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RELIABILITY AND VALIDITY OF THE HEXOSKIN WEARABLE BODY METRICS TELEMETRY SHIRT

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ABSTRACT
Objective: To examine the reliability and validity of the Hexoskin wearable body metrics telemetry shirt. **Setting:** Data were collected for three days a week for three weeks in a clinical lab setting. **Participants:** Six healthy young, nonsmoking participants (3 males and 3 females) were selected for this study (age 23.7 +/- 2.3 years, height 171.66 +/- 9.71 cm, weight 73.53 +/- 8.8 kg, body fat percentage 15.9 +/- 5.8, body mass index 24.9 +/- 1.82 kg/m^2). **Interventions:** Two distinct phases of examining the reliability and validity of the Hexoskin shirt during moderate and vigorous intensities. **Main Outcome Measures**: To establish test-retest reliability, data were analyzed using Pearson-r by validating the reliability from each week's treadmill test using the calories per-minute data from each participant while wearing the Hexoskin telemetry shirt. Validity was established using criterion related concurrent validity methodology by computing Pearson-r correlation calories per-minute data for the Hexoskin, and the corresponding data from the ParvoMedic TrueOne®2400 Metabolic Cart (VO_2 Max). The Hexoskin heart rate was also compared between each moderate test and vigorous test using nonparametric statistics because of the small sample size. Wilcoxon signed-rank test was used to compare the heart rates between each intensity. **Results:** Of the many data points provided by the Hexoskin, the study focused on calories, breathing rate, and heart rate. The reliability of accurate calorie burn was tested at the moderate and vigorous levels for all six participants based off the Harris-Benedict equation. Breathing rate readings from the Hexoskin were compared at the moderate and vigorous levels against the ParvoMedic TrueOne®2400 Metabolic Cart at moderate and vigorous levels. Finally, the Hexoskin heart rate was also compared between each moderate test and vigorous test using nonparametric statistics because of the small sample size and that the cases were matched samples. **Conclusions:** The current study examined the Hexoskin under typical exercising constraints of moderate and vigorous intensities with healthy adults. The study demonstrated that with a properly fitting Hexoskin shirt and following proper protocols, the Hexoskin shirt could be used as a tool to accurately monitor levels of telemetry data during physical activity. It was concluded that the Hexoskin wearable body metrics telemetry shirt is a reliable and valid tool to be used during moderate and vigorous activities.

Keywords: Hexoskin, Reliability, Validity, Wearable Telemetry Body Metrics Shirt

INTRODUCTION

The prevalence of obesity in the United States currently stands at 35% among adults and 17% among adolescents [1, 2]. The main concern with obesity is that it leads to many other health issues including type-2 diabetes, cardiovascular disease, and metabolic syndrome [3]. One way to combat these major health issues and achieving a healthy lifestyle is with physical activity (PA). One way of measuring PA is with accelerometers. Accelerometers have become the standard of measuring physical activity in field-based research [4]. But with the advancement of technologies, there has been an emergence of consumer-based activity monitors used to measure health data for those interested in health, fitness, and weight management [5]. Although monitoring physical activity is important; it's more important that the data being measured are valid [6, 7]. Without a valid measurement, it is difficult to assess treatment outcomes [5]. However, very little research has been conducted on the validity and reliability of these consumer-based activity monitors [5, 8, 9, 10].

Hexoskin (Carre Technologies Inc., Montreal, Que., Canada) is a body metrics product that measures a variety of telemetry data such as heart rate, heart rate variability, breathing rate, breathing volume, and activity levels such as pace, cadence, and sleep [10]. The Hexoskin is marketed as the epitome of the fitness trackers due to its ability to measure all of the above variables through a smart shirt that is infused with integrated sensors [11]. Because it is easy to wear, the Hexoskin is considered to be one of the most accurate fitness trackers on the market to measure telemetry data while exercising [11]. "We realized the technology had to be part of something people were already wearing to be successful," said Pierre-Alexandre Fournier, cofounder and chief executive officer of Hexoskin [12]. The Hexoskin is said to be more accurate than the typical wristband and retains accuracy even in contact sports like basketball. In 2013, Hexoskin finished first out of 18 competitors demonstrating their wearable devices at the Wearable Tech Expo in Los Angeles, CA. It was awarded the "Best Wearable Device" for 2013. In 2016, Hexoskin was recognized by the International Consumer Electronics Show (CES) for a 2016 CES Wearable Tech Award. Hexoskin Smart was also recognized as the Best in Show Award for the Smart Clothing Category [13].

