Validity of Wearable Technology Assessments of Heart Rate and Energy Expenditure Under Exercise Conditions

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Introduction

The popularity of wearable Smart Watches has grown over the last decade. According to Statista (2022), there are currently 202.6 million Smart Watch users worldwide. However, this number is expected to rise to 231.3 million by 2026. Toward the end of the 20^{th} century and beginning of the 21^{st} century, technology became more advanced and small enough to be worn on the wrist (Gregersen, 2022). With this expansion in technology, many functions such as texting or answering phone calls, normally done on a mobile phone, can also be accomplished at the convenience of Smart Watches. Most importantly, basic health information can be stored and analyzed within the watch. This has led to increased use for individuals to track their cardiorespiratory and physical fitness levels. According to ValueWalk (2015), “the Apple Watch's health and fitness features such as Move, the achievement badges, the Exercise and Stand rings, the progress updates, workout summaries, personalized feedback and others, have inspired early adopters to become more health-conscious than before.”

Chandrasekaran et. al. (2020), completed a longitudinal study looking at key factors affecting the use of Smart Watches in the United States. Researchers found that 30% of adults in the United States use Smart Watches and most Smart Watch users are younger, healthier, wealthier, more educated, and techno-literate adults. However, such watches provide benefits to all demographics because they offer a convenient way to store and share health information in real time. Apple’s website claims users can choose to allow Apple Watches to notify users if their heart rate exceeds 120 beats per minute, when there is no sign of activity for 10 minutes or if their heart rate drops below 40 beats per minute (Healthcare). Smart Watches provide feedback to users to make appropriate changes to daily routines or behaviors, can facilitate remote patient monitoring and provide faster data to physicians for patients with or without cardiovascular risk or other illnesses (Chandrasekaran, 2020). Therefore, wearable Smart Watches have potential to significantly improve health.

According to Times of India (2022), Apple Watches are the leader of all Smart Watch sales in the World. Technology and commodities in Apple Watches are photoplethysmography and accelerometers, which are used to measure heart rate and calorie expenditure. Determining and knowing heart rate and calorie expenditure are key factors to help reach cardiorespiratory goals. Cardiorespiratory fitness "refers to the capacity of the circulatory and respiratory systems to supply oxygen to skeletal muscle mitochondria for energy production during physical activity" (Raghuveer et. al. 2020, p. 101). Cardiorespiratory fitness is a measure that reflects functional consequences of physical activity levels or even certain disease status (Sui et al., 2007). Functional consequences refer to the bodily changes that occur in response to exercise. These bodily changes can include reduced resting heart rate, increased stroke volume, and strengthen bone density. This measure is important to individuals to support longevity and quality of life.

According to Düking et. Al. (2020) "HR [heart rate] reflects the intensity of physical activity, while monitoring EE [energy expenditure] is particularly helpful for individuals seeking to regulate their body mass or composition." Physical activity is shown to be effective in primary and secondary prevention of many different chronic diseases while working to improve overall health creating astounding benefits from just exercising. Exercise programs work in the prevention of diabetes, cancer, and osteoporosis according to Warburton et. al. (2006). Deery (2019) states the following: "Current guidelines recommend that adults participate in at least 150 min of moderate or vigorous-intensity physical activity weekly. Despite the benefits, just over half of U.S. adults meet these recommendations" (p. 2). These guidelines are from the U.S.

Department of Health and Human Services and provide information to the public about maintaining health.

There are many strategies that the Centers for Disease Control and Prevention have tried implementing in order to push individuals to be more physically active. Centers for Disease Control and Prevention (2022) suggest incorporating activities into everyday routines. These routines could be as simple as taking public sidewalks to work or the grocery store and utilizing other activity-friendly routes. There are also many campaigns to implement school and youth programs, encouraging individuals to exercise in a setting that prompts social or individual support, and providing access for all individuals to be able to exercise (Centers for Disease Control and Prevention, 2022). With the hope that many of these plans are close to being implemented or already implemented, there will be or already is greater accessibility for all people to reach 150 minutes (about two and a half hours) of physical activity per week. Apple Watches have a feature called "rings" to encourage exercise. In order to close the "exercise ring" on the Apple Watch daily (or at least five times per week), an individual must complete 30 minutes of physical activity per day. It is perceived that the 30 minutes per day of exercise that Apple Watches push relate to the 150 minutes per week that is suggested (Abt et al., 2018).

