0.08	4.77 ± 0.06†‡
MC*	15.04 ± 0.48†‡	11.13 ± 0.14†‡	9.65 ± 0.14‡	6.22 ± 0.17†‡	5.80 ± 0.14†	5.13 ± 0.10	4.70 ± 0.08†
Actual*	18.78 ± 0.11	12.30 ± 0.05	9.38 ± 0.05	7.20 ± 0.04	6.45 ± 0.06	5.09 ± 0.02	4.42 ± 0.03
Distance (km)							
miCoach							
LC*	0.55 ± 0.02	0.89 ± 0.03†	1.16 ± 0.03†	1.38 ± 0.03	1.58 ± 0.05	1.92 ± 0.03	2.28 ± 0.07
MC*	0.62 ± 0.02†	0.98 ± 0.03†	1.27 ± 0.04†	1.37 ± 0.04	1.52 ± 0.04	1.94 ± 0.06	2.26 ± 0.07
Nike+							
LC*	0.66 ± 0.03†‡	0.91 ± 0.01†	1.05 ± 0.01	1.56 ± 0.05†‡	1.66 ± 0.04	1.94 ± 0.03	2.12 ± 0.03†‡
MC*	0.68 ± 0.02†	0.91 ± 0.01†	1.05 ± 0.02‡	1.64 ± 0.05†‡	1.75 ± 0.04†‡	1.97 ± 0.04	2.16 ± 0.04†
Actual*	0.53 ± 0.00	0.81 ± 0.00	1.07 ± 0.01	1.39 ± 0.01	1.55 ± 0.02	1.97 ± 0.01	2.26 ± 0.02
Energy Expenditure ($kcal \cdot min^{-1}$)							
miCoach							
LC*	3.48 ± 0.07†§	5.78 ± 0.24†§	7.55 ± 0.30†	9.14 ± 0.28†	10.58 ± 0.44†	12.65 ± 0.35†	14.95 ± 0.41†
MC*	4.19 ± 0.15†	6.70 ± 0.24†	8.65 ± 0.38†	9.30 ± 0.40†	10.38 ± 0.46†	13.19 ± 0.61†	15.48 ± 0.66†
Nike+							
LC*	2.93 ± 0.10‡	4.00 ± 0.05‡	4.64 ± 0.05‡	9.77 ± 0.31†	10.44 ± 0.27†	12.15 ± 0.22†	13.24 ± 0.19†‡
MC*	2.96 ± 0.08‡	3.99 ± 0.05‡	4.62 ± 0.06‡	10.15 ± 0.31†	10.91 ± 0.27†	12.38 ± 0.27†	13.49 ± 0.23†‡
Actual*	2.61 ± 0.10	3.59 ± 0.14	4.90 ± 0.19	7.86 ± 0.35	8.51 ± 0.34	10.37 ± 0.38	11.92 ± 0.37

Midsole configuration (MC) and Laces Configuration (LC). *Significant difference from subsequent stage ($p \leq 0.032$); †Significantly different from Actual ($p \leq 0.045$); §Significantly different from MC ($p \leq 0.021$); and ‡Significantly different from Adidas miCoach ($p \leq 0.041$).

3.4 Discussion

There are no known studies that have assessed the miCoach or Nike+ during outdoor PA and only one study found to assess PA monitors during outdoor walking and running on a 400 meter track (Conger, Strath, & Bassett, 2005). Therefore, the purpose of this study was to evaluate the ability of the Adidas miCoach and Nike+ Sport Kit to accurately estimate pace, distance and energy expenditure while located within the midsole, or attached to the shoelaces during outdoor, over-ground walking and running. Validity was investigated by comparing the miCoach and Nike+ estimates of pace, distance, and EE with that of the actual, criterion measurements of pace, distance, and EE. The main finding of this study is the ability of the miCoach to closely estimate running stages of increasing intensity, for both pace and distance, despite having some issues estimating walking stages and significantly over estimating EE. It also appears as though only the Nike+ stages associated with calibration speeds are closely estimated despite the inability to estimate the remaining stages.

