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Predictability of VO_{2max} using a commercially available GPS sports watch

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Predictability of VO_{2max} Using a Commercially Available GPS Sports Watch

by

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Dedication

To my mother, for supporting me every step of the way, regardless of the choices I made in life. To my father, who would have loved nothing more than to see how far I have come. To my brother and sister, for providing encouragement and advice along the way.

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To Becca, for being the greatest possible advisor any graduate student could ask for, encouraging me to always produce my best work, pushing me to pursue a Ph.D. from the first day I met you in 636, teaching me to love dogs, and becoming someone I can ask for help for the rest of my career. To Steve, for spending countless hours in the lab with me, teaching me how to run, and struggling through graduate school and life together. To Andrea, for always listening to my nutrition rants, providing unwavering support, and encouraging me to be myself in all aspects of my life. To my friends, for making me laugh when I don’t want to, being there for me during the difficult times, and supporting me no matter where I go in life.

Abstract

The purpose of this study was to examine the predictability of VO_{2max} using a GPS sports watch. Thirty participants volunteered for this study and performed a treadmill-based graded exercise test, a 15-minute submaximal outdoor run, and three additional runs of at least 30 minutes in duration while wearing a GPS sports watch. Three separate VO_{2max} values were recorded during the study: direct, predicted, and adjusted, respectively. A two-way (2 fitness groups x 3 VO_{2max} time points) repeated measures ANOVA was conducted to determine if a significant difference existed between recorded VO_{2max} values. The GPS sports watch did not accurately predict VO_{2max}. Participants were placed into two fitness groups determined by directly measured VO_{2max}. The watch was unable to accurately predict VO_{2max} for participants with a VO_{2max} of greater than 50 ml/kg/min. The watch could accurately predict VO_{2max} for individuals with a directly measured VO_{2max} of less than 50 ml/kg/min.

Structured Abstract

PREDICTABILITY OF VO_{2MAX} USING A GPS SPORTS WATCH

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Using accurate submaximal methodologies to estimate VO_{2max} is a convenient alternative to maximal exercise testing. Submaximal testing is practical because it provides a cheaper, more time-efficient method to determine VO_{2max} and allows a wider range of individuals to be tested. **Purpose:** The purpose of this study was to examine the predictability of VO_{2max} using a GPS sports watch. **Methods:** Thirty participants, 16 males and 14 females between the ages of 18 and 55, volunteered for this study. A total of three separate VO_{2max} values were recorded during the study: (a) directly measured VO_{2max}, (b) a predicted VO_{2max} value based on a 15-minute outdoor run, and (c) an adjusted predicted VO_{2max} value based on three subsequent outdoor runs of at least 30 minutes in duration. Participants came to the Running Science Laboratory at Eastern Michigan University (EMU) on two separate occasions. On day one, participants completed a treadmill-based graded exercise test (GXT) to determine VO_{2max}. Participants completed the test using a self-selected pace (mph) that was determined during a 3-minute warm-up period. The self-selected pace remained constant throughout the test while the grade increased at a rate of 2% every 2 minutes. On day two, participants arrived at EMU and completed a 15-minute submaximal outdoor run. Participants were fitted with a GPS sports watch, which was used to predict VO_{2max} based on subject characteristics (gender, age, height [in], weight [lbs.]), as well as

total distance of the run, pace, time (15 minutes), and heart rate (HR) during exercise. Participants were then required to take the watch home and record three additional runs of at least 30 minutes to produce an adjusted predicted VO_{2max} value. A two-way (2 fitness groups x 3 VO_{2max} time points) repeated measures ANOVA was conducted to determine if there was a significant difference between directly measured VO_{2max}, predicted VO_{2max}, and adjusted predicted VO_{2max}. Participants were placed into two fitness groups determined by directly measured VO_{2max} (VO_{2max} of greater than [high] or less than [low] 50 ml/kg/min). A one-way repeated measures ANOVA was conducted to determine if a significant difference in recorded VO_{2max} values was observed within groups. Statistical significance was determined using a *p-value* of .05. **Results:** Two participants (two males) were excluded from the analysis due to failing to return for visit two. The remaining 28 participants were 24.71 ± 5.69 years old, had a height of 168.94 ± 6.94 cm, and weighed 67.22 ± 14.85 kg. A statistically significant difference was observed between directly measured (55.09 ± 9.73 ml/kg/min) and predicted VO_{2max} (51.75 ± 5.16 ml/kg/min);(*p-value* < .05), directly measured and adjusted predicted VO_{2max} (50.68 ± 5.98 ml/kg/min);(*p*-value < .001), and predicted and adjusted predicted VO_{2max} (*p*-value < .05). A significant difference was observed in the high VO_{2max} group between directly measured and predicted VO_{2max} and directly measured and adjusted predicted VO_{2max} (*p*-value < .001). No significant difference was observed between predicted and adjusted predicted VO_{2max} in the high VO_{2max} group (*p*-value > .05). No significant difference was observed between values in the low VO_{2max} group (*p*-value > .05). **Conclusion:** Major limitations of this study included participants performing all activities at a self-selected pace and measuring HR using the radial pulse with an optical sensor. A self-selected pace could have led to inaccuracies in VO_{2max} prediction as participants may not have performed to their full potential. Future research could enforce stricter pace and distance requirements for additional activity recording to test both anaerobic and aerobic energy systems. Additionally, measuring HR using an optical sensor within the watch at the radial pulse has been shown to underestimate average HR values when compared to HR measurement using a chest strap. While the purpose of this study was to test the predictability of only the GPS sports watch, a lower overall average HR for a given activity could have produced overestimates of VO_{2max}.

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Chapter 1

Introduction and Background

Hill, Long, and Lupton (1924) researched the relationship between ventilation and exercise extensively in the early twentieth century. These researchers were among the first to demonstrate a ventilatory limit in response to an increase in exercise intensity, now commonly referred to as VO_{2max}, or simply the maximum amount of oxygen an individual is able to consume during exercise (Hill et al., 1924). Countless methods to estimate and directly determine VO_{2max} have been developed and validated. Regarding the simplest determination of VO_{2max}, from non-exercise (NE) data, different methodologies of estimating VO_{2max} have been developed (Bradshaw et al., 2005; George, Stone, & Burkett, 1997; George et al., 2009; Heil, Freedson, Ahlquist, Price, & Rippe,1995; Jackson et al., 1990; Schembre & Riebe, 2011; Webb, Vehrs, George, & Hager, 2004). These types of estimates typically use physical activity (PA) questionnaires and anthropometric data to create regression models that can accurately estimate VO_{2max}. While these NE models are valid measurements of VO_{2max} and can be useful in special populations such as the elderly and clinical patients, they may not be ideal for all populations.

More conventional methods of determining VO_{2max} are grounded in collecting exercise data for subjects in addition to anthropometric measures and, in some cases, questionnaire data. Protocols to accurately obtain VO_{2max} were developed as early as the 1950s and new protocols continue to emerge in the literature. In most cases, when hearing the term VO_{2max} protocol, a few familiar names come to mind such as Balke, Bruce, Ebbeling, Taylor, Margaria, and Åstrand. These are a few of the more popular protocols used in research and clinical settings. While each method differs in procedure, they all have the same end goal: to determine VO_{2max} for a subject.

Submaximal testing to determine VO_{2max} involves a particular mode of exercise, which can include a step test at a predetermined step height, regression equations using exercise data, cycle ergometer and treadmill (TM) tests, and field tests outside using a known distance such as a 1-mile track jog or a 1-mile track walk (Balke, 1963; Cooper, 1968; Ebbeling, Ward, Puleo, Widrick, & Rippe, 1991; George, Vehrs, Allsen, Fellingham, & Fisher, 1993; George et al., 2009; Kline et al., 1987; Macsween, A. 2001; Vehrs, George, Fellingham, Plowman, & Dustman-Allen, 2007; Waddoups, Wagner, Fallon, & Heath, 2008). While these exercise bouts are not always shorter in duration compared to their maximal counterparts, sub-maximal efforts are of lower intensity and in return lead to an overall better perceived experience and less psychological and physiological stress experienced by the participant. These types of tests have proven to be beneficial for special populations, specifically in clinical settings. The logistics of a submaximal test allow VO_{2max} to be estimated without collecting maximal data, which is much safer for high-risk populations such as cardiac patients. Submaximal testing has its place in clinical research however; maximal protocols are necessary for research geared towards optimizing performance and testing in elite athletes.

Prediction equations to estimate VO_{2max} are one of the most commonly used methods in both clinical and performance settings (Åstrand & Ryhming, 1954; Balke, 1963; Bradshaw et al., 2005; Cink & Thomas, 1981; Cooper, 1968; Ebbeling et al., 1991; George et al., 1993, 1997, 2009; George, Bradshaw, Hyde, Vehrs, & Hager, 2007; Heil et al., 1995; Jackson et al., 1990; Kline et al., 1987; Macsween, 2001; Margaria, Aghemo, & Rovelli, 1965;

Schembre & Riebe, 2011; Vehrs et al., 2011; Webb et al., 2014). Using prediction equations allows researchers to estimate VO_{2max} based solely on NE data or a combination of NE and exercise data that is typically obtained through submaximal tests. These characteristics contribute to an overall safer and more enjoyable testing experience for the participant, as well as a cheaper alternative to a maximal graded exercise test (GXT). In most cases, regression equations are developed using some form of submaximal testing and then validated in the same study using maximal GXT results.

Maximal tests provide a direct measurement of VO_{2max} and are regarded as the gold standard of exercise testing. However, this improved accuracy comes at a cost. Maximal tests are generally much more expensive compared to submaximal tests and impose greater risk to the participant. These tests require an all-out effort, which if executed correctly, requires participants to exercise to their maximal heart rate (HR). While this is completely safe when the necessary precautions are taken, the increased cost and risk inherently limit the populations that can be tested using a maximal protocol. Nevertheless, maximal tests have their place in research and are necessary for performance-based studies, particularly with highly fit individuals.

Similar to the research on submaximal protocols, a substantial amount of literature exists regarding maximal protocols, which has led to the development of countless methods to measure VO_{2max}. Researchers have spent decades attempting to develop protocols, and while multiple valid protocols exist today, they are often geared towards a specific population. Many of the protocols developed decades ago are still used in research today, most of which consist of some variation of a TM test using a particular speed and incline (Bruce, Kusumi, & Hosmer, 1973; George, 1996; Spackman, George, Pennington, &

Fellingham, 2001; Taylor, Buskirk, & Henschel, 1955). The main difference among protocols is whether or not participants were able to use a self-selected pace and the progression of incline throughout the duration of the exercise test (Bruce et al., 1973, George, 1996). For example, the protocol developed by Bruce et al. (1973) requires participants to begin at 1.7 mph and 10% grade and then every 3 minutes the speed of the TM increases by roughly 0.8 mph and incline increases by 2%. Depending on how conditioned the participant is, they progress through three to five stages until volitional exhaustion occurs. In contrast to this protocol, the protocol developed by George (1996) requires participants to walk at a 5% grade for 3 minutes at a self-selected pace. After the initial 3 minutes, participants are then able to continue walking at the same self-selected pace or progress towards a suitable jogging speed for an additional 3 minutes. After the initial 6-minute period that served as a warm-up, participants are then able to select a speed most comfortable to perform the maximal exercise test. This speed is held constant throughout the test and the incline is increased by 1.5% every minute until volitional exhaustion (George, 1996) While the outcome of these two protocols is inevitably the same, the difference in methodology is important in evaluating which protocol should be used for a given population. Generally, the Bruce test is used in clinical populations while the George test is used in athletic populations.

The term *wearable device* spans a broad category and includes all types of personal activity tracking monitors such as pedometers, accelerometers, smart watches, and global positioning system (GPS) watches. The technology used to monitor activity and exercise has made monumental advancements in the last decade. In the past, a pedometer, which counts the number of steps taken by an individual, was used to estimate distance traveled per day (Schneider, Crouter, & Bassett, 2004). The pedometer is a relatively simple way to monitor activity and is worn at the hip, typically placed on the pants of the individual and counts steps taken during the day through movement of the hip. In the past, pedometers often overestimated an individual's step count because movement at the hip while not walking could be misconstrued as a step. While pedometers may not be the most accurate form of measurement, studies have demonstrated the benefits of owning these types of monitoring devices by significantly increasing physical activity (PA) while decreasing body mass index (BMI) and blood pressure (Bravata et al., 2007; Kang, Marshall, Barreira, & Lee, 2009). Recent advancements in pedometer technology have led to increasingly accurate activity tracking, but many researchers have shifted towards accelerometers for activity monitoring (Abel, Hannon, Sell, Lillie, Conlin, & Anderson, 2008; Le Masurier, Lee, & Tudor-Locke, 2004, Tudor-Locke, McClain, Sisson, & Craig, 2007).

With further advancements in technology, widespread use of accelerometers for PA monitoring has been observed in all types of research settings (Abel et al., 2008; Erdogan, Cetin, Karatosun, & Baydar, 2010; Le Masurier et al., 2004, Liden, Wolowicz, Stivoric, Teller, Vishnubhatla, Pelletier, & Farringdon 2002; Reeve, Pumpa, & Ball, 2014; Scheers, Philippaerts, & Lefevre, 2012; Tudor-Locke et al., 2007). Accelerometers are small, reasonably priced, wearable devices that measure PA on a uniaxial or triaxial basis (Hanggi et al., 2013). These devices measure PA by recording duration, intensity, and frequency. Additionally, newer models, such as the ActiGraph GT3X+™ (ActiGraph, LLC, Pensacola, FL, USA), include an inclinometer that is able to detect posture during PA.

The shift from using pedometers to accelerometers in research has been an important turning point in the literature. These more advanced methods of data collection brought forth many studies in order to validate new devices, determine activity cut-points for all populations, identify the most accurate sampling periods (epochs), and determine the most appropriate site to wear the device (Kim, Beets, Pate, & Blair, 2013; Kim, Jung, Park, & Joo, 2014: Pate, Almedia, McIver, Pfeiffer, & Dowda, 2006; Romanzini, Petroski, Ohara, Dourado, Reichert, 2014; Sasaki, John, & Freedson, 2011; Sirard, Trost, Pfeiffer, Dowda, & Pate, 2005; Trost, Loprinzi, Moore, & Pfeiffer, 2011). Accelerometers such as the Actigraph GT1M™ and GT3X™ are particularly useful in pediatric populations as they are able to measure PA on one to three axes instead of only counting steps. In a large of over 2000 British children, van Sluijs et al. (2008) found that roughly 70% of children did not meet PA guidelines when measured using an Actigraph accelerometer over the course of seven days. While research is ongoing as to the validity of these accelerometers, research on GPS, exercise based video games (exergames), and social media applications are emerging, which has led to increased PA in previously lacking populations (Boulos & Yang, 2013; Kerr et al., 2012; Le Faucheur, Abraham, Jaquinandi, Bouyé, Saumet, & Noury-Desvaux, 2007; Le Faucher, Abraham, Jaquinandi, Bouyé, Saumet, & Noury-Desvaux, 2008).

GPS, exergames, and social media are the present and future platforms to promote PA in all populations. Wearable devices equipped with GPS technology allow users to accurately record activities, specifically data on distance, pace, total time, and HR during the exercise bout. Additionally, these devices can determine personal bests and are a convenient way to compare training history and progress over the course of weeks, months, and years. GPS research began in the late 1990s with Schutz and Chambaz (1997) investigating whether GPS could be an accurate tool to determine walking and running speed in humans. In this study, a male was equipped with a GPS device and then required to walk, run, and cycle around a track at different speeds. Schutz and Chambaz found that GPS technology was useful for speed assessment. However, walking accuracy needed to improve. The researchers concluded that GPS technology could potentially be a useful tool to measure PA, but future research is necessary (Schutz & Chambaz, 1997). This initial study sparked an abundance of research on accuracy, validity, reliability, and ultimately the use of GPS technology to measure PA, specifically in relation to the environment. One of the first studies to analyze the accuracy of GPS devices was conducted by Le Faucheur et al. (2007). The authors found that when using a low-cost commercially available GPS (Garmin 60 GPS™), outdoor walking distance could be accurately measured. Additionally, the authors were able to conclude that resting and walking bouts could be identified using GPS and both speed and distance of the exercise could be accurately determined (Le Faucher et al., 2007). Although promising, GPS technology is still relatively new in the literature, and further research is necessary to validate devices and establish standards of measurement.