A Smart Watch allows an individual to monitor exercise and track results of physical activity. Participants who have autonomy over their exercise program, and are confident in data results, are more likely to participate in regular exercise. Nuss et. al (2020) found that the use of wearable fitness trackers proves to be an effective motivational intervention in individuals currently not meeting current exercise recommendations. With most of the United States population not regularly exercising, the technology of a wearable monitor for evaluating an individual's physical activity can be an effective motivational tool. Assessing the accuracy of the

Apple Watch can help individuals easily track their exercise, meet their individual activity goals, and increase their motivation to be physically active. In a survey of over 1,000 Apple Watches users, 75% of the responders stated that they have been standing more since using an Apple Watch. Fifty-nine percent of these users also believe they are making healthier choices since using the watch (ValueWalk, 2015). This monitoring system allows for autonomy among individuals. If individuals feel they have more control over lifestyle choices, it gives more satisfaction. This, in turn, will motivate more people to engage in physical activity. If energy expenditure and heart rate are tracked accurately, individuals can adjust their workout according to that goal. The purpose of this research was to assess the accuracy of Apple Watches when measuring energy expenditure and heart rate.

Review of Literature

History of the Apple Watch (or Smart Watch)

The 1968 Sci-fi move *2001: Space Odyssey* featured creative, future-like pieces of technology. The director of the movie, Stanley Kubrick, wanted to make the most believable futuristic pieces for his movie and commissioned Hamilton, a luxury watch manufacturing company, to tackle this task. Following the production of *2001: Space Odyssey*, Hamilton highlighted the first electric watch with an LED display in an 18-karat gold setting (The History, 2014). According to Britannica, the first watches that can be considered the forefront of a Smart Watch were the Calcron (1975) and the Seiko (1980). The Seiko had a nine-digit display with computing capabilities (Encyclopedia Britannica, n.d.). In the early 2000s, watches comparable to today's Smart Watches were developed. Fossil released a touchscreen watch in 2003 and Microsoft followed in 2004. Microsoft's SPOT (Smart Personal Object Technology) is considered the first true “smart watch” (Encyclopedia Britannica, n.d.). These watches were capable of changing TV channels, checking stocks, weather and sports, as well as receiving emails and instant messages. However, the recipient could not reply to such messages (The History, 2014).

Watch technology continued to evolve as technology used in phones advanced. In 2010, Sony developed a watch that could receive data from a phone. In 2015, Apple released their equivalent of a Smart Watch that could synchronize to a mobile phone (Encyclopedia, n.d.). Apple watch set the stage for other Smart Watch manufacturers due to their ability to be used as a fitness band (The History, 2014). According to Apple Insider, by 2018, Apple reduced emphasis on social features and transitioned to a greater concentration on health and fitness. As of 2022, Apple has released seven versions of the watch (O’Hara et al. n.d.).

Technology used in Apple Watch

When first receiving an Apple Watch, an individual must input personal information about body demographics, such as age, sex, height, weight, and current level of fitness (Sartor et al., 2018). Such information is important because the maximum heart of an individual declines with age (Tanaka & Seals, 2018). This information is used in combination with other technology to determine heart rate. The major features in Apple Watches that support cardiorespiratory fitness are photoplethysmography, accelerometers and gyroscopes. Balli et. al (2018) report that when photoplethysmography, accelerometers and gyroscopes work together in a Smart Watch, simple activities such as walking, running, and vacuuming can all be identified.