Although the current protocol was considerably different, one study, estimating distance during outdoor over-ground walking and running (Conger et al., 2005) incorporated some methodological similarities to the current protocol; use of a laces configurations (primary configuration of the miCoach and secondary configuration of the Nike+), the use of an outdoor track and a broad range of speeds self-selected by participants. Conger et al. (2005), reported the FitSense FS-1 Speedometer (Fitsense technology Inc., MA, USA) was able to closely estimate walking distance but significantly underestimated running distance by 3.5% during outdoor over-ground exercise at average "self-paced" speeds of 6.7 $km{\cdot}hr^{-1}$ (111.6 $m{\cdot}min^{-1}$) and 13.1 $km{\cdot}h^{-1}$ (218.3 $m{\cdot}min^{-1}$). In our study, the miCoach significantly overestimated distance for all walking stages except 53.6 $m{\cdot}min^{-1}$ in the LC; however, both the LC and MC were essentially correct in the estimations of all running stages, over- or under-estimating distance by an average of 1.5% at the LC and 1.2% at the MC. The Nike+ also significantly overestimated walking stages; however, the Nike+ also significantly overestimated all running stages not associated with the speed at which the unit was calibrated. The ability of the miCoach to distinguish stages of increasing intensity gives the miCoach a potential advantage over other similar monitors, such as the FitSense FS-1, for outdoor exercise.

This ability to correctly estimate running stages for pace and distance also corresponds to data previously reported by this laboratory investigating the miCoach and Nike+ PA monitors, in which the miCoach was able to correctly estimate running stages, and the Nike+ was able to correctly estimate values for stages that correspond with the speeds at which the Nike+ was calibrated (King et al., PEND). In contrast, no significant differences were reported for the miCoach, during treadmill walking (King et al., PEND). A possible explanation for the contradiction of significant differences in treadmill walking, and the over- or under-estimation of pace and distance at walking stages during over-ground walking could be attributed to inter-individual characteristics of stride rate during walking speeds on a treadmill versus over-ground exercise. There could have been an inability of the miCoach calibrations to adjust properly to over-ground walking, which creates a larger joint range of motion, due to the sensor being calibrated at a "self-paced run" only, possibly preventing the sensor from differentiating between walking and running accelerations. Riley, Paolini, Della Croce, Paylo, & Kerrigan (2008) found that individuals adopt a different gait during treadmill exercise when compared to over-ground running and walking. This was also supported by Lee and Hidler, (2008) and Watt et al. (2010), in which participants adopted a quicker cadence and shorter stride length during treadmill walking compared to over-ground walking, as well. Based on this information, it would seem as though the miCoach could potentially have had an issue with the walking stages of pace and distance due to the inability of the sensor to properly quantify acceleration at walking stages.

Since the miCoach and Nike+ each report pace, distance and EE, and are both meant to be configured on or in the shoe of the participant, it was advantageous for us to create a simultaneous comparison of these units. At the time of data collection, the primary location of the miCoach was the laces because there were limited options for manufactured midsole compatible shoes for the miCoach device. Do to this factor, a neutral Nike+ manufactured shoe was used for testing. The Nike+ manufactured shoes prefabricate the left shoe with a midsole compartment (as do the miCoach manufactured shoes); therefore, a MC was created in the right shoe in order to provide simultaneous data collection. Our laboratory has previously reported the accuracy of the miCoach LC and MC, as well as the Nike+ LC and MC during indoor treadmill walking and running, and found them to be interchangeable (King et al., PEND) despite previously addressed issues with proper affixing of the sensor to reduce rotational motion (Kavanagh & Menz, 2008). However, there is a potential of the miCoach device to receive excess motion in the shoe and a potential of excess movement attached to the shoelaces, due to the outdoor environment and the difference in ground force reaction (GFR) to be considered. The interchangeability of the miCoach and Nike+ LC and MC for indoor treadmill walking and running (King et al., PEND), together with the similarities seen in the miCoach LC and MC during outdoor running stages and Nike+ for speeds associated with calibration (where higher GFR are potentially present), lead us to infer that artifact had a minimal influence on our data. It is also possible that there were biomechanical differences in gait between the left and right sides of the body, which could have affected the sensors of a given shoe. Future research should employ a counter-balanced approach to control for bilateral differences in gait. However, participants were instructed to maintain normal gait and if the purpose of the calibration procedure is to define gait characteristics, the calibration should have accounted for any variations in gait characteristics between the left and right side of the body.