GPS technology is necessary for social media applications and exergames to be utilized for everyday activity. While this is relatively novel research, the literature has shown that GPS exergames can be a motivational tool to promote exercise in youth while simultaneously acting as a video game to capture attention. These benefits target two major problems in adolescents: lack of physical activity and a short attention span. The research indicates that GPS exergames could act as an alternative or in conjunction with conventional outdoor activities to promote PA in youth (Boulos & Yang, 2013). Additionally, research on the Nintendo Wii™ in older adults indicate that exergames can be used as a motivational tool to increase in PA, cognition, and psychosocial outcomes as well as a safe, practical way to exercise (Chao, Scherer, & Montgomery, 2014). In addition to exergames, social media applications such as the Garmin™ and Fitbit™ applications allow users to compare PA to their friends, thus creating a competitive atmosphere in order to further promote exercise in all populations. Future research on the role of such applications is necessary and potentially a method to combat the ever-growing obesity epidemic across America in all populations.

The validity and reliability of any advancement in technology is a major concern in research. However, recent studies have shown that GPS devices can accurately determine location in unobstructed conditions with some devices still being able to monitor location in obstructed environments (Duncan, Stewart, Oliver, Mavoa, MacRae, Badland, & Duncan, 2013). Additionally, Wieters, Kim, and Lee (2012) tested the accuracy of four GPS models for outdoor recording of PA and found that the units demonstrated an acceptable level of reliability and validity to be used in research on PA. An abundance of research has emerged on GPS and accelerometry, specifically on how this technology can be utilized to examine the relationship between PA and the environment. In general, the research shows the importance of preserving green space, which is often used for vigorous activity (Almanza, Jerrett, Dunton, Seto, & Pentz, 2012; Coombes, van Sluijs, & Jones, 2013; Jones, Coombes, Griffin, & van Sluijs, 2009; Lachowycz, Jones, Page, Wheeler, & Cooper, 2012; McCrorie, Fenton, & Ellaway, 2014; Wheeler, Cooper, Page, & Jago, 2010). While these studies have demonstrated the important relationship between the environment and PA in children, several other studies have incorporated the use of GPS technology in PA monitoring (Oreskovic, Blossom, Field, Chiang, Winickoff, & Kleinman, 2012; Quigg, Gray, Reeder, Holt, & Waters, 2010; Rainham, Bates, Blanchard, Dummer, Kirk, & Shearer, 2012; Rodríguez et al., 2012; Southward, Page, Wheeler, & Cooper, 2012). These studies, which generally focused on children, incorporate the use of GPS and accelerometry to record the contribution of walking to and from school to daily PA as well as other walking bouts. In a review conducted by Maddison and Mhurchu (2009), the use of GPS in over 35 studies that are directly related to human movement is documented. The authors found that while GPS was used extensively in the research and can be a useful tool in measuring PA, future research is necessary. Specifically, research that focuses on the interaction of individuals with their environment, effectiveness of an intervention, adjustments in PA patterns, and improving data analysis methods (Maddison & Mhurchu, 2009).

Recently, a few abstracts have emerged that utilize GPS based smart watches to predict VO_{2max} (Johnson & Beadle, 2017; Snyder, Willoughby, & Smith, 2017; Willoughby, Snyder, & Smith, 2017). These studies incorporated the use of Polar™ and multiple Garmin™ smart watches and compared a directly measured VO_{2max} obtained via a maximal GXT to a predicted value following either a resting or submaximal fitness test. One study used a Polar FT60™ smart watch to predict VO_{2max} through a fitness test which required participants to lie down while wearing the watch for 5 minutes while resting HR is collected (Johnson & Beadle, 2017). HR data, combined with participant's characteristics, such as gender, age, weight, and height, are used to predict VO_{2max}, which then adjusts following additional activity input. The results indicated that the fitness test overestimates VO_{2max} by roughly 10% when compared to a directly measured VO_{2max} test obtained in lab (Johnson & Beadle, 2017). Two recent studies have tested the predictability capability of the V800 Polar™ smart watch and two different GPS smart watches developed by Garmin™: the Garmin Forerunner 230™ and the Garmin Forerunner 235™. The main difference between these two Garmin™ models is that the 230 utilizes a chest strap to record HR while the 235 uses an optical sensor within the watch to record HR via the radial pulse. The first study compared the accuracy of VO_{2max} prediction using the V800 (Polar™), the 230, and the 235

(Garmin™). Similar to the study mentioned above, a directly measured VO_{2max} value obtained using a standard TM based GXT was compared to a predicted value from the three smart watches. The V800 predicts VO_{2max} following a resting HR variability test, which requires participants to lie down and rest for 5 minutes. The 230 and 235 predict VO_{2max} following a 10-minute outdoor run completed using a self-selected pace (Snyder et al., 2017). Significant differences between directly measured and all predicted VO_{2max} values were observed. The results indicated that the smart watches typically overestimated VO_{2max} in males, while an overestimate and underestimate, depending on the watch, was found in females (Snyder et al., 2017).

In a similar study, predicted VO_{2max} values were compared using the results of a 10-minute self-paced outdoor run while wearing the Garmin Forerunner 230™ and the Garmin Forerunner 235™. As mentioned above, the 230 utilizes a chest strap to record HR while the 235 uses an optical sensor that records HR via the radial pulse. This difference in HR technology led to differences in average HR recorded during the 10-minute run (Willoughby et al., 2017). Participants completed the outdoor run while wearing a chest strap and both watches. No significant difference in maximum HR, distance, pace, or kcal were observed during exercise for males and females. However, average HR recorded by the 230 was significantly higher for both males and females. In females, no significant difference in predicted VO_{2max} was found between devices. However, in males, a significant difference was observed with the 230 predicting a lower VO_{2max} value. The authors concluded that the average HR recorded using the 230 was significantly higher for both genders and that the predicted VO_{2max} value from the 230 was lower than the 235 in men due to differences in average HR during activity (Willoughby et al., 2017).

Statement of the Problem

GPS technology is fairly new in terms of PA measurement and exercise testing, and while a wide variety of devices have been developed for recreational and professional use, research on available commercial devices is lacking. With new and improved products emerging on the market each year, the literature regarding reliability and validity of such devices is falling behind. Major companies such as Garmin™, Polar™, and Fitbit™, have developed devices that act as pedometers, accelerometers, and include GPS technology to document PA. Some of these devices have been validated but with new products on the horizon, research is necessary to determine if these devices can accurately measure PA. Companies have and continue to develop wearable devices such as smart watches, which now claim to be able to estimate an individual's VO_{2max} using a regression equation, which is inaccessible to the public. Since these companies do not include references or provide any literature on the reliability and accuracy of said devices, research is necessary to assess these claims and to determine how accurately a smartwatch can estimate VO_{2max} based on submaximal exercise. These regression equations likely estimate VO_{2max} based on several characteristics including an individual's gender, age, weight, height, and maximal HR as well as a single exercise bout that records time, pace, distance, and HR during the activity. The ability of these devices to accurately estimate VO_{2max} is beneficial for future research as it will lead towards a convenient way to obtain VO_{2max} in populations who may be unfit or incapable of participating in maximal exercise such as clinical patients, the elderly, and pediatric populations. Submaximal tests are a safer alternative for these special populations and potentially have increased accuracy for pediatric populations who may not complete or produce a true VO_{2max} during testing. Additionally, these advanced features that newer models are equipped with serve as a great tool to motivate the user to improve their fitness levels and drive up their VO_{2max} value and personal bests. With validation of GPS smart watches, this method can be utilized in research and serve as a substitute for the more expensive alternative of maximal testing using metabolic carts and portable units.

Justification and Significance

Research is necessary to validate emerging technology to test how accurately VO_{2max} can be predicted using a GPS sports watch. This study evaluated the Garmin Forerunner 235's™ ability to predict VO_{2max} based on a 15-minute submaximal outdoor run and how this value changes after additional activity input. This research is important, as it assessed claims made by Garmin™, which could lead towards future research in VO_{2max} prediction technology and, hopefully, lead to improvements in wearable device technology. With these advancements, wearable devices may play an important role in future research regarding physical activity measurement, particularly of VO_{2max} without the expense and risk of TM-based maximal exercise testing. This could lead to a wider range of individuals being able to participate in exercise testing as the risk and cost will be reduced using GPS-based wearable devices to record physical activity and predict VO_{2max}.

Purpose of the Study

The purpose of this study was to examine the predictability of VO_{2max} using a GPS sports watch. Three separate values for VO_{2max} were obtained: (a) directly measured VO_{2max}, (b) a predicted VO_{2max} value based on a 15-minute outdoor run, and (c) an adjusted predicted VO_{2max} value based on three subsequent outdoor runs of at least 30 minutes in duration.

Research Hypotheses

Based on the existing literature on estimations of VO_{2max}, GPS technology, and minimal research regarding the Garmin Forerunner 235™, the researchers hypothesized the following:

1. It was hypothesized that the Garmin Forerunner 235™ will not be accurate predictor of VO_{2max} for the general population.
2. It was hypothesized that the Garmin Forerunner 235™ will be an accurate predictor of VO_{2max} for individuals with a VO_{2max} of less than 50 ml/kg/min.

Definition of Terms

1. VO_{2max}/VO_{2peak}: The maximum amount of oxygen that can be inhaled and utilized by the body, specifically muscular tissue, during exercise. For this study, relative VO_{2max} was used that is expressed in ml/kg/min to incorporate body weight as a factor.
2. Volitional exhaustion/fatigue: The point at which a participant is no longer able to maintain the required intensity to continue exercising at a particular speed and incline on the treadmill.
3. GPS: Global positioning system that is used to determine location on Earth using a satellite.

Limitations

1. Using an optical sensor to record radial pulse as a measurement of heart rate instead of a chest strap can potentially lead to inaccurate values for heart rate. If the watch slightly slips on the wrist or moisture exists between the sensor and skin due to accumulation of sweat during exercise, inaccurate heart values could be recorded. To

avoid this limitation, the researcher ensured that the watch was secured tightly on each subject's wrist before testing.

2. Using GPS to determine distance traveled and pace for an exercise bout is largely dependent on signal strength and accuracy of the GPS device. Certain precautions were taken, such as waiting for the watch to read "GPS Ready" before beginning exercise. The GPS signal is indicated by five increasingly large vertical bars in the top corner of the watch display similar to a cell phone's reception. When all five bars are lit up green, the watch vibrates and reads "GPS Ready." Once this occurs, the subject can begin exercising.
3. Using a self-selected pace for an outdoor run could potentially allow unmotivated participants to not perform the test to their full potential. To minimize this risk, only individuals with past experience in running were recruited for this study.
4. Additional activity input beyond the initial 15-minute outdoor run was not specified beyond a time requirement of 30 minutes. This led to the majority of participants running for exactly 30 minutes for each run. While this is not considered a limitation, as Garmin™ does not specify the type and duration of additional runs required to predict VO_{2max}, participants could have been required to perform different types of runs by adjusting pace and time to include shorter runs at a faster pace and longer runs at a slower pace to assess the anaerobic and aerobic energy systems.

Chapter 2

Review of Related Literature

A variety of methods that encompass estimating, calculating, and obtaining VO_{2max} directly have been developed over the last century. While these techniques have been validated, modern methodologies are emerging that allow for exciting new ways to collect data outside of the laboratory setting. With the explosion in popularity of wearable devices made by companies such as Garmin™, Fitbit™, and Polar™, research must be conducted in order to assess the claims made by these and other companies and determine the validity of these devices.

A wearable device is a piece of equipment that can be worn on the body, generally on the wrist as a watch or at the waist in the case of a pedometer or accelerometer. These devices incorporate computer technology, heart rate (HR) monitors, and in more advanced cases, a global positioning system (GPS). Because of the large increase in popularity of these devices, companies are developing more advanced models which now include methods to predict various race finishing times (5k, 10k, etc.) and estimate VO_{2max} based on a brief run outdoors while wearing the watch.

While companies do not typically publish the particular equation they use to estimate VO_{2max}, it can generally be thought of as a regression model that uses multiple variables to estimate VO_{2max}. These variables include, but are not limited to, age-predicted max HR, age, weight, height, body mass index (BMI), gender, recorded HR during exercise, distance traveled and pace during the exercise bout, and total time of the activity. Whether or not these newly developed devices are indeed a valid measurement of VO_{2max} has yet to be documented in the literature. Research is necessary in order to establish validity so these devices may be used for future research. A wearable device could be a valuable tool for researchers in all populations as it will lead to improvements in estimating VO_{2max} based on actual exercise data and is a much cheaper, time efficient alternative to laboratory measurement.

Submaximal Exercise to Determine VO_{2max}

Research on submaximal exercise spans several decades and includes many of the widely recognized names in exercise physiology including Åstrand, Balke, Cooper, Ebbeling, and Margaria. Protocols developed in the 1950s and 60s are still being used today to estimate VO_{2max} based on submaximal data. In 1954, Åstrand and Ryhming tested 50 men and 62 women to develop a simple submaximal test to produce information regarding aerobic capacity. Using their results, the authors developed a nomogram that uses an individual's HR and workload to estimate oxygen intake based on submaximal exercise (Åstrand & Ryhming, 1954). Because of the positive linear relationship that exists between HR, workload, and oxygen intake, VO_{2max} can be estimated using gender and HR at any given submaximal workload. In 1981, as a follow up to Åstrand and Ryhming's research, Cink and Thomas sought to validate the Åstrand-Ryhming nomogram that is used to predict VO_{2max}. The authors tested 40 male students between the ages of 18 and 33. Participants were required to perform a submaximal and maximal exercise test from which the results were compared to evaluate validity. Cink and Thomas concluded that there was no statistically significant difference between VO_{2max} predicted using the Åstrand-Ryhming nomogram with age correction factors and VO_{2max} obtained using a maximal cycle ergometer protocol (Cink & Thomas, 1981). Further expansion on Åstrand and Ryhming's research was conducted in

2001 by Macsween who examined the reliability and validity of the Åstrand nomogram by comparing this method to linear extrapolation using a HR/oxygen intake plot based on the theoretical maximum HR (Macsween, 2001). The study consisted of testing 28 volunteers ages 18–50 years old in which all subjects performed a maximal graded exercise test (GXT) using the Bruce treadmill (TM) protocol (Bruce et al., 1973) while wearing a portable gas analyzer and a HR monitor. Two trials were performed per week over the course of 4 weeks and average oxygen consumption was measured at three submaximal HRs (120, 146, and 172 bpm for females and 122, 146, and 170 bpm for males). From these oxygen consumptions values, three VO_{2max} values were predicted and then averaged using the Åstrand nomogram (Macsween, 2001). For extrapolation, a linear regression equation was generated to be fitted over the HR/oxygen consumption plot and the equation was solved for age-predicted max HR, which yielded an extrapolated VO_{2max}. Macsween (2001) found that submaximal data can be accurately used in both a clinical and research setting to predict VO_{2max}.

In 1963, Balke conducted a three-part study to develop a running test protocol that could be used to evaluate physical fitness out in the field for the Federal Aviation Agency. Balke examined how physical conditioning improved working capacity in several areas including TM and cycle ergometer performance as well as completion time for two and three mile runs. Eight male subjects were tested for part one of the study in which work capacity on a TM was examined after a 10-week training period. Work capacity was measured using a procedure previously developed by Balke in 1959 (Balke, 1963), which involved a TM protocol of increasing workload. Participants then ran several running bouts varying in duration, which allowed oxygen intake to be calculated from average velocity for each run. In part two of the study, nine untrained males performed a similar TM test followed by runs of two and three miles in length. Average velocity of the outdoor runs was used to calculate oxygen intake, which was compared to the VO_{2max} from the maximal TM test. Part three of the study tested 34 high school boys who performed a 15-minute TM test in which participants were asked to achieve the greatest distance possible in 15 minutes (Balke, 1963). Balke found there exists a linear relationship between oxygen intake per unit body mass and running velocities. The author also developed a field test to assess physical fitness which consisted of a 15-minute run about a known distance. Velocity could then be computed from distance and time and therefore estimate VO_{2max} (Balke, 1963).

Based on Balke's (1963) field testing research, Cooper (1968) sought to slightly modify the Balke field test and then compare the results to a VO_{2max} value obtained using a maximal GXT. The study consisted of testing 115 US Air Force males with an age range of 17–52 years old. Instead of the 15-minute field test presented by Balke (1963), participants performed a 12-minute field test on a flat surface around a one-mile course. After the field test, participants performed a maximal GXT using methods presented by Taylor (1955) which consisted of several 3 minute intervals that were each separated by a rest period of 10 minutes. Incline and grade were increased with each interval based on the participant's fitness level with an attempt to exhaust participants within three or four exercise intervals (Cooper, 1968). Cooper found that field testing is an accurate method to predict VO_{2max} in young individuals if the participant is well motivated. These results are beneficial because a field test is a free alternative to maximal GXT testing and can be performed in a group setting. However, the accuracy of predicted VO_{2max} is dependent upon individual motivation (Cooper, 1968).