Photoplethysmography (PPG) is used to measure heart rate. Heart rate can be described medically as the number of R-wave events, or heart beats, per unit of time (Barbieri et al., 2005). PPG measures heart rate by detecting blood volume changes in small vessels under the skin using small wavelengths of light (Allen, 2007). Green LED light is the most chosen color of light to monitor heart rate, because it penetrates deepest into muscle. However, it is not unheard of for red light to be shone as well (Castaneda, 2018). PPG is non-invasive, convenient, and relatively inexpensive; therefore, this technology is used in hospitals (typically as a pulse oxygen monitor) but also in Smart Watches (Castaneda, 2018).

Energy expenditure refers to the measure of energy used by an individual for essential body functions, such as respiration, digestion, and movement (Branson & Johannigman, 2004). Energy expenditure is measured in Apple Watches using a three-axis accelerometer in combination with a gyroscope. Each axis (x,y,z) of the accelerometer measures a different direction of dynamic acceleration. The three accelerometers are sensors that measure the position of a human body and the inertia acceleration in that axis. The data of the three axes are then combined to create a three-dimensional picture of the user and their movement (Tai et al., 2020).

Gyroscopes, better known as fiber optic gyroscopes, are sensors used in spacecraft, aircraft, self-driving cars, and Smart Watches (Fink et al., 2018). The gyroscope in an Apple Watch is the technology that measures the rotation around the axis of the accelerometer (Riemen, 2018). The measurement of rotation tells valuable information about the velocity of movements and aids the Smart Watch in identifying motion and exercise that occurs without the movement of arms, such as running, jogging, biking, etc. (Koundinya, 2022). Apple's developmental website states: "On-device gyroscopes and accelerometers can supply data about a device's movement in the physical world" (Inc.).

Functional Consequences of Physical Activity

There are many aspects of health that physical activity addresses. Physical activity refers to movement of skeletal muscles that requires the use of energy expenditure (Singh et. al., 2020). One of the most important health benefits attributed to exercise is the benefits to an individual's cardiovascular health and their heart (Centers for Disease Control and Prevention, 2020). With cardiovascular disease being the leading cause of death in the United States, it is important to convey the importance of how exercise can be used as a medicine for the heart (Thijssen et al., 2022). The Centers for Disease Control and Prevention (2022) mentions that high cholesterol levels, high blood sugar and high blood pressure all are dangers to the heart and cardiovascular system. However, exercise is single handily one of the best things an individual can do to lower or stabilize cholesterol, blood sugar and blood pressure levels (Centers for Disease Control and Prevention, 2020).

In a recent meta-analysis, studies revealed that regular exercise helps prevent coronary artery disease. Moderate intensity exercise decreases the risk of coronary artery disease by 12% to 27% (Nam, 2011). Nam’s research suggests that the relationship between decreases in coronary artery disease and exercise is contributed to “exercise-induced blood pressure lowering, improved body composition, glucose tolerance, insulin sensitivity, and platelet function” (Nam, 2011, p. 113). Exercise is extremely important for keeping the heart strong and functioning to the best of its ability.

Research confirms the value of regular physical activity and exercise on the heart, but many may not be aware of the physiological and other health benefits associated with such activity. Iversen (2018) states: “Physical activity and exercise have positive health effects for the circulatory, digestive, endocrine, excretory, immune, integumentary, muscular, nervous, respiratory, and skeletal systems” (p.1). Regular exercise can help treat certain diseases, cancers and conditions such as depression (Trueland, 2020). Hupin et. al. (2017) reported that physical activity helps reduce the risk of mortality by working with the autonomic nervous system.

Physical effects of exercise (muscle growth and weight loss) are more well-known than the cognitive effects of exercise. Tseng et. al. (2011) discuss how there are several relationships between exercise and cognitive functioning. Initially, exercise increases blood flow therefore, increasing the amount of oxygen and glucose that reach the brain, thus enhancing enzymes and function. The increase of nutrients stimulates neurogrowth, such as neurogenesis and interconnections between synapses. This in return can release calcium, resulting in increased dopamine and acetylcholine secretions. Most importantly, Tseng et. al. (2001) explain how exercise reduces aging of the brain and decreases chances of developing certain disorders, all while encouraging positive feelings, relaxations and decreasing stress responses.