As for EE, many commercially available PA monitors have been shown to overestimate EE at walking speeds. King, Torres, Potter, Brooks and Coleman, (2004) evaluated multiple currently available accelerometers (RT3, SenseWear Pro Armband, and Biotrainer-Pro 2) against IC (COSMED K4 b^2), utilizing a treadmill protocol with similar stages of varying intensity to this study, and reported that the majority of these monitors significantly overestimated EE at most speeds. In the only other known study looking at the miCoach specifically, the miCoach was shown to overestimate EE at each stage except 134.0 $m \cdot min^{-1}$; however, in that same study, the Nike+ was shown to underestimate EE at each stage, during a similar treadmill protocol (King et al., PEND). Contradictory to King et al., (PEND), the only other known study on the

Nike+ (Kane, Simmons, John, Thompson & Bassett, 2010), found that the Nike+ overestimated EE at walking speeds while showing no significant differences at running speeds. In the current study, both the miCoach and Nike+ overestimated EE at each stage except for 107.2 $m\cdot min^{-1}$ for the Nike+. The average overestimation of the miCoach LC EE was 33.8%, while the MC EE was overestimated by 45.9%. The average overestimation of the Nike+ LC EE was 13.4%, while the MC EE was 15.6%.

It is not known if there are separate algorithms for each variable or if each unit utilizes the pace and distance data to calculate EE because of the proprietary nature of the algorithms. Prior to analysis, it was hypothesized that the equations were all inclusive, and due to pace and distance being mostly overestimated, while being essentially correct for the Nike+ at 107.2 $m\cdot min^{-1}$, it does appear as though the Nike+ calibration involves pace and distance measurements for estimations of EE. However, the ability of the miCoach to correctly estimate running stages while still significantly overestimating EE, may suggest that the EE estimations are potentially not associated with the overestimations of pace and distance. While the algorithms are unknown, because of the ability of the miCoach LC and MC to distinguish between running stages, it is inferred that there are separate walking and running equations for pace and distance, and for EE.

It should be noted that the AC EE values recorded by the COSMED $K4b^2$ appear lower than what would be predicted (ACSM, p. 173, 2013) for a given exercise stage. It is possible, but not likely, that the participants of our study exhibited a greater mechanical efficiency than the general population. However, the participants of this outdoor study also completed our treadmill study (King et al., PEND) and a closer examination of the treadmill data indicates that the recorded AC EE values were greater for the treadmill than for over-ground exercise. This contradicts what we would expect because the energy cost of over-ground activity is greater at a given absolute work rate than for flat activity on a motor-driven treadmill (Pugh, 1970). This leads us to speculate that a potential error may exist in the AC EE data reported by the COSMED $K4b^2$.

The outdoor track used for this study is situated in an east-west orientation. Due to the orientation and location of the track, there was a potential for one straightaway to receive wind assistance and the opposite straightaway would receive wind resistance. Trials were completed between 8 AM and 10 AM, wind observations were taken prior to the start of each stage, and temperature was recorded prior to and following each stage for all testing sessions. The average wind reading for the outdoor trials was approximately 2.5 $m \cdot s^{-1}$, which is 0.5 $m \cdot s^{-1}$ above the allowable wind speed for a track and field event (Rule 262.4, USATF, pp. 158, 2011). The relative change in temperature was roughly 5.9º Celsius, over all trials. If the wind and/or temperature affected the AC EE data, then the miCoach and Nike+ would have been expected to underestimate EE because the sensors are not sensitive to the added physiological stress of ambient conditions on metabolism. Because both the miCoach and Nike+ generally overestimated EE, it is unlikely that temperature or wind affected the outcome of this study.

3.5 Conclusion

The results indicate that during outdoor over-ground walking and running the miCoach is a valid tool for estimating pace and distance at running stages, but not for walking or estimation of EE; while the Nike+ is not valid for estimating pace, distance or EE. For practical purposes, miCoach seems to be useful; however, the Nike+ seems to fall short of the manufacturers' claims. The inability of both the miCoach and Nike+ to correctly estimate pace, distance and EE across the entire range of speeds indicates that these do not appear to be valid assessment instruments for outdoor research purposes.

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used. Additionally, the results of the present study do not represent an endorsement of any product by the authors.