In 1965, Margaria et al. examined indirect methods to determine VO_{2max} by using HR values measured during a bench step-test. By using a slightly more complex nomogram than originally developed by Åstrand and Ryhming (1954), Margaria et al (1965) tested several subjects ages 9 to 47 years old to compare directly measured VO_{2max} to values estimated using HR, step frequency, and step height. VO_{2max} was estimated using an equation that required an upper limit for HR (160, 180, or 200 bpm), step frequency (15 or 25 times/min), and a bench height of 40 cm (Margaria et al., 1965). The authors concluded that the directly measured VO_{2max} values were in agreement with the VO_{2max} values estimated from a step-test using the nomogram (Margaria et al., 1965). Similar to the protocol used by Margaria et al., Webb et al (2014) aimed to develop an individualized step test to predict VO_{2max} in fit, college-aged individuals. Eighty relatively fit subjects, 38 males and 42 females, ages 18–29 years old were tested for the purpose of this study. Before any exercise testing took place, subjects completed a perceived functional ability (PFA) and a physical activity readiness questionnaire (PAR-Q). All subjects then performed a submaximal step test and a maximal GXT using a TM protocol. The step test used a single step that ranged in height from 10 to 16 in. based on the individual. Before the test, 75% of maximal HR was determined and then set as an endpoint for the test. The test consisted of 2 minute stages and at the end of each stage, stepping frequency increased by 5 steps/min while step height remained the same. Each subject then completed a maximal GXT using a protocol developed by George et al. (2009; Webb et al., 2014). From the results, the authors developed an individualized step test that can accurately predict VO_{2max} in college-aged males and females using a prediction equation that utilizes recovery HR as well as non-exercise (NE) data from questionnaires (PFA and a modified PAR-Q; Webb et al., 2014).

VO_{2max} has been accurately predicted based on a simple one-mile track walk using subject characteristics. Kline et al. (1987) developed a field test in which subjects were required to walk around a track for one mile and from this time, VO_{2max} can be estimated using test time, gender, age, and body weight. The authors tested 390 healthy individuals, 183 males and 207 females, ages 30–69 years old. Initially, subjects performed a maximal GXT using a protocol of constant speed and increasing incline to determine VO_{2max}. This value was then compared to the estimated value from two one-mile track walks separated by at least one day in which test times were required to be within 30 seconds of each other. HR was recorded every minute during the walking bout and at the end of each 0.25-mile segment. From the data collected, four HR values were used to generate regression equations that could estimate VO_{2max} (Kline et al., 1987). Cross-validation groups were also used in the study to develop the VO_{2max} regression equations. From the results, six different equations were created that estimated VO_{2max} based on test time for the one-mile walk, HR values, weight, gender, and age. Kilne et al. (1987) concluded that all six equations shared similar accuracy and can be used to estimate VO_{2max}.

Similar to Kline et al.'s research, George et al. (1993) developed a submaximal one-mile track jog protocol that could accurately estimate VO_{2max} in college-aged individuals. Additionally, the authors tested the accuracy of the previously developed 1.5 mile run that is used to estimate VO_{2max} in college-aged individuals. The study consisted of testing 149 college students, 88 males and 61 females, ages 18–29 years old. All subjects performed a maximal GXT to obtain a VO_{2max} value. Then, 106 subjects performed the one-mile track jog protocol while 96 performed the 1.5-mile run. The one-mile jog could be performed on the same day as the maximal GXT as it is a steady-state, submaximal test. However, the 1.5 mile run and maximal GXT were performed on separate days. The maximal GXT performed by all subjects consisted of a TM protocol at a self-selected constant pace between 5.0 and 7.0 mph with a 2.5% increase in grade every minute after a 3-minute warm-up period at the self-selected pace. The one-mile track jog consisted of a self-selected pace with HR and speed upper limits. Test times had to be greater than 8 minutes for males and nine minutes for females. Final HR values had to be less than 180 bpm to ensure a submaximal level of effort. For the 1.5 mile run, subjects were required to complete the test as fast as possible. George et al. (1993) concluded that the one-mile track jog is an acceptable alternative to the 1.5-mile run for predicting VO_{2max} and the one-mile jog is a safer, more enjoyable method compared to the 1.5-mile run and other field tests.

A familiar test that is still used today in clinical and research settings is the Ebbeling protocol which was developed by Ebbeling et al. in 1991. The protocol consists of a submaximal exercise test that uses HR, TM speed, age, and gender to estimate VO_{2max}. Ebbeling et al. tested 166 volunteers, 77 males and 89 females, ages 20–59 years old in order to create and cross-validate an equation obtained using submaximal data to estimate VO_{2max}. All subjects performed an exercise test which consisted of three stages of four minutes in duration at 0, 5, or 10% grade. The walking pace was kept constant at 2, 3, 4, or 4.5 mph. After completion of the three stages, the test progressed into a maximal GXT to obtain a VO_{2max} value which consisted of either walking at the same speed or running at a higher speed with a 2.5% increase in grade every two minutes until volitional exhaustion was reached (Ebbeling et al., 1991). HR was measured using an electrocardiogram (ECG) and rate of perceived exertion (RPE) was recorded using a 15 point Borg scale at the end of each stage. Subjects were then randomly placed into either an estimation or validation group. This method allowed regression equations to be generated based on submaximal data and then validated using a separate group's data. From these results, Ebbeling et al. (1991) developed an accurate equation that could be used to estimate VO_{2max} using a single stage, submaximal TM protocol. The authors concluded that this was a time-efficient method to determine VO_{2max} for low risk individuals.

Further expanding on Ebbeling et al.'s research, Waddoups et al. (2008) set out to determine if the single-stage submaximal protocol previously developed by Ebbeling et al. in 1991 could accurately predict VO_{2max} at the lower (50% HR max) and higher (70% HR max) extremes of the HR testing range. In total 34 subjects, 17 males and 17 females, ages 18–55 years old were tested in this study with all subjects completing a submaximal exercise test and 22 subjects completing a VO_{2max} test. Testing consisted of three separate sessions with the first session to allow familiarization with the protocol and to determine TM speeds that would produce HR values in the low and high ranges as described above. Session two was the first submaximal TM test in which subjects were randomly assigned to either the low or high intensity group with the other test being completed during the third testing session. For submaximal testing, the protocol developed by Ebbeling et al. (1991) was used which required subjects to walk for three minutes at a grade of 5% after a warm-up period at 0% grade. The same procedure was used during session three with the opposite intensity test being performed. For both tests, HR was recorded to be used in estimating VO_{2max}. A VO_{2max} test was also performed after the submaximal test during the third session of exercise testing. The authors found a significant difference in VO_{2max} when estimated using low intensity (50%) versus high intensity (70%) results. Waddoups et al. (2008) suggested that the best predictive validity for the Ebbeling protocol exists in the lower to middle HR ranges.

Using the protocol developed by Ebbeling et al., George et al. (2009) worked to improve the protocol and develop a more inclusive submaximal TM test that could include jogging and running as other options for healthy adults. In total, 100 subjects, 50 females and 50 males were used for data analysis. Initial anthropometric data were collected and subjects were then required to complete a PFA and a modified PAR-Q. Subjects then submitted to a submaximal TM test in which subjects exercised at a self-selected pace within a defined interval while progressing through three 4-minute stages. The stages increased in intensity from walking (3.0-4.0 mph) to jogging (4.1-6.0mph), and finally to running in stage three (>6.0 mph). The test was stopped when 70% of maximal HR was reached. After completion of the submaximal exercise test and a 2-5-minute cooldown period, subjects performed a maximal GXT using the protocol developed by George et al. (1997). The authors concluded that the submaximal TM test used in this study can accurately predict VO_{2max}. The benefit of this modified version of the Ebbeling test is that individuals are allowed to walk, jog, or run at a submaximal effort level in order to estimate VO_{2max} which is of particular use in healthy adults with higher fitness levels (George et al., 2009).

Developing accurate submaximal means to determine VO_{2max} is particularly important for special populations who may not be able to perform maximal exercise. Tests which elicit a submaximal effort are generally much safer by imposing less risk on the individual. Additionally, submaximal measurements are a cheaper, time-efficient alternative to laboratory testing using a metabolic cart. The combination of these benefits allows submaximal testing to be ideal for research in clinical patients where safety is the primary concern during testing.

Maximal Exercise to Determine VO_{2max}

The relationship between oxygen consumption and work rate was first discovered by Hill et al. (1924). A.V. Hill was the main subject with the incorporation of a few others throughout the course of the study. The test consisted of running around an outdoor, all grass track which was roughly 90 meters in length. The pace of the individual was determined by recording the amount of time elapsed for each consecutive trial. Oxygen and carbon dioxide values were recorded in cc/min. to be used to calculate the respiratory quotient and ventilation was calculated in L/min. A total of 14 trials were performed on Hill and the authors were able to conclude a relationship between oxygen intake and work rate exists. Hill et al. (1924) found that oxygen intake increases directly as a result of increased speed and that a maximum can be reached at a certain point of exercise (VO_{2max}). Although there exists much debate on the topic, the authors concluded that when a maximum effort is reached it is due to the inability of the circulatory-respiratory system as opposed to the need for greater amount of oxygen (Hill et al., 1924).

Research to develop protocols to elicit VO_{2max} is ongoing and dates back to the 1950s when Taylor et al. (1955) documented the methods used in their lab for determining VO_{2max} as well as particular limitations and potential use in a research setting. Data for this study were recorded over the course of several separate studies and in total the results of 115 subjects were used to draw conclusions. All subjects were males with a total of 27 soldiers and 46 volunteers from the University of Minnesota ages 18–35 years old. All subjects were considered to be fit individuals and were required to be present for three to five days of initial testing to determine a work rate that would elicit a VO_{2max}. On the first day of testing, a grade was established that would produce a maximal effort on a separate day. This was accomplished using scores from the Harvard Fitness Test (Taylor et al., 1955). On the second day of testing, subjects were required to walk at 3.5 mph at 10% grade for as little as 10 minutes and as long as one hour. After finishing the walking portion of the test, subjects then ran at 7.0 mph for 3 minutes at 10% grade while respiratory gases were collected to determine VO_{2max}. On the final day of testing, the same protocol from day two was followed but instead subjects ran at a grade of 12.5%. Respiratory gases were again collected and VO_{2max} values from days two and three were compared to evaluate the difference. If the scores were in agreement (difference of <150 cc/min or 2.1 cc/kg/min), a VO_{2max} value was produced based on the work rate. If the scores differed by more than the previously described values, a fourth visit was added to establish a grade that would produce similar values. The authors concluded that a protocol of increasing incline is the most efficient way to elicit VO_{2max} whereas increasing the speed while keeping the grade constant did not always lead to an increase in oxygen consumption (Taylor et al., 1955).

One of the most common VO_{2max} protocols used in both clinical and research settings is the Bruce protocol developed by Bruce et al. (1973). The study, which presents five criteria to measure VO_{2max}, uses data spanning a period of over nine years and 10,000 tests to develop a protocol that could be used in all populations to produce a VO_{2max}. The purpose of the study was to provide evidence of the 5th criteria for evaluating VO_{2max} which, briefly, is to provide normal standards and reliable methods to measured VO_{2max}. The remaining four criteria are: 1.) focusing on the use of large muscle groups to perform dynamic exercise, 2.) start with a submaximal workload that progresses towards a maximal effort using incremental stages of increasing workload until volitional exhaustion, 3.) a safe test that proposes minimal risk to the participant, and 4.) provide accurate results in a time-efficient manner for the both the participant and the researcher (Bruce et al., 1973). The results consist of previously measured data on a total of 295 subjects, which include 85 males, 144 females, and 66 young men and women (< 45 years old). Subjects were placed into either a physically active or sedentary group. A multistage TM test was used to determine VO_{2max} for subjects which consisted of several three minute stages beginning at 1.7 mph and 10% grade (Bruce et al., 1973). The speed and grade of the TM was then increased every 3 minutes with no resting periods until subjects were no longer able to continue. Bruce et al. concluded that the protocol developed is a reliable and safe method when administered correctly to measure VO_{2max} and is of particular use in clinical populations. The Bruce protocol is still widely used today, however, alternative protocols have been developed in recent years that are more suited towards healthy individuals and performance testing (George, 1996; George et al., 2007; Spackman et al., 2001).

In 1996, J.D. George devised a protocol geared towards college-age individuals that can accurately measure VO_{2max} using a more personalized approach. The study consisted of testing 126 college students, 52 males and 54 females, ages 18–29 years old for part one of the study and 20 additional subjects for part two. Before any exercise testing took place, subjects were required to complete a PAR-Q and anthropometric data was collected. Then, subjects were placed into either a validation group or a test-retest reliability group. Both groups performed a maximal GXT on a TM in which subjects ran at a self-selected pace that was held constant throughout the test with a 1.5% increase in grade every minute. The test was ended when subjects could no longer continue and experienced volitional exhaustion. The author determined that this particular protocol was easy to follow and is more realistic for college-age students because of its personalized approach. George also concluded that

VO_{2max} could be accurately measured when following this time efficient protocol, now deemed the ASU protocol, as total test time lasted roughly 4–8 minutes following a six-minute warm-up (George, 1996).

Continuing George's research, Spackman et al. (2001) investigated VO_{2max} protocol preference by comparing the Bruce protocol (Bruce et al., 1973) to the ASU protocol (George, 1996). In total, 34 active students, 17 males and 17 females, ages 18–29 years old were used for the purpose of this study, all of which were unfamiliar with VO_{2max} testing protocols. Initial anthropometric data were collected and all subjects completed a PAR-Q. Subjects were then informed of all testing protocols and were allowed to exercise wearing the one-way breathing apparatus in order to gain familiarity with the device. All subjects performed the ASU and Bruce maximal GXT TM protocols on two different occasions that were separated by three to six days. In both cases, subjects completed a questionnaire that addressed their preferred protocol (Spackman et al., 2001). In addition to rating satisfaction of the protocol, subjects also noted whether or not the grade and speed of each protocol was preferred and more individualized to their fitness level. The questionnaire consisted of questions using a Likert scale (1 to 7) and lastly subjects chose which protocol they would prefer to perform again, if necessary, two days later. The authors were able to make several conclusions based on the results of this study. Most notably, 93.8% of subjects who participated in the study preferred the ASU protocol over the Bruce protocol if required to perform an additional VO_{2max} test two days later. Spackman et al. (2001) also concluded that the ASU protocol is preferred as it allows participants to self-select a pace that is comfortable to run at and is overall a more individualized experience for relatively fit college-aged individuals.

In 2007, J.D. George further expanded his research on the ASU protocol by developing a regression model to predict VO_{2max} in a broader range of individuals. One-hundred participants, 50 females and 50 males, ages 18–65 years old were tested for the purpose of this study. All subjects performed the ASU maximal GXT protocol developed by George (1996). The protocol, which is previously described above, was used to measure VO_{2max} after a warm-up period of 5–10 minutes. These results were then used to generate a regression model that can predict VO_{2max} using gender, age, body mass index (BMI), TM speed, and TM grade. George et al. (2007) found that the regression model developed in the study can accurately predict VO_{2max} in a wider age range of individuals (18–65 years old) using results from the ASU protocol.

Maximal exercise testing, while intense in nature, can be performed safely when conducted by an experienced individual who assures that the necessary precautions are taken. Maximal measurements are of particular importance for performance research where accuracy is the primary concern. While several protocols for maximal testing exist, selecting the appropriate protocol that is best suited for the desired sample is necessary for any research study to produce accurate results. VO_{2max} tests are the gold-standard for determining and individual's cardiorespiratory fitness and should be used as the criterion measurement for any validation research.

Estimation of VO_{2max}

Several techniques exist to estimate VO_{2max} based on non-exercise (NE) data and predict VO_{2max} using regression equations centered around PA questionnaires (Bradshaw et al., 2005, George, 1997, Heil et al., 1995, Jackson et al., 1990, Schembre & Riebe, 2011).

These methodologies are of particular use in populations who are unfit for PA as exercise data is not required to estimate VO_{2max}. Research on this subject emerged in the 1990s when Jackson et al. (1990) tested several groups of subjects who were employees at the Johnson Space Center for NASA. The authors aimed to evaluate whether or not models to predict VO_2 using NE data were valid estimates of cardiorespiratory fitness (Jackson et al., 1990). In this study, estimates obtained using the NE models were compared with results obtained from a maximal GXT. Although there were several groups of subjects used in the study, a total of 2009 subjects were tested, 1,814 males and 195 females. Of this large sample, two groups were formed for the study, a validation group (*N* = 1,532) and a cross validation group (*N* = 467). Anthropometric data were collected and all subjects completed a questionnaire before any exercise testing took place (Jackson et al., 1990). All subjects completed a maximal GXT using the Bruce TM protocol while wearing a 12 lead ECG to record HR, which was recorded during the last 15 seconds of each minute. Submaximal data was also used and recorded only for the last minute of the first three stages of the Bruce TM test. From these results, a total of four NE regression models were generated (two for males and two for females). These equations predict VO_{2peak} using only NE data, which included either percent body fat or BMI, age, and a value corresponding to the answers recorded from the PAR-Q (Jackson et al., 1990). Using these regression models the authors concluded that the NE models can accurately estimate VO_{2peak}. Depending greatly on the fitness level, the equations were more accurate for individuals of lower fitness status and should not be used to estimate VO_{2peak} aerobically fit individuals. In some cases, these models were a better estimate of VO_{2peak} than values predicted using the Åstrand nomogram (Jackson et al., 1990).