According to the American Council on Exercise [14], over 19 million fitness trackers were used in 2014 and this number could triple by 2018. Thompson [15] reported that in 2015, wearable technology would be the most popular fitness trend. Considering the large market in the fitness and technology industry, reliability and validity of a fitness tracker such as the Hexoskin is warranted. One of the main justifications for this study is only two research projects have been completed to date concerning the validity and reliability of the Hexoskin product. Villar, Beltrame, and Hughson [10] examined the validity of heart rate (HR), breathing rate (BR), and hip-motion intensity (HMI). The researchers concluded that HR, BR, and HMI from the Hexoskin demonstrated low variability, limited error, good agreement, and consistency. In a study by Banerjee, Anantharam, Romine, Lawhorne, and Sheth [16], the researchers validated the Hexoskin on cadence, breathing rate, minute ventilation, and activity level. However, according to Duking et al. [8], measurement of parameters coinciding with training and health of athletes has not been studied while training. In a review from the National Health Service in the United Kingdom, "the need for the citizens to start playing a more active role

in their health care by accessing, entering, and uploading data into their own online medical record", indicates that telemetry data from wearable technology is being integrated into the health care system as well [17].

It is paramount that validity and reliability of the Hexoskin and other accelerometer products be determined so consumers, fitness, professionals, and researchers can make informed decisions when choosing these products. Therefore, the purpose of this study was to examine the reliability and validity of the Hexoskin wearable telemetry shirt while participants exercised at moderate and vigorous levels. The present study could add new information to the literature by formally evaluating the validity and reliability of the Hexoskin wearable telemetry shirt. Participants will be led under semi-structured free-living conditions, with energy expenditure (EE) being analyzed by the metabolic analyzer as the criterion standard.

MATERIALS AND METHODS

Participants

Six healthy young, nonsmoking participants (3 males and 3 females) were selected for this study (age 23.7 +/- 2.3 years, height 171.66 +/- 9.71 cm, weight 73.53 +/- 8.8 kg, body fat percentage 15.9 +/- 5.8, body mass index 24.9 +/- 1.82 kg/m^2). Participants were required to complete a Physical Activity Readiness Questionnaire [18] prior to testing. Participants responded "No" to all seven questions on the PAR-Q, reported no prior injuries, or any orthopedic complications prior to testing. Participants also completed a Physical Activity Rating (PAR) questionnaire that described their weekly physical activity level and classified them as trained participants. Participants received written and verbal instructions regarding the purpose of the study and its experimental procedures along with any potential risks involved prior to signing the informed consent form approved by the Office of Research at Tennessee Technological University. All participants were given pretest instructions to wear comfortable clothing such as socks and athletic gear, drink at least 0.5 liters of fluid two hours prior to testing, and refrain from alcohol 24-hours prior to testing.

Experimental Design

Participants reported to the laboratory on the first day to receive written and verbal details of the experimental procedures, sign the informed consent forms, and for the researchers to collect demographic data such as height and weight. After the first day, the participants agreed to meet for three days a week for the next three weeks; totaling nine testing days. On day one of week one, the participants were fitted for the correct size of the Hexoskin wearable device (small, medium, large, or extra-large). Participants were familiarized with the protocol and treadmill settings and then proceeded to walk at a moderate pace of 5.6 km/h at a 2% grade for 15-minutes. During testing, telemetry data were measured including calories per minute. On day two of week one; the participants followed the same protocol from day one to test for reliability. On day three of week one, the participants followed the same protocol but were connected to the ParvoMedic TrueOne®2400 Metabolic Cart Measurement System (ParvoMedic Inc., Sandy, UT) to measure volume of oxygen uptake (VO_2 Max). The ParvoMedic TrueOne®2400 Metabolic Cart is a gold standard measurement for VO_2 Max testing and was calibrated prior to each day of testing. The researchers then measured the validity of the Hexoskin telemetry data with the gold standard metabolic cart. On day one of week two, the participants ran at a moderate pace of 8.1 km/h at a grade of 2%

for 15-minutes. The participants followed the same protocol as week one using the pace and grade from day one of week two. On day one of week three, the participants ran at a high pace of 12.1 km/h and a 2% grade for 15-minutes. The participant followed the same protocol for the week as week one using the pace and grade from week three. Each participant followed the same protocol during their three weeks of testing.