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Appendix A

Literature Review

4.1 Physical activity

Physical activity, even in small amounts, has been shown to provide health benefits by increasing physical fitness and ultimately decreasing risk factors for chronic diseases (Haskell et al., 2007). When measuring PA however, it is important to mention that PA and EE are not equal (Tudor-Locke, Williams, Reis, & Pluto, 2002); therefore, when using accelerometers to measure PA, the goal is to assess activities that quantify human movement with a high degree of accuracy to better interpret individual exercise programs (Bassett, Ainsworth & Swartz, 2000b; Chen & Bassett, 2005). In addition to individual exercise programs, the volume and mode of PA for individual and public health benefits must be interpreted (Schutz, Weinsier, & Hunter, 2001). Dynamic activities such as walking and running contribute to PA in daily life; however, the intensity of the movement has to be considered for EE (walking vs. brisk walking) (Meijer, Westerterp, Verhoeven, Koper, & ten Hoor, 1991). Advances in technology have generated interest in objective measures (accelerometers and pedometers) for which numerous short and long term studies have been designed. Despite the array of PA monitors available, there are major limitations in objective, non-obtrusive methods that accurately quantify a range of activities. The current study presented a unique comparison of PA, utilizing the Adidas miCoach and Nike+ sport kit at a variety of intensities to incorporate a wide range of PA.

4.2 Energy expenditure

In 1668, the first recorded respirometer, a chamber constructed by John Mayrow to quantify the usable portion of air, was developed to institute the proposal that ambient air consists of different parts. However, only some of those parts are utilized for the process of respiration (Speakman, 1998). Later in 1757, Joseph Black and in 1774 Joseph Priestly discovered carbon dioxide (CO_2) and oxygen (O_2), respectively (Speakman, 1998). Antoine Lavoisier and Armand

Séguin, during this same period as Black and Priestly, then discovered that large individuals consume more O_2 than small individuals and individuals at rest consume less O_2 than those in movement, eventually establishing calorimetry for measuring energy expenditure (Speakman, 1998). The first sealed calorimetry chambers lead to open flow chambers, however, with the minimal space of the chambers, accurate measurements of free-living activity is limited. In attempts to create free-living activity measurements, indirect calorimetry has become a prominent method, through the development of many sophisticated chambers and automated analyzers, as well as doubly labeled water (DLW) for long term (4-20 days) assessment (Anislie, Reilly, & Westerterp, 2003; Campbell, Crocker, & McKenzie, 2002; Speakman, 1998).

4.2.1 Indirect calorimetry

The traditional method of indirect calorimetry (IC), the "Douglas Bag," has since given way to automated systems of IC. The development of these automated systems has allowed IC, as well as Doubly Labeled Water (DLW), to become the primary methods, or "gold standards," for measuring human EE (Douglas, 1911; Speakman, 1998; Yang & Hsu, 2010). Specifically, automated systems use electronic devices, such as gas analyzers and flow meters, linked to portable computers to create a variety of laboratory based, semi-portable and fully portable IC systems. In particular for this study, the fully portable system, COSMED K4 b^2 portable metabolic analyzer (COSMED S.r.l., Italy) was used in order to perform outdoor over-ground IC collection. Indirect calorimetry is generally done in laboratory settings with the use of a treadmill and a metabolic measurement system, however, the introduction of the COSMED K4 b^2 allows equivalent measurement outside of a laboratory setting (Shrack, Simonsick, & Ferrucci, 2010). The COSMED K4 b^2 was determined by McLaughlin, King, Howley, Bassett and Ainsworth (2001) to be a valid and accurate source of IC measurement for oxygen consumption (VO_2), carbon dioxide production (VCO_2), ventilation (V_E) and respiratory exchange ratio (R).

4.2.2 Doubly labeled water

Fundamentally, the doubly labeled water (DLW) method offers information on O_2 consumption through the flow of body water (H_2O) as well as inspiration of O_2 and expiration of CO_2 (Speakman, 1998). Lifson, Gordon, Visscher and Nier (1949), through forced breathing of O_2 enriched air and injecting stable oxygen isotopes (^{18}O) in water into laboratory mice, attempted to locate the source of O_2 in respiratory CO_2, finding that O_2 in body H_2O and respiratory CO_2 were equilibrated. The ^{18}O and hydrogen isotopes are naturally occurring ideal tracers for O_2 and hydrogen thought body H_2O activity through almost identical physico-chemical properties (Butler, Green, Boyd & Speakman, 2004; Speakman, 1998). These isotopes are lost rapidly from the body, specifically through CO_2 and body H_2O, which are both produced and lost from the body through breathing, as well as urine and sweat. The difference between the removal rates of these isotopes, as the ^{18}O is lost more rapidly than hydrogen through both body H_2O and CO_2 rather than just body H_2O, indirectly estimates EE through the measurement of O_2 consumption and CO_2 production (Ainslie et al., 2003; Butler et al., 2004; Speakman, 1998; Lisfson, Gordon & McClintock, 1955).