In 1995, Heil et al. worked to improve the accuracy of existing NE regression models that are used to predict VO_{2peak} previously developed by Jackson et al. (1990). The study consisted of testing 439 healthy volunteers, 210 males and 229 females, ages 20 to 79 years old. Subjects were randomly placed into either a validation group (*N* = 374) or a cross-validation group (*N* = 65;Heil et al., 1995). Anthropometric data were recorded prior to exercise and all subjects rated the amount of PA performed in the past month on a scale of 0 to 7. All subjects then performed a maximal GXT and HR was recorded using an ECG (>40 years old) or a Polar™ HR monitor (< 40 years old). Using subject characteristics including anthropometric data, specifically body fat percentage, the authors developed regression models that could accurately predict VO_{2peak} (Heil et al., 1995). These newer models were of comparable accuracy to the older models presented by Jackson et al. (1990) and those developed to predict VO_{2max} using exercise data from the one-mile walk test (Kline et al., 1987). As previously observed in 1990, the authors again found that the regression model struggled to predict VO_{2peak} in aerobically fit individuals (relative VO_{2max} > 54 ml/kg/min) due to sharing similar characteristics such as fitness level, gender (male), and weight (Heil et al., 1995).

To further improve accuracy of estimation techniques using regression models, George (1997) created a questionnaire that could be used in place of exercise data combined with subject characteristics to predict $VO_{2max.}$ The authors also compared the accuracy of new NE regression models to those previously developed. One-hundred college students, 50 males and 50 females, ages 18–29 years old participated in this study. Prior to exercise testing, all subjects were required to complete a PAR-Q and a PFA questionnaire. The PFA questionnaire is designed to evaluate the subject's perception of how well they could maintain various exercise intensities such as walking, running, or jogging over specific distances and durations. These bouts included a distance of one-mile, three miles, and one bout of 30 minutes in duration. Subjects were required to rate the activities as easier or harder (George et al., 1997). In addition to the information recorded using the PFA questionnaire, subjects also answered exercise questions established by Jackson et al. (1990). Then, anthropometric data were recorded and subjects submitted to a maximal GXT to determine VO_{2max}. From these results, NE VO_{2max} prediction equations were developed using multiple linear regression analysis (George, 1997). Two sets of equations were developed in this study with the first only taking into account questionnaire data while the second equation used both exercise and questionnaire data. George (1997) found that the incorporation of the data obtained from the PFA questionnaire improved the accuracy of NE equations used to predict VO_{2max} in active college-aged individuals. Interestingly, the authors also found that when using the second prediction equation, which included exercise data, the ability to predict VO_{2max} did not improve (George, 1997).

Expanding the research of George (1997), Bradshaw et al. (2005) developed a NE regression model to predict VO_{2max} in older individuals as opposed to specifically college students. One-hundred subjects, 50 males and 50 females, ages 18–65 years were used as subjects for the study (Bradshaw et al., 2005). Similar to the protocol mentioned in the study above, subjects initially filled out two questionnaires (PAR-Q and PFA) followed by anthropometric data collection. All subjects then performed a maximal GXT using a TM protocol developed by George (1996). Using the results, a regression equation was generated which was used to predict VO_{2max} based on gender, age, and BMI as well as PFA and PAR-Q data (Bradshaw et al., 2005). The authors concluded that the newly developed NE prediction equation for older individuals is an accurate way to predict VO_{2max} in both males and females. As is the case with most prediction equations, the results are largely dependent on the truthfulness of questionnaire responses, and the authors found that the PFA data contributes greatly to improved accuracy of predicting VO_{2max} (Bradshaw et al., 2005).

In 2011, Schembre and Riebe created and tested a regression equation that could be used to accurately estimate VO_{2max} based on responses from the International PA Questionnaire (IPAQ) in young adults. Participants in this study included 43 males and 37 females who were all considered healthy and generally between the ages of 18 and 20 years old (Schembre & Riebe, 2011). Using the short version of the IPAQ, PA habits were recorded as well as anthropometric data. All subjects performed a maximal GXT using the Bruce protocol. A randomly selected group of subjects which was representative of different fitness levels was created to validate the developed regression equation based on IPAQ responses and anthropometric data (Schembre & Riebe, 2011). The authors developed a regression equation that predicts VO_{2max} based on gender and PA per week. Schembre and Riebe concluded that VO_{2max} can be accurately predicted using the regression equation based on data obtained from the IPAQ. However, in many cases, the equation overestimated VO_{2max} in unfit individuals while underestimating in aerobically fit individuals (Schembre & Riebe, 2011).

Estimation of VO_{2max} using prediction equations is a useful tool for researchers as it allows data to be obtained quickly and accurately. One of the main benefits of using regression models that incorporate questionnaire data is that accurate VO_{2max} values can be obtained based solely on individual characteristics without the need for exercise testing.

Several valid NE prediction equations exist and can be useful in determining fitness levels in populations who may not be able to perform exercise at any level of intensity.

Wearable Devices

Wearable devices such as pedometers, accelerometers, and GPS devices have become increasingly popular during the twenty-first century. While research is ongoing, some of the earliest studies began to emerge around the turn of the century in which pedometers and early models of accelerometers were evaluated for use in PA based health interventions. In 2002, Liden et al. evaluated the SenseWear Armband™ by collecting physiological data from participants who wore the device for varying periods of PA. In this study, 40 participants were selected to produce four groups that were evenly divided by sex, height, age, and BMI (Liden et al., 2002). Before exercise, anthropometric data were collected so that it could be programmed into the armband. The exercise portion of the study consisted of two separate sessions of PA. For the first session, participants either walked at a slow or fast pace, ran, sat, or biked while breathing into a mouthpiece so that respiratory gases could be collected. The same basic protocol was followed for the second session with the only difference being a change in the order and duration of particular activities (Liden et al., 2002). Using the results, the authors concluded that the SenseWear Armband™ possesses low error rates and can be used to accurately assess PA. In comparison to other devices on the market at the time, the SenseWear Armband™ was cheaper and could produce more accurate results to be used for PA monitoring (Liden et al., 2002). These devices are often used in research, particularly in the clinical setting.

In 2010, Erdogan et al. compared a Polar S810i HRM™ (HR monitor) and a SenseWear Pro Armband™ to determine the accuracy at which energy cost associated with a particular exercise could be estimated. Forty-three subjects, 16 males and 27 females, of which 24 were overweight with the remaining 19 being obese, were tested while performing an indoor rowing exercise (Erdogan et al., 2010). Anthropometric data were collected in addition to percent body fat which was estimated using bioelectrical impedance analysis. Exercise testing consisted of an increasing intensity rowing protocol with a 20 second resting period between 2-minute stages so that a blood sample could be taken. The test was ended when subjects were not able to perform at the desired intensity. All subjects then returned to the lab on a separate day to perform a submaximal rowing protocol while wearing the SenseWear Armband™ and Polar HRM™. The submaximal effort which was preceded by a short warm-up period consisted of two 10-minute stages at workloads corresponding to 50 and 70% of VO_{2max} with a rest period of two minutes between each stage. In addition to the wearable devices, a Cosmed K4™ was used to collect respiratory gases (Erdogan et al., 2010). The authors concluded that the Polar™ and SenseWear™ monitors could accurately estimate energy expenditure (EE) for indoor rowing in an overweight population and that the armbands do not yield significantly different values of EE compared with values obtained using the Cosmed K4™ (Erdogan et al., 2010).

In a related study, Scheers et al. (2012) further expanded research on the SenseWear Armband™ by determining sources of variances in PA as well as observing the number of days the device needs to be worn to reliably determine PA patterns. The results are based on data from the pilot and main study which included a total of 502 subjects who were required to wear the armband for 14 days. Of the 502 subjects, data from 313 subjects, 190 males and

204 females, were used as seven complete monitoring days were necessary to produce accurate results. A complete day of monitoring consisted of at least 1,368 minutes (95% wear time) of recorded activity. In addition to wearing the device, subjects were required to record in an electronic diary whenever they began a new activity (Scheers et al., 2012). Based on the results, Scheers et al. (2012) found that PA patterns differed on the weekends with Saturday being a day of increased activity while Sunday was a day of decreased activity compared to a normal weekday. The authors also concluded that a wear time of at least three days spanning a normal work week (Monday through Friday) was necessary to determine normal PA patterns and the device needed to be worn Saturday and Sunday because of the differences previously mentioned (Scheers et al., 2012).

Further research was conducted on the SenseWear Armband™ by Reeve et al. (2014) who evaluated the ability of the armband to record EE during resistance training. The study consisted of 18 participants, 11 males and 7 females, who were experienced (at least six months) with resistance training. However, data on only 15 participants were obtained. After initial measurements, exercise took place over four unique sessions that included familiarization to the protocol, maximal strength testing, and two resistance training sessions that were based on maximal results. VO_2 was also measured throughout the course of the study using a Cosmed K4™ system. The final two exercise sessions consisted of participants completing nine separate exercises using a protocol of 10 reps for three sets at 70% of their one rep max (Reeve et al., 2014). Reeve et al. concluded that the SenseWear Armband™ and BodyMedia FIT™ can be used during resistance training to reliably measure EE.

Research on accelerometers spans numerous topics as they are especially useful for PA monitoring in adolescents. In 2007, Tudor-Locke et al. compared two devices, the

Lifecorder EX™ (LC) and the ActiGraph accelerometer™ (AG), under free-living conditions to evaluate their ability to record steps taken and time spent in different categories of PA intensity and assess reliability of the LC. The study consisted of a rather small sample of 10 individuals, 5 males and 5 females (Tudor-Locke et al., 2007). Initial measurements were taken one day prior to exercise. On the day of exercise, two LCs were worn, one on each hip, with only one AG monitor placed on the right hip using an elastic belt to house the devices. Participants were required to wear the devices for all waking hours aside from water activities for a 24-hour period and during a run that lasted at least 20 minutes The authors found that the LC possessed high intra-reliability and recorded 1,516 fewer steps than the AG over the course of a single day. Tudor-Locke et al. (2007) concluded that motion sensors such as these are a new technology and can be used to assess PA. The authors also recommend that research needs to continue on devices in the future in order to establish standardization so that results can be compared across populations and between other studies.

A similar study conducted by Abel et al. (2008) compared the LC and AG by measuring step count and EE during walking and running on a TM. A sample of 20 subjects, 10 males and 10 females, were used for this study. Resting metabolic rate was determined using indirect calorimetry before exercise testing took place. Accelerometers were programmed with subject information and were then placed into an elastic belt to be worn at the waist. Two LCs were placed in the belt, one on the left and one on the right, while one AG was placed on the right side of the hip. Additionally, each subject was also equipped with a mouthpiece and nose plugs so that respiratory gases could be collected. All subjects completed a total of three walking and three running TM bouts that increased in speed and lasted for 10 minutes each (Abel et al., 2008). A 2-minute rest period was given between each trial to wash out the data and following the conclusion of the last trial so that the accelerometers could record a period of zero steps. To compare to the steps measured by the accelerometers, two researchers counted the number of steps taken using direct observation. Abel et al. found that step count for walking and running is generally underestimated while monitoring using these types of devices. However, the authors concluded that the LC and AG are useful devices for researchers, clinicians, and the public and can be used to estimate EE and track steps taken. Further development and improvement of devices is necessary to improve accuracy and measurements for all populations (Abel et al., 2008).

Before accelerometers were used in research, pedometers were the go-to device for PA monitoring. A review conducted by Bravata et al. (2007) examined a total of 2,246 articles and narrowed this collection down to just 26 studies after exclusion based on specific inclusion criteria. The authors examined the correlation of pedometers with PA and improvements in health in outpatient adults (Bravata et al., 2007). Studies were only included in the study if they met the following inclusion criteria: (a) use of pedometers in assessment of outpatient adults, (b) reported a difference in steps per day, and (c) the sample used in the study was greater than five participants. Based on the review and results of 26 studies, the authors concluded that pedometers and PA are correlated because the use of pedometers demonstrates an increase in PA as well as a decrease in BMI and BP. Further research is necessary to determine if these positive outcomes are sustainable (Bravata et al., 2007). In a related study, a meta-analysis on pedometers was conducted by Kang et al. (2009) to evaluate the effect pedometers have on motivation so that they can be used as an intervention. The meta-analysis consisted of a total of 32 studies that met the inclusion criteria which consisted of (a) pedometers were used daily by at least one group of subjects, (b) pedometers were used as a way to motivate individuals during the intervention, (c) step counts were recorded both pre and post intervention, and (d) the duration of the intervention lasted at least four weeks (Kang et al., 2009). Based on the 32 studies, Kang et al. (2009) found results similar to Bravata et al. (2007) in that the use of pedometers as an intervention tool had a positive effect on PA and, in general, an average increase of 2,000 steps was seen for all studies.

Wearable devices such as accelerometers and pedometers are great tools that can be used to measure PA. These devices are particularly useful in measuring free-living and outdoor PA. Accelerometers and pedometers serve as substantial motivation tools that promote PA by recording steps taken, distance traveled, and even energy expenditure. With further advancements in technology and the development of new devices, research must continue to validate devices so that they can be of use in PA research.

GPS Technology and Devices

Before GPS technology became widespread and popular, Schutz and Chambaz (1997) theorized that a device utilizing satellite technology (GPS) could potentially be useful to record PA on an individual basis. The study tested a GPS device's ability to determine velocity of walking, running, and cycling in one male subject (Schutz & Chambaz, 1997). The subject was fitted with a GPS receptor while performing the previously mentioned exercises at various velocities around a track. From the results, the authors determined that using GPS to measure velocity of various activities could be of use in the future but further research is necessary, specifically on improving accuracy of determining velocity while walking (Schutz & Chambaz, 1997). While this study was conducted almost two decades ago, it set the course for a new direction of activity monitoring in the literature and eventually prompted a switch from using pedometers to more accurate devices that use GPS technology to record activity.

In a review paper by Maddison and Mhurchu (2009), 36 studies were analyzed in order to determine the prevalence of GPS use in the literature over the span of two decades. The paper dives into great detail about what exactly GPS is, how it can be utilized, and references several studies that have found GPS to be useful in the following fields of research: (a) GPS to measure human movement, (b) GPS use in sports, (c) use of GPS to record activity under controlled and free-living conditions, as well as (d) presenting potential limitations to using GPS as a research tool (Maddison & Mhurchu, 2009). After reviewing 36 studies, the authors found that using GPS to monitor PA is a novel method, particularly for monitoring activity under free-living conditions in different environments. Maddison and Mhurchu concluded that while future research is necessary to improve accuracy and analysis of data, GPS can be used as an additional tool to understand PA (Maddison & Mhurchu, 2009). A more recent review paper published by McCrorie et al. (2014) details the combined use of GPS, geographic information systems (GIS), and accelerometers to determine the relationship between PA and the environment in young individuals (5–18 years old) as well as directing future research topics. The study was comprised of a total of 14 papers that met particular inclusion criteria that consisted of: (a) use of accelerometers to measure PA in humans, (b) use of GPS to measure PA, (c) combined use of GPS and accelerometers to be used with GIS, and (d) the age of the participants was between 5 and 18 years old (McCrorie et al., 2014). Using 14 studies the authors determined that there may be a slight risk with ongoing research as many studies are not replicable because of unclear protocols. Specificity of methodologies is necessary in the literature to prevent the occurrence of non-replicable studies. However, McCrorie et al. (2014) also found that data on GPS devices point to the importance of pavement and greenspace in order to increase PA in young individuals. Both previously mentioned review studies are of great importance as they demonstrate the increasing presence of GPS monitoring in research and while future research is necessary, the link between PA monitoring and greenspace has been well documented in the literature (Almanza et al., 2012; Coombes et al., 2013; Jones et al., 2009; Lachowycz et al., 2012; McCrorie et al., 2014; Wheeler et al., 2010).