Cai et.al. (2022) reports that the immediate reading of heart rate for individuals provides them the power to meet their goals. Since Smart Watches track heart rate consistently during workouts, individuals can address the intensity of a workout and adjust as necessary. In doing so, it could potentially protect an individual from overloading an exercise. Ultimately, Smart Watches aid in meeting the individual goals a person wants to achieve and could serve as a protecting agent from overuse injuries. Additionally, Smart Watches are more affordable than equipment used in a laboratory or research project.

Barriers to Maintaining a Physically Active Lifestyle

Singh et al. (2020) discuss that current guidelines for physical activity for adults are 150 minutes (about two and a half hours) weekly of moderate intensity with at least two days of muscle strengthening workouts. The Centers for Disease Control and Prevention identifies moderate intensity exercise as exercise that breaks a sweat. Moderate intensity exercise could be further explained as being able to talk while working out, but not being able to sing (Centers for Disease Control and Prevention, 2022). Deery (2019) also discusses physical activity guidelines, without mention of muscle strengthening. This research discusses the hardships of changing the behavior in individuals to achieve optimal levels of physical activity. A key theme that affects all age groups with not meeting their physical activity guidelines is the support from family and environment in which we live (Tuso, 2015). This is worrisome as obesity rates continue to increase over time. Westerterp and Speakman (2008) discuss the dramatic incline of obesity rate as energy expenditure declines. New strategies for motivating individuals to be more physically active are on the rise.

Research by Beighle and Morrow (2014) discuss that barriers to maintain a physically active lifestyle are multidisciplinary. These factors are broken into personal, environmental, and social barriers. Personal barriers include time restrictions, confidence, knowledge of physical activity, and motivation levels and are usually within the control of the individual. These are most often the hardest to intervene. Environmental barriers out of the control of an individual include weather and occupation. Social barriers cultural expectations and support from those around the individual. All these areas are slow to treat as everyone has a complex circuitry of level barriers. Because of the individualistic approach, more research is needed.

Value of Smart Watches to Measure HR During Exercise

Smart Watches have the capability to cause a large-scale shift in the behaviors of sedentary individuals and currently active individuals alike (Fuller et. al., 2020). The level at which an individual’s heart rate sits during physical activity can induce further benefits leading to a direct goal. These levels determine an individual’s intensity and duration of physical activity. Burke (1998) describes the importance of measuring heart rate:

> Your heart is the most important muscle in your body. In fact, it serves as a barometer for the rest of your body, telling you how hard you are exercising, how fast you are using up energy, and even what the state of your emotions is. It pulls these physiological variables together, weighs them, and then comes out with a single number that reports your overall condition (p. vii).

No matter an individual's fitness goal, heart rate indicates whether an individual is in the zone, out of the zone, training safely, or being unsafe. The heart is the most important muscle in the body and during exercise, the goal is to work the heart harder. In this way, the heart becomes healthier and stronger. The need for heart rate monitoring is for the benefit of the user to increase longevity. Longevity can be increased through physical activity and moving the body. In a study by Nguyen and Kim (2012), research found that sitting for long increments of time (two hours) increases the risk of diabetes by five to seven percent. By simply standing, which can contribute to walking or other exercise, lowers the risk of many chronic diseases (Nguyen & Kim, 2012).

Value of Smart Watches to Measure EE During Exercise

Amongst the multitude of functions that an Apple Watch can accomplish, measuring EE is one of the most important to maintain a healthy lifestyle. Psota and Chen (2013) state: "The measurement of energy expenditure (EE) is recommended as an important component of comprehensive clinical nutrition assessments in patients with altered metabolic states, who failed to respond to nutrition support and with critical illness that require individualized nutrition support." As of 2018, one-third of the United States population is suffering from some form of metabolic disease, such as syndrome X, insulin resistance, hypertension, abdominal obesity and hyperlipidemia (Saklayen, 2018). Knowing EE can be crucial for many individuals attempting to initially gain or regain a healthy lifestyle.