The DLW method is the "gold standard" for measuring gross EE, in measurement periods lasting from 4 to 20 days (Ainslie et al., 2003; Bassett, 2000a; Butler et al., 2004; Westerterp, 2009). The DLW method, however, is not without disadvantages; the accuracy for a focal individual, the significant error generated with multiple conversions when using inappropriate respiratory quotients, as well as its cost, approximately $1000 for a 70 kg human are all limitations to the use for this particular study (Butler et al., 2004).

4.3 Accelerometers

Accelerometers are versatile measurement tools which can continuously record body movements through linear acceleration (Godfrey, Conway, Meagher, & O'Laighin, 2008); and sense angular motion estimating the amount and intensity of PA (Ainslie et al., 2003; Chen & Bassett, 2005; Yang & Hsu, 2010). Accelerometers can be uniaxial (horizontal), biaxial (vertical and horizontal), triaxial (vertical, horizontal and lateral), or omnidirectional, (operates in unspecified directions in space) (Chen & Bassett, 2005). Accelerometers are grouped into four classes: capacitive, strain gauge, piezoelectric and piesoresistive (Kavanagh & Menz, 2008). Capacitive accelerometers monitor the change of capacitance through silicon mass surrounded by several capacitors. The reaction to movement causes deformation when the capacitors on either side become unbalanced, creating an electrical signal proportional to acceleration (Godfrey et al, 2008; Kavanagh & Menz, 2008). Strain gauge accelerometers monitor the relationship between the electrical changes in resistance of certain materials that are relative to the length of the conductor due to the elasticity of inertial forces (Morris, 1973; Window, 1992, p.3).

Piezoelectric accelerometers operate with the use of a crystal which when deformed applies pressure to the crystal that generates a voltage signal proportional to the acceleration applied by a horizontal level beam (Chen & Bassett, 2005). The piezoelectric crystal, which has the ability to produce high outputs from small strains across a large range of activity, will generate a voltage signal that is proportional to the applied acceleration, which is then translated into accelerometer counts via specific algorithms (Bassett, Mahar, Rowe, & Morrow, 2008, Chen, & Bassett, 2005). Specifically, the miCoach and Nike+ utilize piezoelectric accelerometers logging the raw (analog) acceleration data from their stride sensors into a computer interface using specific data and proprietary algorithms, populating PA assessments. Finally, Piezoresistve accelerometers sense external acceleration forces through a substrate, typically a poly-silicon seismic mass material, whose electrical resistance changes based on the external applied force (Huang et al, 2005).

4.4 Accelerometer placement

The location of activity monitors on the trunk of the body, or center of mass (Bouten, Koekkoek, Verdiun, Kodde, & Janssen, 1997a; Meijer et al, 1991; Yang & Hsu, 2010), the lower extremity (Foster et al., 2005; Herzog, Nigg, Read, & Olsson, 1989; La Porte et al., 1979; Godfrey et al., 2008; Meijer et al., 1991), and the back or waist (Bouten, Sauren, Verduin, &

Janssen, 1997b; Moe-Nilssen, 1998; Kavanagh & Menz, 2008) has been widely researched; however the miCoach and Nike+ were designed to be located in the midsole or attached to the shoelaces of a sensor compatible shoe. There have been studies that have looked at limb placement; however, only Kane, Simmons, John, Thompson, & Bassett, 2010) have used the Nike+ in is recommended position and only King, Torres, Potter, Brooks, & Coleman, (2004) had similar procedures looking at the variable of placement. The need for further examination of placement is necessary, regardless of location, as the accelerometer should be properly affixed in order to reduce rotational movement and vibration that could add access movement, causing incorrect assessment (Bouten et al., 1997a; Kavanagh & Menz, 2008).