A series of studies conducted by Le Faucher et al. (2007, 2008) were among the first to document the use of GPS in outdoor environments on healthy and clinical populations. In 2007, a Garmin 60 GPS™ was tested to assess the accuracy of recording outdoor walking distance using previously determined distances on an outdoor track. The study was separated into three parts in which a total of 30 participants were used. For part one, each participant was fitted with a Garmin 60™ and performed a walking protocol that lasted 31.5 minutes up to four times. The walking protocol consisted of six individual bouts lasting 15 seconds, 30 seconds, 1 minute, 2 minutes, 4 minutes, and 8 minutes. Each trial was separated by a rest period that corresponded to the duration of the previously performed bout. Participants were instructed to walk at a self-selected pace on the inside lane of the track. The GPS device recorded position starting 15 minutes prior to exercise and continued until 15 minutes post exercise (Le Faucher et al., 2007). In part two of the study, participants were fitted with a backpack that housed the GPS device, a watch, and an MP3 player that was used to present a walking protocol vocally that lasted 18–20 minutes Participants were then instructed to walk to a nearby public park and performed the walking task after letting the GPS determine position for 10 minutes (Le Faucher et al., 2007). For the final portion of the study, participants completed two separate walking protocols of 2,000 meters that were made up of a series of distances in a randomized order (100, 200, 300, and 400 meters). Using all of the results obtained over the course of the study, the authors found that the commercially available GPS device (Garmin 60™) can be used when evaluating outdoor activity for healthy subjects. In particular, the GPS device could be used to determine walking and resting periods as well record speed and distance during exercise (Le Faucher et al., 2007). The authors also stated that GPS devices could be of use in evaluating PA and capacity in clinical populations.

Continuing their research from 2007, Le Faucher et al.(2008) analyzed walking distance and speed using a GPS device in patients with peripheral arterial disease (PAD). Their aim was to compare TM analysis of walking to non-TM methods in clinical patients as well as present both benefits and limitations to each method of measurement (Le Faucher et al., 2008). A total of 24 patients with PAD were used to assess walking distance and speed. The study was divided into five parts which consisted: (a) a walking impairment questionnaire, (b) self-reported maximal walking distance, (c) a TM walking test at 10% grade with increasing speed up to 4 minutes followed by a maximum of 16 minutes of walking at the capped speed, (d) a 6-minute walking test, and (e) an unsupervised walking activity using a GPS device (Garmin 60™) that lasted at least 45 minutes in which participants walked freely around a public park (Le Faucher et al., 2008). The authors found that maximal walking distance recorded by the GPS device was highly correlated to maximal walking distance measured during the TM test. Le Faucher et al. (2008) concluded that GPS recording of PA for research in clinical populations is an upcoming field and an alternative approach to laboratory testing.

Validity and reliability of GPS devices are a major concern in PA research as the accuracy of measuring is largely dependent on the use of satellites to determine location, which proposes obvious issues with any potential obstruction such as a large building or trees. In 2012, Wieters et al. tested the ability of four different GPS devices to measure outdoor PA. The researchers used a Garmin Forerunner 205™, a Garmin Foretrex 201™, a Globalsat DG-100™, and a Wintec Easy Showily™. The accuracy of each GPS device was evaluated by determining the deviation from a known route walked, difference in position after changing the position of the unit on the participant's body, and variation of position from a known geodetic point (Wieters et al., 2012). A geodetic point is a static reference point on Earth that can be used to determine location. After assessing all units, the authors concluded that GPS could be used as a recording tool in PA research based on an acceptable level of reliability and validity demonstrated by each GPS. Further, the Garmin Forerunner 205™ demonstrated the greatest accuracy by producing the fewest errors in measurement during the walking route. Wieters et al. (2012) suggested that future research is necessary to evaluate new equipment as accuracy in measurement using GPS increases. This will inevitably lead to more convenient methods to collect PA data in the open environment.

Further expanding the research on the validity of GPS devices, Duncan et al. (2013) tested seven different GPS units to assess the static validity of measurement in varying environments and evaluated the time it took for satellites to acquire a signal and determine location across all models. In particular, a Garmin Forerunner 205™ and Garmin Foretrex 201™ were used among the seven devices. For the study, six environmentally unique geodetic sites were used on three separate occurrences to assess signal acquisition time and battery life. The setting of each geodetic site differed as some locations were set under an open sky to produce no interference whereas others were next to high-rise buildings to cause a potential disruption in the signal. Duncan et al. found that the Forerunner 205 outperformed the other devices and particularly excelled under conditions of high signal disruption. In unobstructed conditions, GPS devices can be used with confidence to determine static location (Duncan et al., 2013). However, obstructed conditions such as high-rise buildings and trees can potentially produce errors in certain lesser models. While in its present form GPS is useful in research, future research is necessary, specifically for free-living activities to evaluate the performance and accuracy of GPS monitoring in the field (Duncan et al., 2013).

Recent research has emerged on the role of GPS devices in promoting PA through exergames. The effect of implementing exergames as an intervention in older adults has been well documented in a review paper by Chao et al. (2014). The review includes 22 studies that met inclusion criteria including the use of Nintendo Wii™ exergames as an intervention for cognitive performance, physical function, and psychosocial factors in older individuals (Chao et al., 2014). After analyzing the results of all 22 studies, the authors concluded that exergames are a great source of motivating older adults to participate in PA using a safe and reasonable method to exercise. Chao et al. also found that Nintendo Wii™ exergames have beneficial effects on cognition, physical function, and psychosocial outcomes through improving mood, social support, and PA. Additionally, the authors concluded that exergames could be a useful intervention tool, particularly in populations lacking motivation, although further research is necessary (Chao et al., 2014). The combined effect of GPS and exergames was presented by Boulos et al. (2013), who examined over 45 different exercise based games, applications, devices, and gadgets to determine their effect on health and fitness. To find relevant studies, an online search was conducted to identify research involving GPS, exergames, geosocial applications, and gadgets. The authors also browsed popular mobile application stores and marketplaces to find various exercise applications (Boulos et al., 2013). Using the results, the authors concluded that GPS based exergames could be a potential alternative or accessory to traditional sports such as football and skiing, particularly for adolescents. Buolos et al. (2013) recommend that future research should expand on the use of GPS and exergames as they could be used to combat the growing obesity epidemic since they are a form of video games that require individuals to be outside and engage in PA.

VO_{2max} Prediction Using Smart Watches

The VO_{2max} prediction feature of sports watches is relatively new and few studies exist on the topic. Recently, three abstracts were published on the topic and tested the predictability of several different watches including the Polar FT60™, Polar V800™, and the Garmin Forerunner 230 and 235™. One study, conducted by Johnson and Beadle (2017) examined the predictability of VO_{2max} using the Polar FT60 Fitness Test™. The test aimed to predict VO_{2max} using resting heart rate, participant characteristics, and activity level from the past three months. Thirty-one subjects, 13 males and 18 females, volunteered for the study and all testing was completed in one visit. After initial anthropometrics were recorded each participant's VO_{2max} was predicted using the Polar FT60 Fitness Test™. This test requires participants to lie down and rest for 5 minutes while wearing the sports watch and a heart monitor contained in a chest strap (Johnson & Beadle, 2017). During the test, resting heart rate variability is collected and used to predict VO_{2max} along with participant characteristics and previous activity level. Following the resting fitness test, participants completed a VO_{2max} test on a TM. The authors found that the Polar FT60 Fitness Test™ overestimated

VO_{2max} by roughly 10% compared to the directly measured value obtained during the GXT (Johnson & Beadle, 2017).

Similar to the study above, Snyder et al. (2017) examined the accuracy of prediction of three different sports watches. In this study, a directly measured VO_{2max} value obtained using a standard TM protocol was compared to a predicted value by the Polar V800™ and Garmin Forerunner 230 and 235™. The Polar V800™ predicts VO_{2max} using resting heart rate variability during a 5-minute test in which the participant lies down and relaxes. The Garmin 230 and 235™ predict VO_{2max} based on a 10-minute outdoor run performed at self-selected pace (Snyder et al., 2017). The main difference between these two watches is that the 230 records HR using a standard chest strap monitor while the 235 records HR using an optical sensor within the watch and collects HR data at the radial pulse. Forty-two participants, 24 males and 18 females volunteered for the study. On day one of testing, participants completed a resting fitness test while wearing the V800 and a VO_{2max} value was predicted based on participant characteristics and different training zones programmed into the watch. Afterwards, participants completed a GXT using a TM protocol so that a direct VO_{2max} could be obtained. On day two of testing, within 48 hours, participants completed a 10-minute outdoor run while wearing the 230 and 235. This run was completed outdoors because the watch uses GPS signal to measure distance and was performed using a self-selected pace (Snyder et al., 2017). The authors found significant differences between directly measured and all predicted VO_{2max} values. The results differed by gender with an overestimation by the watches in all cases for males whereas the watches overestimated and in some cases underestimated VO_{2max} in females (Snyder et al., 2017).

Using the same data as the study above, Willoughby et al. (2017) compared VO_{2max} values predicted by the Garmin Forerunner 230 and 235™. Additionally, distance, kcals, cadence, and average and maximal HR obtained during a 10-minute outdoor run was compared. The comparison of average and maximal HRs were particularly important as HR values are collected differently across the two watches. The 230 records HR using a chest strap while the 235 records HR at the radial pulse using an optical sensor in the watch. Each participant performed a 10-minute outdoor run using a self-selected pace while wearing both watches and a chest strap. A location free of GPS interference was used and participant characteristics including gender, age, height, and weight were programmed into the watch before any exercise took place (Willougby et al., 2017). The authors found no significant differences for maximum HR, distance, pace, or kcals. However, average HR was significantly higher in the 230 for both genders. Interestingly, no significant difference in predicted VO_{2max} was observed in females while a difference in predicted VO_{2max} occurred in males. The 230 consistently predicted a lower value compared to the 235. Willoughby et al. concluded that the 230 predicted a significantly lower VO_{2max} value because average HR recorded using the 230 (chest strap) was significantly higher.

Summary

VO_{2max} can be measured using several different techniques that all possess certain benefits as well as inherent limitations. Whether determining VO_{2max} through submaximal exercise, maximal testing protocols, or estimation using regression models, each method can be utilized to provide the most accurate results for a given population. In research, exercise testing should be geared toward the target population to ensure safety of the participant.

Submaximal methods and prediction equations are of great interest as they offer a cost-effective and time-efficient alternative to standard maximal exercise testing.

The combination of the aforementioned methodologies with GPS monitoring could lead to major advancements in exercise testing, PA monitoring, and produce more efficient styles of collecting data. Pedometers and accelerometers have been used extensively in PA monitoring and have been shown to increase PA, improve health outcomes, and even accurately measure EE during exercise. GPS devices are already a growing field in the literature with most research focusing on measuring the association between PA and the environment. While the connection between greenspace and increased PA has already been thoroughly documented, research on the use of GPS technology in exercise physiology research is necessary.

Chapter 3

Research Design and Methodology

Participants

Thirty participants, 16 males and 14 females between the ages of 18 and 55 years old, volunteered for this study. Sample size was determined using G*Power 3.1. An a priori power analysis was selected for a one-way repeated measures ANOVA (1x3; within factors). Alpha was set at 0.05, beta (power) as 0.08, and effect size F as 0.25. This produced a sample size of 28. All participants were considered to be fit individuals who exercised at least three times per week. Participants were recruited by word of mouth and flyers that were hung around Eastern Michigan University's (EMU) campus. Prior to any measurements and exercise testing, all participants read and signed a written consent form that explained in full detail the expectations, benefits, and risks of the study (Appendix A). Additionally, participants filled out a PAR-Q (Appendix B) and Health-History Questionnaire (Appendix C) to ensure that they were ready for exercise. This study has been approved by EMU's institutional review board (Appendix D).

Procedures

All participants completed a VO_{2max} test using a treadmill (TM) protocol, a 15-minute run outside around a 0.5-mile loop while wearing a Garmin Forerunner 235™ GPS watch (Garmin™, Ltd., Schaffhausen, Switzerland) and wore the watch for up to one week after initial testing. After the submaximal 15-minute outdoor run on EMU's campus, participants wore the watch for a maximum of 7 days and were required to perform three additional runs of at least 30 minutes in duration. Exercise testing took place over the course of two visits that were separated by a minimum of 24 hours and time between tests did not exceed 7 days. Total time required by the participant to complete this study was 2 weeks or less. On both days of testing, participants arrived at the Running Science Laboratory located in Rackham Hall at Eastern Michigan University. Participants were required to arrive in a fasted state (no nutrient intake in the past three hours), which generally consisted of an overnight fast. In addition to fasting, participants were required to refrain from consuming any caffeine within the past three hours and were asked to avoid strenuous exercise 24 hours prior to testing.

Garmin Forerunner 235™

The Garmin Forerunner 235™ (Garmin, Ltd., Schaffhausen, Switzerland; weight, 42.0 g; width, 45.0 mm; height, 45.0 mm; thickness, 11.7 mm) is a global positioning system (GPS) sports watch that records distance, time, pace, and monitors heart rate (HR). Continuous HR monitoring is achieved by measuring beats per minute (bpm) using an optical sensor within the watch at the radial pulse, which conveniently allows users to run without a chest strap. The GPS watch also produces personalized HR zones based on maximal and resting HR values that are programmed in when customizing the user profile. The user profile allows individualized programming of the watch and can be reset after each use for new participants. Programming of the user profile consists of gender, birth year, height (in.), weight (lbs), and HR zones detailed above. In addition to activity monitoring, the watch has a race predictor feature (5k, 10k, half and full marathon), the ability to customize goal-oriented workouts, personal record tracking, and the ability to estimate recovery time and VO_{2max} based on a single run of 10 minutes outdoors. In this study participants ran for 15 minutes outdoors to ensure an estimated VO_{2max} was produced. In some cases, during pilot testing, VO_{2max} was not estimated after running 10 minutes. There are several factors that could have contributed to this error, particularly GPS accuracy and continuous HR monitoring, which are both described in the discussion. Only the estimated VO_{2max} feature was used for the purpose of this study. Other activity tracking features that the watch possesses are recording total steps, distance traveled, estimated calories burned for a 24-hour period, and sleep monitoring. The built-in accelerometer allows distance, pace, and time to be recorded so that users can run on an indoor track or TM. In addition to the watches activity monitoring features, it serves as a social media platform through the online Garmin Connect Network™ from which users can share their results with one another. Other applications exist on the App Store and Google Play that allow unique customizability of the watch.

Visit 1

On day one, participants arrived at the Running Science Laboratory at EMU in a fasted state. Upon arrival to the testing site, participant's height (cm) and weight (kg) was recorded prior to exercise using a Tanita™ BWB-800S scale (Tanita Corporation of America Inc., Arlington Heights, IL, USA) for weight and a DETECTO™ 439 Physician Scale (DETECTO Scale Company, Webb City, MO, USA) to measure height while wearing light clothes and no shoes. All measurements were taken twice to ensure accuracy and then the average of the two values was recorded and entered into the computer for calibration of the metabolic cart. All participants completed a maximal GXT test on day one of testing. GXT tests were performed on a True Fitness™ S Drive TM (True Fitness Technology, St. Louis, MO, USA). Respiratory gases were collected and analyzed at a 10 second sampling interval using a Parvo Medics TrueOne 2400™ metabolic cart (Parvo Medics, Sandy, UT, USA). Calibration of all equipment was done prior to participant arrival on the day of testing.

A maximal exercise protocol similar to the Arizona State University protocol developed by George (1996) was used for the purpose of this study. Participants began by straddling the TM while the protocol was explained in detail as well as the necessary actions and precautions to take when terminating the test. The protocol used for this study consisted of two minute stages at a self-selected jogging pace with a 2% increase in grade at the beginning of each new stage (Table 1). For the warm-up portion of the test, participants selected a pace greater than 6.0 mph for males and 5.5 mph for females that they believed could be maintained for 30 minutes at 0% grade. After a two-minute warm-up at the self-selected, the TM is stopped and participants again straddled the TM. Participants were then fitted with headgear, nose plugs, and a mouthpiece (Hans Rudolph, Inc., Shawnee, KS, USA) with the purpose of collecting respiratory gases to be analyzed in determining VO_2 continuously throughout the test. Additionally, participants were fitted with an electric HR monitor (Polar Electro Inc., Lake Success, NY, USA) so that HR could be monitored for the duration of the test. Then, the timer was started and respiratory gas collection began while participants stood idly for 2 minutes to allow baseline measurements to be completed. After the initial 2-minute sampling period, the TM was set to the speed selected by the participant during the warm-up portion with 0% grade and the exercise portion of the test began. Every 2 minutes thereafter, TM grade was increased by 2% while speed remained constant until the participant experienced volitional exhaustion and voluntarily ended the test due to fatigue. VO_2 and HR were recorded each minute during the GXT and the full results were printed and stored as a hard copy after the test which provided respiratory and metabolic values every 10 seconds during the test. An example of the protocol with a participant running at 6.0 mph can be found in Table 1. After completion of the test, the headgear, mouth piece, and nose plugs were immediately removed, and participants were required to walk on the TM at a self-selected pace and 0% grade as a cool down until their HR fell below 100 bpm. Once the participant's HR was below 100 bpm and they verbally communicated that they felt normal, the participant was free to leave the testing site.