On the other side of metabolic disorders, knowing EE is also crucial for many athletes, coaches and exercise personnel. Determining EE for athletes influences their health but also their means to train and practice. Maintaining a balance of energy demands, and energy intake are crucial to the development of muscle and preventing energy loss (McMurray, 2002). Knowing EE allows athletes and all individuals to have a better sense of energy (or calories) expended in exercise or activities of daily living in order to calculate necessary dietary needs.

Current Accuracy of Apple Watch Measuring HR

Current research on the accuracy of the Apple Watch seems to be more consistent. Research by Düking et. al. (2020) found that the Apple Watch had the smallest error rate when measuring heart rate of light-to-vigorous physical activity, when compared to three other Smart Watches. While the Apple Watch performed the best, it is important to note that there was still an error rate occurring. Because the error rate was smaller, individuals were able to rely on the Apple Watch during exercise. However, not all the research agrees.

Khushhal et. al. (2017) conducted an experimental design with 21 males in order to assess the accuracy of the Apple Watch in measuring heart rate during exercise and recovery. The results concluded that the Apple Watch had high validity during walking and recovery. However, researchers reported that the validity of heart rate measurement decreased as exercise intensity increased. These findings were similar to the findings of Wallen et. al. (2016). These findings reported that the Apple Watch was the most accurate at lower exercise intensities, but underestimated heart rate as the intensity increased. Furthering the research, analyses show more accuracy as technology has advanced.

As the software of Apple Watches continues to change, accuracy when measuring heart rate has seemingly improved. This could also be attributed to the advancement in accessibility to technology to learn about the Smart Watch. In a research review by Fuller et. al. (2020), the authors found that the Apple Watch had less than a three percent error rate most of the time. When looking into 49 studies, the Apple Watch reported accurately 35 of those times. This statistic is important because it shows improvements over time.

Current Accuracy of Apple Watch Measuring EE

Energy expenditure measurement seems to be lacking when looking into validity of the Apple Watch. Düking et. al. (2020) reported that the Apple Watch Series, along with three other Smart Watches, were not effective at measuring energy expenditure when tested on light-to-vigorous physical activity. The research had error rates that determined whether the Smart Watch was suitable or not in these measurements. The error rate was so high that it caused the Apple Watch to not be considered for measurement. This was not the only research that showed a considerable error.

In a meta-analysis Fuller et. al. (2020) reviewed 36 studies to investigate the accuracy of energy expenditure measurement. Of these studies, the Apple Watch tended to overestimate energy expenditure 58% of the time. The other times, the Apple Watch was still not accurate with measurements of actual expenditure. As a result, the Apple Watch was not viewed as efficient for energy expenditure measurement. Because the Apple Watch is overestimating, individuals may not be taking in as many calories for their own individualized goals.

Methodology

Introduction

The purpose of this research was to assess the accuracy of Apple Watches when measuring energy expenditure and heart rate. With most of the United States population not regularly exercising, the technology of a wearable monitor for evaluating an individual's physical activity can be an effective motivational tool. Assessing the accuracy of the Apple Watch can help individuals easily track their exercise, meet their individual activity goals, and increase their motivation to be physically active. For already active athletes or individuals, having accurate heart rate and energy expenditure data can be important for formulating future workouts and appropriate nutrition plans.

Having accurate readings of heart rate will help many people determine the intensity of their exercise and help individuals achieve the health benefits associated with reaching certain heart rate percentages. Knowing energy expenditure is crucial for individuals on weight loss or medical journeys as well as individuals who must consume enough calories throughout the day to either maintain or gain weight.

Participants

The participants were current Lenoir-Rhyne students classified anywhere as sophomore through senior class level. Nine students participated in this study (6 Female, 3 Male). These participants included adults aged 19 through 21.

The requirement of these participants was that they own an Apple Watch, updated with the latest software (9.3.1). These participants completed multiple 5-minute workout routines with no serious health risks.