4.5 Limitations of Accelerometers

The majority of popular accelerometers tend to be less accurate distinguishing between intensities at higher running speeds causing errors in predicting EE (Conger, Strath, & Bassett, 2005). According to John, Tyo, and Bassett (2010), accelerometers tend to generate a leveling effect at higher speeds, showing an inability to distinguish different running speeds (Abel et al., 2008; Brage, Wedderkopp, Franks, Anderson & Froberg, 2003; Haymes and Byrnes, 1993; King et al., 2004; Rowlands, Stone & Eston, 2007), walking speeds (Arvidsson, Slinde, & Larsson, 2009; Kang et al., 2007; King et al., 2004), or changes in elevation (Kavouras, Sarras, Tsekouras & Sidossis, 2008; Montoye et al. 1983; Terrier, Aminian & Schutz, 2001), which can in turn cause them to be less accurate at predicting EE, usually through underestimation (Conger et al., 2005). However, King et al., (2004) compared five activity monitors (Biotrainer-Pro, CSA, RT3, SenseWear Armband and Tritrac-R3D) finding all monitors generally overestimate EE at most speeds both walking and running.

4.6 Over-ground vs. Treadmill Exercise

Laboratory studies conducting EE measurements typically prefer to utilize the treadmill to simulate over-ground running due to its controlled and convenience for testing (Alton, Baldey, Caplan, & Morrissey, 1998; Bassett et al, 1985). McMiken and Daniels (1976) reported that level track and treadmill running caused no significant differences in EE within a range of 180 to 260 $m \cdot min^{-1}$, which was further established to be true by Bassett et al. (1985) in their findings, showing no significant EE requirements between treadmill and over-ground running, at an incline. Others such as Pugh (1970) reported increased EE at higher velocities (358 $m \cdot min^{-1}$) due to increased wind resistance. Due to these references, this study was conducted on both treadmill and over-ground running platforms in order to distinguish if the miCoach and Nike+ PA monitors demonstrate the ability to distinguish between walking and running at a range of speeds.

4.7 Conclusion

Accelerometers were introduced as objective measures of PA in the 1980's. Since then accelerometers have been serving as reliable, non-invasive techniques for assessing PA, as well as gait analysis, balance control, fall detection and posture recognition, despite some limitations such as elevation change or incline (Kavouras et al., 2008; Matthews, 2005; Montoye et al., 1983; Murphy, 2009; Terrier et al., 2001) and accuracy at higher running speeds (Abel et al., 2008; Arvidsson et al., 2009; Brage et al., 2003; Conger et al., 2005; Haymes, & Byrnes, 1993; Rowlands et al, 2007). The placement of accelerometers on the waist, closest to the center of mass (Bouten et al., 1997b; Meijer, et al, 1991; Yang & Hsu, 2010) is a common consensus among research; however, little research has been done on the shoe-mounted placement of the Adidas miCoach and Nike+ sport kit, which are commercially-available accelerometers designed for placement under the insole of a shoe. There was little to be found on the validation of the Adidas miCoach for PA; however, there has been one published conclusion on the Nike+ sport kit (Kane et al., 2010), as well as published conclusions for sensor placement (Conger et al., 2005) and experimental design (King et al., 2004) the support the development of this study. Therefore, as new accelerometers are manufactured and released for commercial sale, there is a continuous need for assessing the validity and reliability of these devices as accurate predictors of PA for individual exercise guidelines as well as the potential to assist in academic research questions, as well. The purpose of the current study was to validate the accuracy of both the Adidas miCoach, and Nike+ sport kit to estimate pace ($min \cdot km^{-1}$), distance (km) and EE ($kcal \cdot min^{-1}$), in two different sensor configurations during outdoor over-ground walking and running.

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Appendix B

Heath/Activity Status Questionnaire

Please complete the following questions as accurately as possible.

Date of Birth: ______/_____/______ Age:________yr.

Average number of hours worked per week:

☐ Less than 20 ☐ 20-40 ☐ 41-60 ☐ over 60

More than 25% of time spent at work/school is: (mark all that apply)

☐ Sitting at a desk ☐ Lifting or carrying loads ☐ Standing
☐ Walking ☐ Driving

Medical History

Please mark any who have died of heart attack before age 50 years:

☐ Father ☐ Mother ☐ Grandparent ☐ Brother ☐ Sister

Please mark any who have had a stroke, blood clots, or pulmonary embolism:

☐ Father ☐ Mother ☐ Grandparent ☐ Brother ☐ Sister

Specify:____

Date of your last physical exam: ______/_____/______

Date of your last physical fitness test: ______/_____/______

Please mark and date all surgeries you have had:

☐ Back	______/______	☐ Heart	______/______
☐ Kidney	______/______	☐ Eyes	______/______
☐ Joint	______/______	☐ Neck	______/______
☐ Ears	______/______	☐ Hernia	______/______
☐ Lung	______/______	☐ Hysterectomy	______/______
☐ Other	__________________________		______/______