The test is considered to be a maximal effort and therefore a VO_{2max} if at least two of the following three criteria are satisfied based on a study conducted by Kline et al. (1987): (a) no further increase in oxygen consumption despite an increase in workload, (b) a respiratory exchange ratio (RER) $\geq$ 1.10, and (c) a HR within 15 bpm of the participant's age predicted max which was found using the equation 220 – age = maximal HR (Kline et al., 1987).

Visit 2

On day two, participants arrived at the Running Science Laboratory at EMU in a fasted state. Before their arrival, the researcher recorded the outside weather conditions for the area (zip code 48198), which consisted of relative humidity (%) and temperature (Celsius and Fahrenheit) from www.noaa.gov. After height (in.) and weight (lbs.) are recorded, the researcher programed the GPS watch based on the participant's characteristics, specifically gender, age, height, and weight. The GPS watch was used to record duration of the exercise, distance, pace, HR using the radial pulse, and estimated VO_{2max} based on exercise data recorded during the run as well as participant characteristics (gender, age, height, weight, and maximal HR). Before any exercise took place, the participant was fitted with the GPS watch before walking outside. This was done to ensure accurate HR readings before and during exercise. This is a known issue according to Garmin's troubleshooting section of their website for the Garmin Forerunner 235™. Their suggestion to correct this error in measurement is to warm-up with the device on for 5–10 minutes before beginning recording any activity. Additionally, the watch was fitted to the participant before stepping outside to allow time for the GPS software to locate the participant and be ready for activity monitoring. Participants wore the watch around their wrist which was placed on the anterior aspect of the wrist so that the radial pulse may be collected as efficiently as possible.

The participant was then directed outside to a 0.5-mile loop previously measured on EMU's campus. They were instructed to run around the 0.5-mile course as many times as possible in 15 minutes at a pace that feels comfortable to them. Participants were required to refrain from walking at any time during and were motivated to complete the submaximal run to the best of their ability. Additionally, the participant was informed how to stop the timer on the watch once 15 minutes had elapsed which consisted of pressing one button on the upper right corner of the watch. Before beginning the timed run, the researcher and participant stood still at the starting point to ensure GPS accuracy. Once the watch face read "GPS Ready," the researcher pressed the start button on the watch and the participant began the test. After completion of the exercise bout, participants were instructed to press the "Stop" button, which prompts them with a red stop sign on the watch face and data collection ends. The participant then removed the watch and handed it to the researcher while walking around freely to cool down. Upon acquiring the GPS watch from the participant, the researcher saved the activity by using the watch's activity recording function. Total time (~15 minutes), distance, pace, and predicted VO_{2max} were recorded.

After completion of the timed run and before departure, the participant was given detailed instructions orally by the researcher and received a handout explaining how to operate the GPS watch for additional use over the course of the next week. Participants were then required to wear the Garmin Forerunner 235™ for a maximum of seven days and perform a minimum of three outdoor runs of at least 30 minutes. The original outdoor run on EMU's campus predicts relative VO_{2max} based on the variables mentioned above and any input thereafter from recorded activity adjusts their VO_{2max} value accordingly. As the GPS watch is also a pedometer, accelerometer, and HR monitor, VO_{2max} only adjusts based on recorded activity and not based on number of steps taken per day or HR throughout the day. Because of this technological advancement, participants were not required to wear the watch 24 hours per day and were also instructed to remove the watch if performing aquatic activities or showering. After 7 days and performing three outdoor runs of at least 30 minutes in duration, the participant returned the GPS watch to the Running Science Laboratory at EMU. The researcher checked the activity history to ensure that three activities had been recorded and satisfied the time requirement. Total time, pace, and distance were recorded for each exercise bout completed by the participant. Additionally, the adjusted predicted VO_{2max} value was recorded to be compared to the predicted value received one-week prior and to the directly measured VO_{2max} value on day one of testing. These methods yielded three relative VO_{2max} values, one maximal and two submaximal for analysis.

Statistical Analysis

To determine statistical significance, a confidence level of 95% (p-value = .05) was used for all tests. Additionally, descriptive statistics of mean and standard deviation were used for age, weight (kg), height (cm), treadmill speed (mph), directly measured VO_{2max} (ml/kg/min), predicted VO_{2max} (ml/kg/min), adjusted predicted VO_{2max} (ml/kg/min), pace (min) and distance (mi) for the initial 15-minute outdoor run, and pace and distance for the three additional exercise bouts. Three measurements of VO_{2max} were recorded for each participant. A post hoc power analysis was conducted for a repeated measures ANOVA with within-between interaction (two-way repeated measures ANOVA). Alpha was set at 0.05, beta (power) as 0.08, and effect size F as 0.25. This produced a sample size of 28, indicting enough participants had completed data collection for this type of analysis to be conducted. A two-way repeated measures ANOVA was conducted to determine if there was a statistically significant difference between directly measured VO_{2max}, predicted VO_{2max} based on a 15-minute outdoor run and adjusted predicted VO_{2max} based on three additional running bouts of at least 30 minutes in duration over the course of no greater than seven days. All activities recorded using the GPS sports watch were performed outdoors to ensure GPS signal strength and accuracy. The differences between all VO_{2max} measurements were examined for all participants. Further, participants were divided into two groups based on directly measured VO_{2max}: VO_{2max} greater than 50ml/kg/min (high) and VO_{2max} less than 50 ml/kg/min (low). A one-way repeated measures ANOVA was conducted to determine if there was a statistically significant difference between recorded VO_{2max} values for each group.

Table 1

Data Collection Sheet

Time (min)	Speed (mph)	Grade (%)	HR	VO_2 (ml/kg/min)
01:00 Baseline Measurements	0.00	0.00		
02:00	0.00	0.00		
01:00 Exercise	6.00	0.00		
02:00	6.00	0.00		
03:00	6.00	2.00		
04:00	6.00	2.00		
05:00	6.00	4.00		
06:00	6.00	4.00		
07:00	6.00	6.00		
08:00	6.00	6.00		
09:00	6.00	8.00		
10:00	6.00	8.00		
11:00	6.00	10.00		
12:00	6.00	10.00		
13:00	6.00	12.00		
14:00	6.00	12.00		

Chapter 4

Presentation and Analysis of Data

Of the 30 participants who volunteered to participate in this study, 28 participants (14 males and 14 females) completed the necessary requirements. One participant failed to return for the second visit and one participant suffered an ACL injury independent of the study and was therefore excluded from data analysis. Descriptive statistics for all participant characteristics, VO_{2max} measurements, and recorded exercise activities can be found below in Tables 2, 3, and 4, respectively.

Table 2

Descriptive Statistics of Participants

Descriptive Statistics

	N Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Std. Deviation Statistic	Skewness Statistic
Age	28	20	46	24.71	5.689	2.587
Weight (kg)	28	46.40	101.00	67.2186	14.84907	.824
Height (cm)	28	159.50	187.00	168.9418	6.93607	.644
Valid N (listwise)	28					

Table 3

Descriptive Statistics of All VO_{2max} Values

Descriptive Statistics

	N Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Std. Deviation Statistic	Skewness Statistic
VO2max (ml/kg/min)	28	41.4	77.7	55.093	9.7339	.509
Predicted VO2max (ml/kg/min)	28	43	62	51.75	5.161	.522
Adjusted Predicted VO2max	28	43	63	50.68	5.976	.951
Valid N (listwise)	28					

Table 4

Descriptive Statistics of Additional Exercise Activity

Descriptive Statistics

	N Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Std. Deviation Statistic	Skewness Statistic
Speed of TM (mph)	28	5.5	10.3	6.804	1.3282	1.240
Distance (mi.)	28	1.59	2.34	1.9275	.23092	.573
Pace (min/mile)	28	6:24:59.99	9:26:00.00	7:56:17.14	0:54:22.05895	-.378
Run #1 Pace	28	6:28:59.99	10:48:00.0	8:45:42.86	1:10:16.06	-.305
Run #1 Distance	28	2.78	10.01	4.2864	1.78941	1.796
Run #2 Pace	28	6:23:00.00	11:49:00.0	8:48:53.57	1:13:29.30	-.182
Run #2 Distance	28	2.54	8.39	4.0514	1.47357	1.833
Run #3 Pace	28	6:22:00.00	12:46:00.0	8:44:36.43	1:24:57.35	.547
Run #3 Distance	28	2.74	13.14	4.6589	2.59990	2.326
Valid N (listwise)	28					

The purpose of this study was to examine the predictability of VO_{2max} using a global positioning system (GPS) sports watch. Three separate values for VO_{2max} were obtained: (a) directly measured VO_{2max}, (b) a predicted VO_{2max} value based on a 15-minute outdoor run, and (c) an adjusted predicted VO_{2max} value based on three subsequent outdoor runs of at least 30 minutes in duration. It was hypothesized that the Garmin Forerunner 235™ would not be an accurate predictor of VO_{2max} for the general population. A two-way (2 fitness groups x 3 VO_{2max} time points) repeated measures ANOVA was conducted to determine if a statistically significant difference existed among direct, predicted, and adjusted predicted VO_{2max} recorded during the study for all participants. Additionally, participants were divided into two fitness groups based on direct VO2max: high (> 50 ml/kg/min) and low (< 50 ml/kg/min VO_{2max}). A one-way repeated measures ANOVA was conducted to determine if a significant difference existed among VO_{2max} values for groups. Descriptive statistics for groups separated by VO_{2max} can be found in Tables 5 and 6. Statistical significance was set using a *p*-value of .05.

When first interpreting the results of a two-way repeated measures ANOVA, the assumption of sphericity must be examined. Sphericity is when the relationship between pairs of measurements, in this study the three different VO_{2max} values that were recorded, is assumed to be similar, which means that the level of dependence between pairs formed by these measurements are roughly equal. If sphericity is violated, then a loss of statistical power occurs. To ascertain if sphericity has been violated, the results of Mauchly's Test of Sphericity are examined to determine if the variances between measured pairs are equal (Field, 2016). If Mauchly's test statistic was not significant, the assumption of sphericity has been met. However, if Mauchly's test statistic was significant, the assumption of sphericity has been violated. The results of Mauchly's test of sphericity are provided below in Table 7. Because Mauchly's test statistic was significant (*p*-value < .001), it can be concluded that significant differences exist between the variances of differences among pairs. This indicates that the condition of sphericity required when performing a repeated measures ANOVA has not been met ($X^2(28) = 15.209$, $p = .000$). Since the conditions of sphericity have been violated, the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.687$). As a result, the degrees of freedom are smaller, which makes the produced F ratio more conservative. The Greenhouse-Geisser estimate of sphericity (ε) is provided below in Table 7.

The Greenhouse-Geisser correction was used to examine the within-subjects effects because ε is less than 0.75 (Field, 2016). Using the Greenhouse-Geisser correction, the results indicate that a significant difference among recorded VO_{2max} values (direct, predicted, and adjusted) was found, $F(1.37, 35.72) = 11.60$, p-value < .01 (Table 8). To determine which VO_{2max} values were significantly different from each other, group means were compared using Bonferroni to adjust for multiple comparisons. The three VO_{2max} values (dependent variables) used for pairwise comparison are denoted below in Table 9. Direct, predicted, and adjusted VO_{2max} are coded as dependent variables 1, 2, and 3, respectively. A statistically significant difference was observed (p-value < .05) between directly measured VO_{2max} (dependent variable 1) and predicted VO_{2max} (dependent variable 2). A statistically significant difference was also observed (p-value < .001) between directly measured VO_{2max} and adjusted VO_{2max} (dependent variable 3). Additionally, there was a significant difference between predicted VO_{2max} and adjusted VO_{2max} (p-value < .05; Table 10).

Table 5

Descriptive Statistics of the High VO_{2max} Group

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Age	17	20	46	25.35	5.979
Weight (kg)	17	46.40	101.00	69.3718	15.10685
Height (cm)	17	159.50	187.00	170.0147	7.62678
VO2max (ml/kg/min)	17	50.6	77.7	61.153	7.4438
Predicted VO2max (ml/kg/min)	17	47	62	54.24	4.867
Adjusted Predicted VO2max	17	46	63	53.53	5.991
Valid N (listwise)	17				

Table 6

Descriptive Statistics of the Low VO_{2max} Group

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Age	11	20	39	23.73	5.331
Weight (kg)	11	48.8	98.1	63.891	14.4958
Height (cm)	11	160.02	179.75	167.2836	5.64310
VO2max (ml/kg/min)	11	41.4	49.4	45.727	2.8720
Predicted VO2max (ml/kg/min)	11	43	52	47.91	2.700
Adjusted Predicted VO2max	11	43	49	46.27	1.954
Valid N (listwise)	11				

Table 7

Mauchly's Test of Sphericity—Two-Way ANOVA

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
VO2max	.544	15.209	2	.000	.687	.740	.500

Table 8

Tests of Within-Subjects Effects—Two-Way ANOVA

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
VO2max	Sphericity Assumed	173.673	2	86.836	11.630	.000	.309
	Greenhouse-Geisser	173.673	1.374	126.413	11.630	.001	.309
	Huynh-Feldt	173.673	1.481	117.278	11.630	.000	.309
	Lower-bound	173.673	1.000	173.673	11.630	.002	.309
VO2max * Fitness	Sphericity Assumed	334.815	2	167.408	22.420	.000	.463
	Greenhouse-Geisser	334.815	1.374	243.706	22.420	.000	.463
	Huynh-Feldt	334.815	1.481	226.095	22.420	.000	.463
	Lower-bound	334.815	1.000	334.815	22.420	.000	.463
Error(VO2max)	Sphericity Assumed	388.278	52	7.467			
	Greenhouse-Geisser	388.278	35.720	10.870			
	Huynh-Feldt	388.278	38.502	10.085			
	Lower-bound	388.278	26.000	14.934			

Table 9

Dependent Variables—Two-Way ANOVA

Measure: MEASURE_1

VO2max	Dependent Variable
1	VO2maxmlkg min
2	PredictedVO2 maxmlkgmin
3	AdjustedPredi ctedVO2max

Table 10

Pairwise Comparisons—Two-Way ANOVA

Pairwise Comparisons

Measure: MEASURE_1

(I) VO2max	(J) VO2max	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	2.368*	.918	.048	.019	4.717
	3	3.539*	.795	.000	1.504	5.574
2	1	-2.368*	.918	.048	-4.717	-.019
	3	1.171*	.449	.045	.022	2.320
3	1	-3.539*	.795	.000	-5.574	-1.504
	2	-1.171*	.449	.045	-2.320	-.022

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

It was further hypothesized that the Garmin™ Forerunner 235 would be an accurate predictor of VO_{2max} for individuals with a VO_{2max} of less than 50 ml/kg/min. A significant interaction between VO_{2max} and fitness level was observed (p-value < .001; Table 11). Participants were divided into groups based on the directly measured VO_{2max} recorded during visit one. Seventeen participants had a VO_{2max} of greater than 50 ml/kg/min. Descriptive statistics for characteristics and all VO_{2max} values recorded for this group can be found above in Table 5. Eleven participants had a VO_{2max} of less than 50 ml/kg/min. Descriptive statistics for participant characteristics and all VO_{2max} values recorded for this group can be found above in Table 6.

Before the results of the one-way repeated measures ANOVA can be interpreted, the condition of sphericity must be examined. The results of Mauchly's test of sphericity are located in Table 12. Because Mauchly's test statistic was significant (p-value < .001) for the high VO_{2max} group, it can be concluded that significant differences exist between the variances of differences among pairs. This indicates that the condition of sphericity required when performing a repeated measures ANOVA has not been met ($X^2(17) = 9.65$, $p = .008$). Since the conditions of sphericity have been violated, the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.678$). Because ε is less than 0.75, the Greenhouse-Geisser correction was used to examine the within-subjects effects[67]. Using the Greenhouse-Geisser correction, the results located in Table 13 indicate that a significant difference among recorded VO_{2max} values (direct, predicted, and adjusted) was found, $F(1.36, 21.70) = 32.32$, p-value < .001 (Table 13). To determine which VO_{2max} values were significantly different from each other, group means were compared using Bonferroni to adjust for multiple comparisons. The results of the way one-repeated measures ANOVA are located below in Table 14. A statistically significant difference was observed (p-value < .001) between directly measured and predicted VO_{2max} for the high group. A statistically significant difference was also observed (p-value < 0.001) between directly measured and adjusted VO_{2max}. No significant difference existed between predicted and adjusted VO_{2max} (p-value > .05; Table 14).