Materials

The purpose of this study was to assess the validity of the Apple Watch in measuring heart rate and energy expenditure during exercise. In this study, heart rate and energy expenditure were measured with different instruments. Heart rate was assessed with a wireless electrocardiogram. Oxygen consumption was measured with open-circuit spirometry. These measurements were compared with measurements from the Apple Watch on the participants' wrist.

Three different pieces of exercise equipment were used for this study. A Monark Bike measured the movement of the arms and legs together. A Quinton treadmill measured walking procedures. Finally, a Concept 2 Rower assessed the physical movement of the arms. Equipment was reset and recalibrated in between each exercise session protocol and participant.

Procedure

Participants signed a consent form before any testing procedures were initiated. Before physical exercise testing occurred, all participants underwent an In-Body scan. The In-Body scan provided information such as height, weight, fat and muscle mass, water percentage in the body and gave a better understanding of the participants' body composition. Once the In-body scan was complete, participants were connected to a wireless electrocardiogram as well as an oxygen consumption device with an open-circuit spirometry. Participants selected one of the categorized exercise groups programmed on to the Apple Watch: Indoor Walk, Rower, or Indoor Cycle matching the exercise the participant prepared for and began their five minutes of steady state exercise at a Rating of Perceived Exertion (RPE) of 11 on the Borg scale or "fairly light" intensity.

After five minutes of exercise was complete, participants ended the workout on their watch and recited the data calculated and it was recorded. Average heart rate, active energy (calorie) expenditure and total energy (calorie) expenditure were recorded and added to an Excel Spreadsheet. After the spurt of exercise, participants rested for five minutes to allow their heart rate to return to a normal resting state. The participants then moved to the next exercise and the appropriate workout session on their watch was selected after their heart rate stabilized. The process continued until all three exercises were completed, monitored and recorded.

Data Analysis

All data collected is present as means ± standard deviation. The total EE and average HR recorded from each participant were compared between Apple Watch and gold-standard measures using Pearson-Product Moment Correlations. These correlations were repeated for the three exercises that the participants completed. Average HR from the ECG was recorded every 30 seconds during the 5-minutes exercise bouts, for a total of 10 measures of data. Bland-Altman plots were created to illustrate a 95% confidence interval between devices for each exercise condition.

Results

Nine students (3M, 6F) participated in this research study (Table 1). Correlations between Apple Watch and Gold Standard measurements for HR and energy expenditure were calculated. EE correlations were the following; treadmill=0.88, bike=0.54, rower=0.87. For HR, the correlations were the following: treadmill=0.99, bike=0.96, rower=0.85

Table 1. Demographic characteristics of participants

	Participants (n=9; 6F, 3M)
Variable	Mean ± SD
Age (years)	20±0.78
Height (cm)	171±8.53
Weight (lbs)	184±63.21
Percent body fat	29±8.69
Predicted VO2 max (ml/kg/min)	38±6.73

Table 2. Standard deviation of EE and HR calculations

	ENERGY EXPENDITURE		*HEART RATE*	
	APPLE W (KCAL)	*GS (KCAL)*	*APPLE W (BPM)*	*GS (BPM)*
VARIABLE	*Mean ± SD*		*Mean ± SD*	
TREADMILL	*34±12.39*	*24±9.05*	*108±10.79*	*109±10.29*
BIKE	*37±11.87*	*24±7.07*	*115±12.08*	*118±9.42*
ROWER	*39±8.49*	*27±9.89*	*119±11.67*	*121±12.31*

Bland-Altman Plots illustrate a bias between Apple Watch calculations and Gold Standard methods of measurements for HR and EE over the 3 exercise conditions (Table 2). Mean bias on the treadmill for EE was –9.625 (Figure 1a) and mean bias on the treadmill for HR was 1.3375 (Figure 1b). Mean bias on the bike for EE was –12.9375 (Figure 2a) and mean bias on the bike for HR was 1.3375 (Figure 2b). Mean bias on the rower for EE was –12.75 (Figure 3a) and mean bias on the rower for HR was 1.65. All samples on all plots fell within the 95% confidence interval.