The three day a week testing and time was manipulated to specifically minimize any carry-over effect of the exercise protocols. The measurements for the three week testing protocol were conducted in a quiet room where temperature was kept constant at 22 C°, humidity at 62%, and barometric pressure at 764.7 mmHg.

Data Acquisition

Data were transferred from the Hexoskin telemetry shirt and Hexoskin device to the Hexoskin Web Dashboard, via Bluetooth technology, using either an Android device (Android 5.0) or Apple device iOS (8.0). Data were downloaded from the Hexoskin Web Dashboard and uploaded to SPSS.

Statistical Analysis

Statistical analysis was conducted using the Statistical Package for the Social Sciences [19]. To establish test-retest reliability, data were analyzed using Pearson-r by validating the reliability from each week's treadmill test using the calories per-minute data from each participant while wearing the Hexoskin telemetry shirt. Validity was established using criterion related concurrent validity methodology by computing Pearson-r correlation calories per-minute data for the Hexoskin, and the corresponding data from the ParvoMedic TrueOne®2400 Metabolic Cart (VO_2 Max), "the most valid measure of functional capacity of the cardiorespiratory system" [20]. The Hexoskin heart rate was also compared between each moderate test and vigorous test using nonparametric statistics because of the small sample size. Wilcoxon signed-rank test was used to compare the heart rates between each intensity.

RESULTS

Of the many data points provided by the Hexoskin, the study focused on calories, breathing rate, and heart rate. The reliability of accurate calorie burn was tested at the moderate and vigorous levels for all six participants based off of the Harris-Benedict equation. Breathing rate readings from the Hexoskin were compared at the moderate and vigorous levels against the ParvoMedic TrueOne®2400 Metabolic Cart at the moderate and vigorous levels. Finally, the Hexoskin heart rate was also compared between each moderate test and vigorous test using nonparametric statistics because of the small sample size and that the cases were matched samples.

Kcal Burn Rate

To determine the reliability of the kcal burn rate, a Pearson correlation was conducted at the moderate and vigorous intensity levels. Of the two intensity levels, the Hexoskin had the strongest correlation at the vigorous rate of Kcal burn. There was a significant positive correlation between the two vigorous tests, $r = 0.993$, $N = 6$, $p = 0.000$. At the moderate intensity level, the Hexoskin showed a medium correlation between the two test, $r = 0.439$, $N = 6$, $p = 0.384$

To determine the validity of the Hexoskin kcal burn rate, a Pearson correlation was conducted on the moderate and vigorous intensity levels correlating the results to the Metabolic Cart kcal burn rate. Of the two intensity levels, there was a

significant positive correlation between the Hexoskin kcal burn rate and the Metabolic Cart kcal burn rate at the vigorous level, r = 0.906, N = 6, p = 0.013. At the moderate intensity level, there was a medium correlation between the Hexoskin kcal burn rate and the Metabolic Cart kcal burn rate, r = 0.586, N = 6, p = 0.222.

Breathing Rate

To determine the validity of the Hexoskin's ability to accurately measure breathing rate, the data were compared against the Metabolic Cart, the gold standard in measuring oxygen consumption. Two levels of exertion were used to test the reliability of the Hexoskin. The participants were tested at a moderate activity level and vigorous activity level. At the moderate activity level, there was a significant positive correlation between the Hexoskin and the Metabolic Cart, r = 0.996, N = 6, p = 0.000. At the vigorous activity level, there was a significant positive correlation between the Hexoskin and the Metabolic Cart, r = 0.962, N = 6, p = 0.002.

In determining the reliability of the Hexoskin's ability to report consistent results, a Pearson's correlation was conducted between two moderate tests and two vigorous tests. The correlation between the two moderate tests indicated a medium correlation at the moderate intensity level, r = 0.502, N = 6, p = 0.311. At the vigorous intensity level, a weak correlation existed between the two vigorous tests, r = 0.105, N = 6, p = 0.843. The weak correlation resulted because two participants had scores that varied greatly between the two vigorous tests. Participant's three breathing rate for the first vigorous test was 37, the second vigorous test was 20. Participant's four breathing rate for the first vigorous test was 33, the second vigorous test was 18. Because of the small sample size, participants three and four scores affected the results of the correlation. Treating participants three and four as outliers, and removing their scores yielded a strong correlation between the two vigorous tests, r = 0.976, N = 4, p = 0.001.