Mauchly's test statistic was not significant for the low VO_{2max} group (Table 12), and therefore, the condition of sphericity has been met and no further correction is necessary. The results of the way one-repeated measures ANOVA are located in Table 14. These results indicate that for the low VO_{2max} group a statistically significant difference does not exist between directly measured and predicted VO_{2max}, directly measured and adjusted VO_{2max}, or predicted and adjusted VO_{2max} (p-value > .05). Additionally, a graphical representation of mean VO_{2max} values for the high and low group can be viewed in Figure 1.

Table 11

Pairwise Comparisons of Groups—One-Way ANOVA

Pairwise Comparisons

Measure: MEASURE_1

(I) Fitness	(J) Fitness	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
>50ml/kg/min	<50ml/kg/min	9.670*	1.777	.000	6.017	13.322
<50ml/kg/min	>50ml/kg/min	-9.670*	1.777	.000	-13.322	-6.017

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Table 12

Mauchly's Test of Sphericity—One-Way ANOVA

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Fitness	Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
VO2max > 50	VO2max	.525	9.652	2	.008
VO2max < 50	VO2max	.595	4.678	2	.096

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

		Epsilon[b]		
Fitness	Within Subjects Effect	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
VO2max > 50	VO2max	.678	.719	.500
VO2max < 50	VO2max	.712	.796	.500

Table 13

Tests of Within-Subjects Effects—One-Way ANOVA

Tests of Within-Subjects Effects

Measure: MEASURE_1

Fitness	Source		Type III Sum of Squares	df	Mean Square
VO2max > 50	VO2max	Sphericity Assumed	603.332	2	301.666
		Greenhouse-Geisser	603.332	1.356	444.814
		Huynh-Feldt	603.332	1.438	419.549
		Lower-bound	603.332	1.000	603.332
	VO2max * Fitness	Sphericity Assumed	.000	0	.
		Greenhouse-Geisser	.000	.000	.
		Huynh-Feldt	.000	.000	.
		Lower-bound	.000	.000	.
	Error(VO2max)	Sphericity Assumed	298.708	32	9.335
		Greenhouse-Geisser	298.708	21.702	13.764
		Huynh-Feldt	298.708	23.009	12.982
		Lower-bound	298.708	16.000	18.669
VO2max < 50	VO2max	Sphericity Assumed	28.364	2	14.182
		Greenhouse-Geisser	28.364	1.423	19.930
		Huynh-Feldt	28.364	1.592	17.816
		Lower-bound	28.364	1.000	28.364
	VO2max * Fitness	Sphericity Assumed	.000	0	.
		Greenhouse-Geisser	.000	.000	.
		Huynh-Feldt	.000	.000	.
		Lower-bound	.000	.000	.
	Error(VO2max)	Sphericity Assumed	89.570	20	4.478
		Greenhouse-Geisser	89.570	14.231	6.294
		Huynh-Feldt	89.570	15.920	5.626
		Lower-bound	89.570	10.000	8.957

Table 13 *continued*

Tests of Within-Subjects Effects

Measure: MEASURE_1

Fitness	Source		F	Sig.
VO2max > 50	VO2max	Sphericity Assumed	32.317	.000
		Greenhouse-Geisser	32.317	.000
		Huynh-Feldt	32.317	.000
		Lower-bound	32.317	.000
	VO2max * Fitness	Sphericity Assumed	.	.
		Greenhouse-Geisser	.	.
		Huynh-Feldt	.	.
		Lower-bound	.	.
	Error(VO2max)	Sphericity Assumed		
		Greenhouse-Geisser		
		Huynh-Feldt		
		Lower-bound		
VO2max < 50	VO2max	Sphericity Assumed	3.167	.064
		Greenhouse-Geisser	3.167	.086
		Huynh-Feldt	3.167	.079
		Lower-bound	3.167	.106
	VO2max * Fitness	Sphericity Assumed	.	.
		Greenhouse-Geisser	.	.
		Huynh-Feldt	.	.
		Lower-bound	.	.
	Error(VO2max)	Sphericity Assumed		
		Greenhouse-Geisser		
		Huynh-Feldt		
		Lower-bound		

Table 14

Pairwise Comparisons—One-Way ANOVA

Measure: MEASURE_1

Fitness	(I) VO2max	(J) VO2max	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound
VO2max > 50	1	2	6.918*	1.284	.000	3.486
		3	7.624*	1.128	.000	4.607
	2	1	-6.918*	1.284	.000	-10.349
		3	.706	.611	.795	-.927
	3	1	-7.624*	1.128	.000	-10.640
		2	-.706	.611	.795	-2.339
VO2max < 50	1	2	-2.182	1.117	.238	-5.386
		3	-.545	.920	1.000	-3.185
	2	1	2.182	1.117	.238	-1.023
		3	1.636	.592	.060	-.063
	3	1	.545	.920	1.000	-2.094
		2	-1.636	.592	.060	-3.335

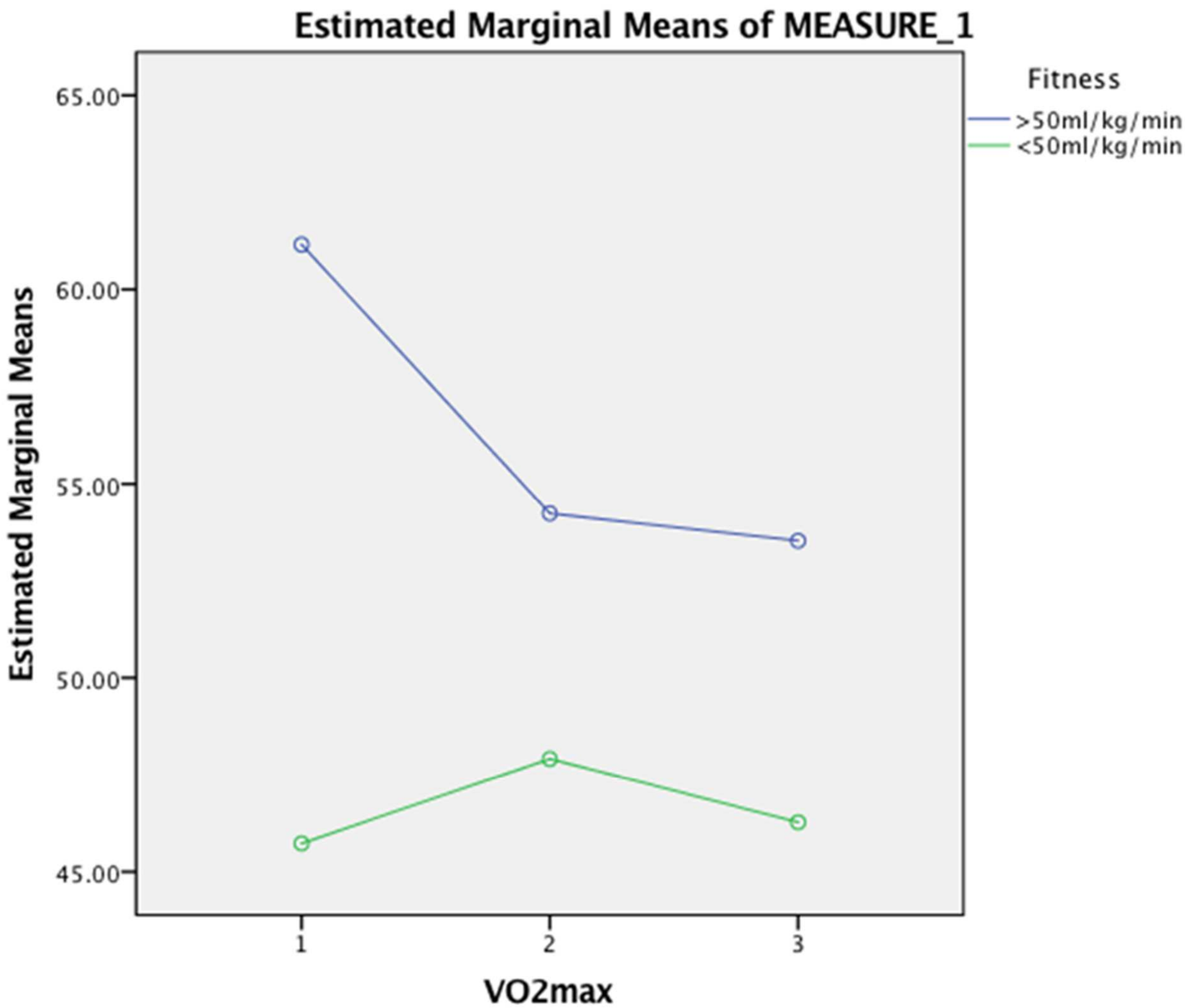

Figure 1. Direct, predicted, and adjusted VO_{2max} values by group.

Chapter 5

Summary

The purpose of this study was to evaluate the predictability of VO_{2max} using a commercially available global positioning system (GPS) sports watch. Three separate VO_{2max} values were recorded for each participant, which included a directly measured VO_{2max} using a treadmill (TM) based graded exercise test (GXT), a predicted value following a 15-minute submaximal outdoor run while wearing the GPS sports watch, and an adjusted predicted value that was influenced by three additional outdoor runs of at least 30 minutes in duration. The secondary aim of this study was to examine if the watch could accurately predict VO_{2max} for individuals with a VO_{2max} of greater than 50 ml/kg/min and for individuals with a VO_{2max} of less than 50 ml/kg/min as measured during the GXT. A two-way repeated measures ANOVA was conducted, and the pairwise comparison results indicated that a statistically significant difference existed between directly measured VO_{2max} and predicted VO_{2max} (p-value $< .05$), directly measured and adjusted predicted VO_{2max} (p-value $< .001$), and predicted and adjusted predicted VO_{2max} (p-value $< .05$). After subjects had been split into two groups based on directly measured VO_{2max} (high or low group), a one-way repeated measures ANOVA was conducted. The results indicated that a statistically significant difference existed between directly measured and predicted VO_{2max} for the high VO_{2max} group (p-value $< .001$). A significant difference was also observed between directly measured and adjusted predicted VO_{2max} for the high group (p-value $< .001$). However, no significant difference existed between predicted and adjusted predicted VO_{2max} (p-value $> .05$). No significant difference existed between VO_{2max} values for the low VO_{2max} group (p-value $> .05$).

Predictors of VO2max

The Garmin Forerunner 235™ utilizes a regression equation to predict VO_{2max} after a single 10-minute self-paced outdoor run. As there are several variables used to predict VO_{2max}, it is difficult to determine which is the largest contributor to inaccuracies observed in the predicted VO_{2max} results. When programming the smart watch for a given participant, age, weight, height, gender (male or female), and maximal heart rate (HR) are entered before any exercise takes place. After a single activity, time of completion, distance, average and maximal HR during exercise, pace, and kcal are recorded. VO_{2max} is likely predicted using a combination of variables including, but not limited to, age, weight, height, gender, average and maximal HR during exercise, distance, and pace for a recorded activity. Each of these variables contributes to the prediction equation and the magnitude of its effect is likely determined by the constant the variable is multiplied by and whether the variable is assigned as a positive or negative in the regression equation. As with most VO_{2max} estimates, a linear regression model is typically used to predict VO_{2max} (Bradshaw et al., 2005; Ebbeling et al., 1991; George et al., 1993, 1997, 2007, 2009, Heil et al., 1995; Jackson et al., 1990; Kline et al., 1987; Schembre et al., 2011; Vehrs et al., 2011; Webb et al., 2014). As most of the variables remain unchanged during exercise, pace and heart rate are assumed to be the largest contributors in the prediction equation.

Pace is expected to be a major factor in the regression model as it is the quotient of distance and time for a given activity. Pace can vary greatly across individuals and in this study pace ranged from 6:22 min/mile to 12:46 min/mile. With such a large range, possibly due to variations in elevation and surface (trail or pavement), it is reasonable to believe that pace is one of the largest contributing variables. Since HR is the greatest contributing physiological variable and was recorded at the radial pulse using an optical sensor, it can be assumed that HR has the greatest effect on VO_{2max} prediction. This is reasonable to assume because HR is a tightly regulated homeostatic variable by the parasympathetic and sympathetic nervous systems and regardless of fitness level, HR increases in response to exercise. The magnitude of increase is what differs between untrained and trained individuals. This key physiological adaptation to training is what led to differences in VO_{2max} prediction if all other variables are held constant.

The wide range of pace mentioned above can be contributed to unobservable differences in elevation during the additional outdoor runs. The Garmin Forerunner 235™ does not record elevation changes during exercise within the watch itself. While this could be considered a limitation to the study, only this watch and its built-in features were tested. Higher-end models developed by Garmin™ have the technology to record elevation, which could greatly influence the predicted VO_{2max} value if the individual is a trail runner or performs outdoor runs in areas with large changes in elevation. However, the Garmin Connect™ mobile application does have an elevation-recording feature. After recording a run using the 235 and syncing the activity with the Garmin Connect™ application, more detailed results are displayed including elevation throughout exercise. While the GPS sports watch itself does not have the ability to record changes in elevation, the mobile application can based on GPS data. Due to this difference in technology, the effect of changes in elevation on pace can be excluded as a limitation because the watch does not include this feature. Future studies with the 235 could enforce stricter requirements for exercise by limiting elevation changes and instructing participants to complete different types of exercise activities such as including longer distance or faster, anaerobic threshold level runs.

Age is another variable to examine in closer detail in regard to prediction equations and exercise data. As is typically the case in exercise physiology, age is often assigned as a negative variable in exercise regression equations. At first glance, this is a reasonable decision because cardiorespiratory fitness typically diminish with age, which is why norms for VO_{2max} decline with age. This idea presents a problem when evaluating regression equations that predict VO_{2max} using multiple variables, particularly in highly fit individuals. For the general population, a decline in fitness with age is normal due to increased time spent inactive and less time spent participating in physical activity (PA). However, in highly fit individuals, specifically, regular runners, this decrease in cardiorespiratory fitness, and therefore VO_{2max}, is often mitigated to a significant degree (Rogers, Hagberg, Martin, Ehsani, & Holloszy, 1990). While a relatively narrow range of individuals were tested in the present study, 24.71 ± 5.69 (mean ± standard deviation) years old due to the convenience of participant recruitment on a college campus, one highly-active male, age 46, was included in the analysis. Interestingly, the male's directly measured VO_{2max} was 55.4 ml/kg/min while the predicted and adjusted predicted VO_{2max} were 59 and 57 ml/kg/min respectively. In contrast, a female, age 39 had a directly measured VO_{2max} of 46.6 ml/kg/min and a predicted and adjusted predicted VO_{2max} of 43 ml/kg/min. While both individuals were significantly older than the large majority of participants tested in the study, opposite results were produced than what was typically observed for the low and high VO_{2max} groups. An overestimate of VO_{2max} was observed for the 46-year-old male while an underestimate of VO_{2max} was observed for the 39-year-old female, opposite of what was observed on average for other participants in both groups. A few conclusions can be drawn from the participant's age, fitness levels, and VO_{2max} values. As observed in the one-way repeated measures

ANOVA, the watch was able to accurately predict VO_{2max} for the low group (< 50 ml/kg/min) while unable to predict VO_{2max} for the high group (> 50 ml/kg/min). For all other individuals in the high VO_{2max} group (*N* = 16), an underestimate in prediction was produced. However, an overestimate was produced in this case. Although there are many variables used in the prediction equation of the watch, these results suggest that age may be a large contributor in the regression equation because although these participants were significantly older compared to others in the study, their predicted VO_{2max} values were opposite compared to all other participants. Additionally, as all participants recruited in this study were active individuals, the fitness levels of the older participants indicate that regular training while aging can combat reductions in cardiorespiratory fitness levels that are typically seen with age. Research shows that in sedentary males, VO_{2max} declines roughly 12% per decade whereas in master athletes, VO_{2max} declines only 5.5% per decade. These results indicate that regular endurance training overtime can blunt the decrease in VO_{2max} by roughly one-half (Rogers et al., 1990).

Similar Research

A recently published abstract compared the predicted VO_{2max}, average and maximal HRs during exercise, cadence, distance, and kcals during a 10-minute self-paced outdoor run in males and females using the Garmin Forerunner 230™ and 235™ (Willoughby et al., 2017). The notable difference between these two devices is that the 230 uses a chest strap to record HR while the 235 uses an optical sensor integrated into the watch to record HR via the radial pulse. This major technological advancement between devices led to differences in average HRs and predicted VO_{2max} values. A significant difference between average HR was observed in males and females with the 230 model yielding a higher average HR. In males, a significant difference in predicted VO_{2max} was found across devices. The 230 predicted a lower VO_{2max} value while no significant difference existed for females. No significant differences were found in maximal HR, distance, pace, and kcal between watches (Willoughby et al., 2017). The main conclusion that was drawn from these results was that due to the lower average HRs recorded using the 235 wrist-based optical sensor model, higher predicted VO_{2max} values were produced. The 235 predicted a higher VO_{2max} value in males, which indicates that variation in average HR is the sole contributing factor to the observed differences.