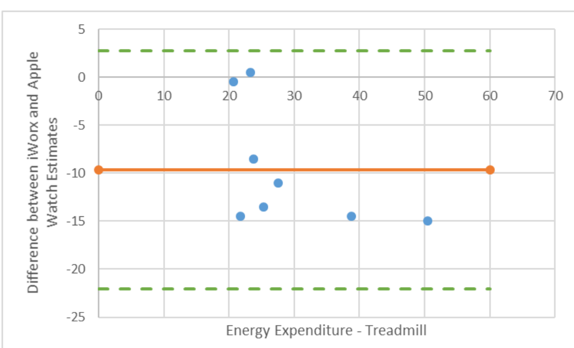


Figure 1a. Bland-Altman Plot comparing energy expenditure measures on treadmill between iWorx and Apple Watch.

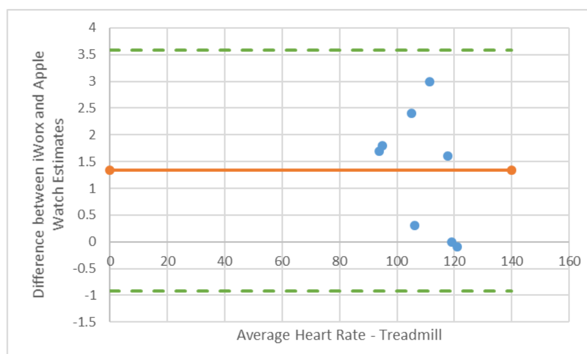
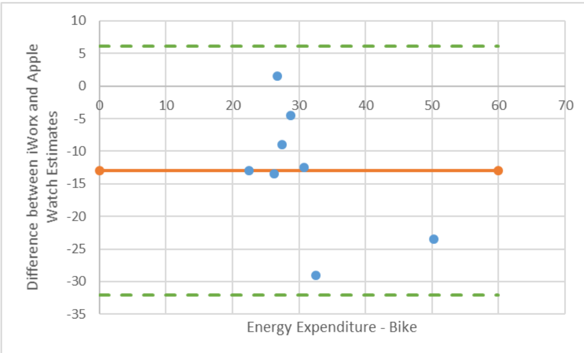


Figure 1b. Bland-Altman Plot comparing average heart rate measures on treadmill between iWorx and Apple Watch.



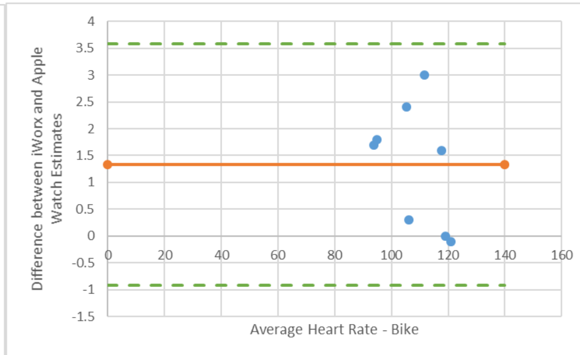
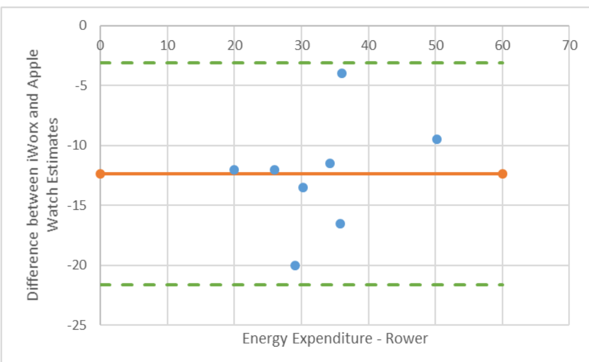


Figure 2a. Bland-Altman Plot comparing energy expenditure measures on bike between iWorx and Apple Watch.

Figure 2b. Bland-Altman Plot comparing average heart rate measures on bike between iWorx and Apple Watch.