Heart Rate

To determine the accuracy of the Hexoskin heart rate monitor, a test of differences between the two moderate tests was performed using the nonparametric Wilcoxon signed-rank test. The median values were examined to provide a better overall picture of heart rates among the six participants. At the moderate level, there was a significant difference in the median between both values with the first value being 119.83 and the second value being 151.17. The nonparametric Wilcoxon signed-rank test indicated that the second test at the moderate level was significantly higher than the first test $p < 0.046$.

At the vigorous level, there was no difference between heart rate measurement in the median between both values with the first value being 158.00 and the second value being 159.00. The nonparametric Wilcoxon signed-rank test indicated that the second test at the vigorous level was not significantly different than the first test $p < 0.854$.

DISCUSSION

The Hexoskin shirt is being marketed for the ability to monitor physiological measurements. One way of combating diseases such as diabetes, heart disease and other cardiovascular diseases is through physical activity. Measuring physical activity is a growing trend using wearable devices allowing for easier access to data collection and measuring the benefits for physical activity. The present study examined the consistency and the accuracy of the Hexoskin wearable body metrics vest. The reliability of

the kcal count at both the moderate and vigorous levels, showed correlations from day to day testing. The breathing rate comparing the results from the Hexoskin shirt to Metabolic cart data showed strong correlations at both the moderate and vigorous levels. Reliability of the Hexoskin shirt at the moderate intensity level showed a medium correlation. The vigorous intensity returned a strong correlation after two outliers were removed. Heart rate was measured using the Hexoskin shirt and compared multiple tests against each other, to find that there was a significant difference between the trials at the moderate level of intensity, while no difference was found at the vigorous levels.

This research project focused on collecting data for calories, breathing rate, and heart rate, while participating in moderate and vigorous physical activity. Comparing the data from multiple testing dates using multiple days of Hexoskin data showed correlations between the data points. The overall results of this study indicate that the Hexoskin technology is valid and reliable tool in measuring physiological measurements during moderate and vigorous levels of exercise which was comparable to the results of Villar, Beltrame, and Hughson [10].

The study did provide new insights into the Hexoskin wearable vest, but it did have some limitations worth mentioning. When participating in light intensity there were some connection and syncing issues. At some points during data collection, constant counts were presented in data, this could have been caused via sensor connections issues. If the sensor was not wet enough, or was being shielded from bodily contact via an article of clothing. The researchers had a female participant who adjusted her sports bra to make sure that the sensor was in better contact with the body, which allowed for data to be better collected from the sensors. We had a small sample size of highly conditioned athletes, instead of having a variety of different conditioned levels of athletes. Having only highly conditioned athletes limited this study in its ability to look at how the shirts readings may have varied with different conditioning levels.

Through our research there are some recommendations for wearing the Hexoskin to make sure that the data collected is the most accurate. The Hexoskin shirt must be tight fitting for the data to be properly collected from the body. If the shirt is not tight, the sensors will not collect the appropriate data. Another recommendation is that all sensors need to be wet to provide the most accurate readings. The wet sensors allow for data to be collected, better than dry sensors. Make sure to wet sensors before activity begins. Dry sensors provide inaccurate data or no data at all. After the participant has begun sweating, is the ideal time to examine the data. This also helps in maintaining the sensors remaining wet as data are being collected.

CONCLUSIONS

The results of this study add to the existing literature on wearable telemetry devices. Previous research by Villar, Beltrame, and Hughson [10] examined validity of the Hexoskin by tracking changes in body positions and various speeds of walking (p. 1021). The current study examined the Hexoskin under typical exercising constraints of moderate and vigorous intensities with healthy adults. The study demonstrated that with a properly fitting Hexoskin shirt and following proper protocols, the Hexoskin shirt could be used as a tool to accurately monitor levels of

telemetry data during physical activity. With new wearable technology seemingly coming out every day, each company is expected to deliver the latest and greatest product to help consumers achieve a healthy lifestyle. It is up to the consumer to use the data wisely while using any type of wearable technology, while participating in physical activity.

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