Please mark all of the following for which you have been diagnosed or treated by a physician or health professional:

- ☐ Alcoholism
- ☐ Anemia, sickle cell
- ☐ Anemia, other
- ☐ Asthma
- ☐ AIDS
- ☐ Back Strain
- ☐ Bleeding trait
- ☐ Bronchitis, chronic
- ☐ Cancer
- ☐ Cirrhosis, liver
- ☐ Concussion
- ☐ Congenital defect
- ☐ Diabetes
- ☐ Emphysema
- ☐ Epilepsy
- ☐ Eye problems
- ☐ Gout
- ☐ Hearing loss
- ☐ Heart problem
- ☐ Heart murmur
- ☐ Hepatitis
- ☐ High blood pressure
- ☐ Hypoglycemia
- ☐ High Cholesterol
- ☐ Infectious mononucleosis
- ☐ Joint problems
- ☐ Kidney problems
- ☐ Liver disease
- ☐ Lung disease
- ☐ Mental illness
- ☐ Neck strain
- ☐ Obesity
- ☐ Phlebitis
- ☐ Rheumatoid arthritis
- ☐ Stroke
- ☐ Thyroid problem
- ☐ Ulcer
- ☐ Other_________

Please mark all medications/supplements taken during the past 6 months:

- ☐ Blood thinner
- ☐ Diabetic
- ☐ Diuretic
- ☐ Insulin
- ☐ Epilepsy medication
- ☐ Heart medication
- ☐ High blood pressure medication
- ☐ Hormones
- ☐ Other_________
- ☐ Other_________
- ☐ Other_________
- ☐ Other_________

Please mark any of the following symptoms you have had recently:

- ☐ Abdominal pain
- ☐ Arm or shoulder pain
- ☐ Breathless with slight exertion
- ☐ Blurred vision
- ☐ Blood in urine
- ☐ Burning sensations
- ☐ Chest pain
- ☐ Cough up blood
- ☐ Difficulty walking
- ☐ Dizziness
- ☐ Feel faint
- ☐ Frequent urination
- ☐ Leg pain/numbness
- ☐ Low blood sugar
- ☐ Low-back pain
- ☐ Palpitation or fast heart beat
- ☐ Shortness of breath
- ☐ Significant emotional problem
- ☐ Swollen joints
- ☐ Unusual fatigue with normal activity
- ☐ Weakness in arms

Health-Related Behaviors

Do you smoke? ☐ Yes ☐ No

If yes, How much do you smoke per day?
Cigarettes: ☐ 40 or more ☐ 20-39 ☐ 10-19 ☐ 1-9
Cigar or pipe only: ☐ 5 or more or any inhale ☐ Less than 5, none inhaled

Do you currently exercise regularly? ☐ Yes ☐ No

What is your primary mode of exercise? ______________________

How long have you been participating in your current exercise program?________

How many days per week do you engage in your primary form of exercise?
☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

How many days per week do you do interval training?
☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

What is your average weekly mileage during the last 3 months?_______________

What is your average weekly mileage during the last month? _________________

What other forms of exercise do you participate in regularly? How many days per week?
______________________ ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7
______________________ ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7
______________________ ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7
______________________ ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7
______________________ ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

On average, what is the length of a typical training session? _________________

Are you currently on a diet or program specifically designed to change your body weight?
☐ Yes ☐ No

During the past 3 months have you been on a diet or program specifically designed to change your body weight? ☐ Yes ☐ No

During the past 3 months has your body weight changed more than 4 pounds?
☐ Yes ☐ No

Vita

Justin Porta was born in Gulf Port, Mississippi, the first child of Gregory Ronald and Diane Marie Porta. He graduated from Archbishop Moeller High School in Cincinnati, Ohio, in the spring of 2004 and entered Marietta College in Marietta, Ohio, in the next fall in pursuit of his bachelor's degree in Sports Medicine. While in pursuit of his degree, Justin worked as a student athletic trainer for the men's soccer, women's softball and Varsity football team. During his senior year he was employed to work as the Head Intern Athletic Trainer for the Columbus Destroyers Arena League football team, before graduating in the spring of 2009. In the fall of 2010, Justin enrolled in the master's degree program at The University of Texas at El Paso in El Paso, Texas.

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