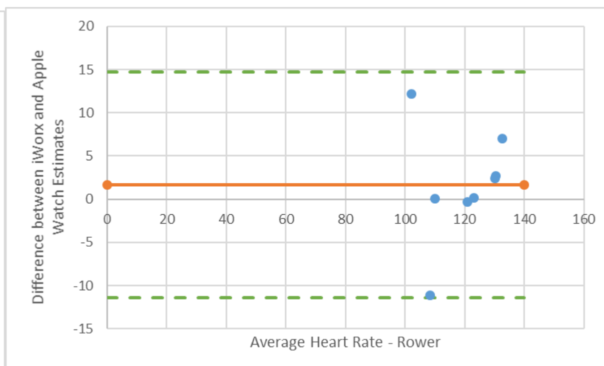


Figure 3a. Bland-Altman Plot comparing energy expenditure measures on rower between iWorx and Apple Watch.

Figure 3b. Bland-Altman Plot comparing average heart rate measures on rower between iWorx and Apple Watch.

Discussion

Apple Watches are a popular commodity to measure EE and HR. The purpose of this research was to assess the validity of the Apple Watch when measuring energy expenditure and heart rate during exercise. This study found that, when compared to gold standard methods, Apple Watches tend to overestimate EE, while being relatively close to gold standard methods of HR. The Bland-Altman plots show that data collection for EE was within the 95% confidence interval, suggesting Apple Watches are consistently over-estimating EE, on a precise basis. HR measurements also fell within the 95% confidence interval, suggesting that HR is accurately being reflected in the Apple Watch.

Khushhal et. al. (2017) conducted a similar study to assess the accuracy of the Apple Watch in measuring heart rate during exercise and recovery. They found that Apple Watches have high validity during walking and recovery. However, researchers reported that the validity of heart rate measurement decreased as exercise intensity increased. This research focused on steady state exercise, at one constant, light intensity (RPE of 11). Under these conditions, we found that Apple Watches are considerably accurate in measuring HR. This supports the claim made by Khushhal et al (2017) as our steady state exercise at an RPE of 11 in a relatively low intensity of exercise.

A meta-analysis of Apple Watch accuracy in regard to energy expenditure reviewed 36 studies (Fuller et.al., 2020). In the studies reviewed, the Apple Watch overestimated EE 58% of the time. The research findings in this study were similar to the current literature. Other research observed that the Apple Watch was not accurate in estimating energy expenditure during light-to-vigorous activity (Düking et. Al., 2020). The present study found similar findings of overestimation of EE while students participated in steady-state exercise. The current study also suggests that Apple Watches are consistently overestimating many different modes of exercise.

This research has a few different limitations. The first limitation is the placement and/or tightness of the Apple Watch on the participants' wrist. It was observed that participants with a tighter band had more accurate readings of average HR to the gold-standard method. Another limitation was the researchers had to hold the ECG portable pack during the exercise modes to most accurately reflect HR, prevent the loss of connection and/or leads popping off the subjects. Depending on the height of the participant, the ECG port cables were sometimes too short to accurately reach the needed areas of the body without coming off. The next imitation applied to how often the participant wore the Apple Watch for regular exercise outside of the study. It was observed that the readings were closer to gold-standard measures if they used their Apple Watch more frequently during day-to-day exercise. Another limitation is the relatively small sample size and unequal sex distribution. Due to this sample of convenience and expense of the device, another limitation is the varying models of Apple Watch within the subject pool.

These findings provide insight into the need for additional research with steady-state exercise. It is suggested that future research address our limitations. Deeper research taking into account the tightness and placement of Apple Watches as well as the frequency of tracking exercise on the subjects' Apple Watch may find more profound data. This research implies that there may be a correlation between how well the Apple Watch pairs up to the subject that wears it more often. This research also suggests that wired ECG systems of measuring heart rate may not be practical for all modes of exercise. Future research is necessary to determine the overall accuracy of the Apple Watch and how energy expenditure can be better estimated.

Apple Watches provide a convenient and valid measure of exercise HR during light-intensity, steady state exercise. Apple Watches appear to reliably overestimate energy expenditure during light steady-state exercise.

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