From a physiological viewpoint, the observed results make sense because if the average HR recorded during an exercise bout was lower than the true value, then the predicted VO_{2max} value would be higher than expected. For example, if two participants with the exact same characteristics (age, weight, height, and maximal HR) were to complete a 15-minute run with an average pace of 7:30 min/mile, the total distance completed would be two miles. If participant one completed the run with an average HR of 160 beats per minute (bpm) and a maximal HR of 180 bpm while participant two completed the run with an average HR of 175 bpm and a maximal HR of 180 bpm, then their predicted VO_{2max} values would be different. Since all other variables were held constant, the only changing and therefore influential variable in the regression model would be average HR during the run. The predicted VO_{2max} value would therefore be higher in the participant with the lower average HR. This is reasonable to conclude as participant one would have completed the run with an overall lower effort level, which when using only a linear regression model would yield a higher VO_{2max} value because the "perceived effort" by the watch would be lower for this individual. However, this concept does not explain the general trend of underestimation of VO_{2max} observed in this study for participants who produced a directly measured VO_{2max} value of greater than 50 ml/kg/min. In comparison to Willoughby et al.'s (2017) results, inaccuracies in prediction made by the smart watch seem to occur when participants with a high level of cardiorespiratory fitness are tested as the watch consistently underestimated VO_{2max} after an initial 15-minute outdoor run and after additional activity recording.

Similar to the present study, another recently published abstract examined the accuracy of VO_{2max} prediction across multiple smart watches including the V800 by Polar™ and the Garmin Forerunner 230™ and 235™ (Snyder et al., 2017). The study compared a directly measured VO_{2max} value obtained using a GXT to a VO_{2max} value predicted by the smart watch. The V800 predicts VO_{2max} based on a resting HR variability test while the 230 and 235 predict VO_{2max} based on a 10-minute self-paced outdoor run (Snyder et al., 2017). The main difference between the protocols of Snyder et al. (2017) and the current study is the requirement of additional activity input used in this study. Garmin™ recommends that additional exercise data is necessary to increase the accuracy of prediction of VO_{2max} (Garmin™, 2015). The results of Snyder et al.'s study demonstrated that a significant difference existed between directly measured VO_{2max} and all predicted VO_{2max} values with a general overestimate of VO_{2max} produced by the smart watches. This is an interesting difference in results between the two studies. While both studies found a significant difference in directly measured and predicted VO_{2max}, an underestimate of VO_{2max} was typically observed in the present study.

This major disagreement between studies can be contributed to two distinct differences: average directly measured VO_{2max} and the requirement of additional activity input to adjust the predicted VO_{2max} value. The average direct VO_{2max} for Snyder et al.'s

(2017) study was 49.5 ± 5.8 ml/kg/min and 42.9 ± 4.8 ml/kg/min for males and females, respectively. The average direct VO_{2max} for this study was 59.0 ± 6.9 ml/kg/min and 51.2 ± 10.8 ml/kg/min for males and females, respectively. These differences can likely be contributed to the inclusion criteria for this study as only participants who run on a regular basis were recruited. Because of the higher average direct VO_{2max} recorded in this study, the trend of underestimate of prediction is reasonable. From the results of this study, it can be concluded that the Garmin™ Forerunner 235 has problems predicting VO_{2max} for individuals with a higher direct VO_{2max}.

The reason for this underestimation is difficult to determine, but the authors theorize that the linear regression model used to predict VO_{2max} is the most likely contributor to the inaccuracies. A linear regression model is problematic in exercise physiology because as the extremes of measurement are approached the uniform nature of a linear model assumes that the largest contributing variables will produce the same result across all individuals. For example, if a highly-trained individual with a direct VO_{2max} of 75 ml/kg/min completes a 15-minute run with an average HR of 180 bpm and an untrained individual with a VO_{2max} of 50 ml/kg/min completes a 15-minute run with an average HR of 180 bpm at the same pace, the smart watch has no method to discern the differences in cardiorespiratory fitness. The physiological adaptation of training is typically a lower resting HR and therefore a higher stroke volume during exercise to lead to an overall increase in VO_{2max}. Exercise HR at any given intensity isn't inherently lower after training although the highly-trained individual would likely have an easier time at the given pace and therefore less overall effort when performing the run in this example. This issue suggests that an exponential regression model may be more appropriate and lead to increased accuracy when predicting VO_{2max} using exercise data from a smart watch.

Strengths and Limitations

Strengths of the study included testing participants with a wide range of VO_{2max} values, evaluating new technology with almost no existing literature, assessing the prediction capability of the device beyond the base claims in the directions, and using three separate VO_{2max} values to increase the accuracy of prediction. Testing participants with a wide range of VO_{2max} values was a strength of the study because this allowed individuals with different levels of cardiorespiratory fitness to be tested. As the Garmin Forerunner 235™ claims to be able to predict VO_{2max} after a 10-minute outdoor run while recording HR, a wide range of participants is important to assess these claims. If every participant tested had the same or similar directly measured VO_{2max} value, conclusions could only be drawn for a narrow range of VO_{2max} values. Overall, this can be viewed as a strength as opposed to a limitation of the study because the watch's predictability feature was tested using participants with VO_{2max} values ranging from 41.4 ml/kg/min to 77.7 ml/kg/min. As very little literature exists on the topic of predictability of VO_{2max} using a GPS watch, this is an obvious strength of the study. The results of this study hope to spark interest in the growing field of wearable devices, GPS technology, exercise testing, and physical activity measurement research.

As mentioned above in the methods section, an additional strength of the study is assessing the prediction model of the watch beyond what the directions state. The Garmin Forerunner 235™ predicts a VO_{2max} value after running outdoors for a minimum of 10 minutes while recording HR using the radial pulse through a sensor located on the back of the watch face. In this study, participants ran for 15 minutes instead to ensure that a value was predicted. In some cases, a VO_{2max} was not predicted after running for 10 minutes during pilot testing. This is likely due to HR data as Garmin's owner's manual states that erratic HR data recording may occur[68]. The websites also lists steps to minimize this from occurring such as warming up for 5–10 minutes. Because of this recommendation, an additional 5 minutes were added to the outdoor run for a total of 15 minutes to improve predication rates. The watch predicted a VO_{2max} value for all 28 participants during this study on the first attempt. Lastly, an additional three outdoor runs of at least 30 minutes were required by all subjects as Garmin's owner's manual states that "the device requires a few runs to learn about your running performance"(Garmin™, 2015). Additional activity input is a major strength of the study as this is a necessary step when evaluating the predictability of the watch. With subsequent exercise bouts, the predicted VO_{2max} adjusts based on each individual activity. Differences in pace, distance, and time will lead to increases or decreases in VO_{2max}.

Limitations of the study included using GPS to measure PA, recording HR using the radial pulse through an optical sensor on the watch, using a self-selected pace when performing the outdoor runs, and failing to vary the level of intensity of additional outdoor runs recorded by participants. While GPS is a valid and reliable method to measure PA (Wieters et al., 2012) and is used extensively in the literature (McCrorie et al., 2014), interference is still a common occurrence, especially in areas that are obstructed by high-rise buildings (Duncan et al., 2013). Additionally, on days with heavy cloud coverage, the GPS watch required more time to acquire acceptable signal strength before recording an activity. The effect of this limitation was minimized by performing the initial 15-minute outdoor run on a closed 0.5-mile loop in the middle of EMU's campus. There were no tall buildings in the vicinity that could cause obstruction of the GPS signal. Further, the researcher walked to the starting point of the run with each individual participant in order to ensure that the watch displayed "GPS ready" before the participant began the test. Through these practices, potential inaccuracy while using GPS to monitor PA was minimized.

Recording HR via the radial pulse is not the most accurate way to measure HR. For example, if the watch was not secured tightly enough on the participant's wrist, HR values may be much lower or higher than expected. Additionally, if the watch slips to one side of the wrist at any point during the run, the same issue will occur. As is often the case with PA, accumulation of sweat could skew the HR values recorded by the watch, particularly during hot and humid days. To ensure accuracy of HR values, participants were required to secure the watch tightly around their wrist before recording any activity. This was then double checked by the researcher before any testing took place and was thoroughly explained to each participant before leaving the laboratory. While HR inaccuracies are potentially the largest limitation of the study due to its likely profound importance as a variable when estimating VO_{2max} using the GPS watch, the purpose of the study was to examine the accuracy of prediction of VO_{2max} using the standard features of the watch. An important selling point and useful feature of the Garmin Forerunner 235™ is that the watch is able to measure and record HR every second without the use of an electrocardiogram or chest strap. Because of this, the researchers tested the watch's ability to predict VO_{2max} using the built-in HR monitor. Accuracy could potentially be improved if a chest strap was used to measure HR. However, this would defeat the purpose of a minimal PA monitoring device.

A self-selected pace while performing all outdoor runs could also affect the prediction result as participants may not have performed to their full potential for each run. This could have led to an overall slower pace and shorter distance for activities recorded on their own. Participants were not externally motivated and volunteered for this study with no additional benefits to themselves. The researchers did their best to motivate the participants for the initial 15-minute outdoor runs, but subsequent activities were performed off campus and on the participant's own time. Failing to vary the level of intensity of additional outdoor runs recorded by participants is another limitation of the study. For example, when recording additional activities beyond the 15-minute outdoor run at EMU, participant's could have been required to perform different types of exercise by varying the level of intensity through enforcing pace and distance requirements. Participants could have been required to still perform only three additional runs but one of the runs could have consisted of sprint intervals to test the anaerobic energy system where the participant sprinted for 2–3 minutes with 30 seconds of rest between intervals. Additionally, participants could have been required to perform one longer run with a distance of greater than eight miles while maintaining a slower than normal pace to test the aerobic energy system. These ideas could be put to use in future research to further examine the predictability of VO_{2max} of the GPS watch while enforcing stricter requirements for subjects to improve the accuracy of results.

Conclusion

In conclusion, the results indicate that the Garmin Forerunner 235™ did not accurately predict VO_{2max} for the general population. The watch generally underestimated VO_{2max} when compared to a direct value obtained using a maximal TM based GXT. Additionally, the watch was unable to accurately predict VO_{2max} for participants with a

VO_{2max} of greater than 50 ml/kg/min. However, the watch could accurately predict VO_{2max} for individuals with a directly measured VO_{2max} of less than 50 ml/kg/min. While there is no one clear variable responsible for the difference in accuracy of prediction, measuring HR using an optical sensor at the radial pulse is the main factor effecting the results of VO_{2max} prediction. These results suggest that the watch accurately predicts VO_{2max} for individuals who may have a lower cardiorespiratory fitness level. This raises the question of the type of population that Garmin™ is targeting when developing new technology: active, everyday runners with higher than average cardiorespiratory fitness levels or a less active population more concerned with having the latest and greatest fitness gear and technology available on the market.

Recommendations for Further Research and Action

Future research should focus on expanding the number of devices tested to include other smart watches available on the market such as models produced by Polar™ and Suunto™ and other more advanced models developed by Garmin™. Comparing the prediction results of three separate smart watches to a direct measurement could lead to a better understanding of why certain models overestimate or underestimate VO_{2max}. Additionally, future research could concentrate on testing the intra-device reliability of VO_{2max} prediction using multiple watches of the same model. This could include testing the reliability of several devices produced by different companies. Examining minor average HR differences or GPS inaccuracies could lead to explaining conflicting VO_{2max} prediction results. Future research for Garmin™ smart watches specifically could also explore how different types of running based exercise effect the predicted VO_{2max} value. Instead of having participants to record three additional runs of at least 30 minutes in duration, stricter pace and distance requirements could be emphasized. For example, three additional runs could still be utilized in data collection, but each run could be performed at a different intensity level. A longer, slower run could be used to test the participant's aerobic energy system while a shorter, faster run would test the anaerobic threshold and energy systems. Lastly, one-mile repeats could be implemented to test the maximal exercise capacity of participants and require two to three one-mile mile repeats recorded for the same exercise bout. The combination of three different types of running activities could lead to increased accuracy of prediction.

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APPENDICES

Appendix A: Consent Form

RESEARCH @ EMU

Informed Consent Form

The person in charge of this study is Andrew Pearson. Throughout this form, this person will be referred to as the "investigator."

Purpose of the study

The purpose of this research study is to compare predicted VO_{2max} from a commercially available GPS watch versus measured VO_{2max}. VO_{2max} is the maximal amount of oxygen a person can consume during exercise and is considered to be the most accurate measurement of cardiorespiratory fitness.

What will happen if I participate in this study?

Participation in this study involves

- You, the participant, will come to the Running Science Laboratory at Eastern Michigan University on two separate days. There must be one day between visits but no longer than one week. Participation in this study will take no longer than one week.
- Prior to any data collection on day 1, you will complete three forms: Informed Consent, Physical Activity Readiness-Questionnaire (PAR-Q), and a health history. The PAR-Q and health history are to ensure you don't have any existing medical conditions that increase your risk with exercise. Following completion of the forms, height and weight will be taken.
- Day 1 of the study will then consist of a VO_{2max} test on a treadmill. A VO_{2max} test is the recognized criterion for cardiorespiratory fitness. The VO_{2max} test consists of running on a treadmill for approximately 9-12 minutes. Throughout the test, speed and grade will increase until you are no longer able to continue running. During the test, you will wear a mouthpiece connected to a metabolic cart that measures expired gases (VO_2, VCO_2). You will also wear a strap around your chest to measure heart rate. From this test, your measured VO_{2max} and maximal heart rate will be determined. The entire visit on day 1 will take approximately 1 hour.
- Day 2 of the study will consist of 15 minutes of running outdoors. You will wear a wrist worn commercially available GPS watch that predicts VO_{2max}. You will be instructed to run at pace you can sustain for 15 minutes around a 0.45 mile loop around campus. Research assistants will be on the course to ensure you know where to go. When 15 minutes of running are complete, predicted VO_{2max} will be recorded from the GPS watch. The entire visit on day 2 will take approximately 30 minutes.
- Following day 2 of the study, you will be asked to take the GPS watch home with you and record 3 additional bouts of exercise of at least 30 minutes in

duration. The purpose of additional recording is to examine how VO_{2max} is affected following subsequent input of activity. You will have a minimum of 3 and a maximum of 7 days to complete the additional physical activity recordings. Upon completion you will be required to return the GPS watch in person to the Running Science Laboratory at Eastern Michigan University.

What are the anticipated risks for participation?

This study does involve exercise. The risk with exercise in this study is no greater than if you went for a run or exercised at your local gym. You will be constantly monitored during the testing sessions, which will minimize risk. A CPR/First aid trained technician will always be present during testing. If medical treatment is required, the costs will be the participant's responsibility and financial compensation will not be provided by Eastern Michigan University. If a serious injury or illness occurs during testing, 911 will be immediately contacted. You will be kept still and not moved, while only trained personnel will provide first aid or CPR. A research assistant will contact EMU public safety at 734-487-1222, to inform them of the emergency and to respond and/or guide the EMS personnel to the victim.

The primary risk of participation in this study is a potential loss of confidentiality.

Are there any benefits to participating?

You will not directly benefit from participating in this research.

What are the alternatives to participation?

The alternative is not to participate.

How will my information be kept confidential?

We will keep your information confidential by using a code to label data with the code linked to identifiable information in a key stored separately from data. Your information will be stored on a password-protected computer and in a locked filing cabinet in the Running Science Laboratory. We will make every effort to keep your information confidential, however, we cannot guarantee confidentiality. There may be instances where federal or state law requires disclosure of your records.

Other groups may have access to your research information for quality control or safety purposes. These groups include the University Human Subjects Review Committee, the Office of Research Development, the sponsor of the research, or federal and state agencies that oversee the review of research. The University Human Subjects Review Committee reviews research for the safety and protection of people who participate in research studies.

We may share your information with other researchers outside of Eastern Michigan University. If we share your information, we will remove any and all identifiable information so that you cannot reasonably be identified.

The results of this research may be published or used for teaching. Identifiable information will not be used for these purposes.

Storing study information for future use

We would like to store your information from this study for future use related to comparing predicted VO_{2max} from a commercially available GPS watch versus measured VO_{2max}. Your information will be labeled with a code and not your name. Your information will be stored in a password-protected or locked file. Your de-identified information may also be shared with researchers outside of Eastern Michigan University. Please initial below whether or not you allow us to store your information:

_________Yes   __________No

Are there any costs to participation?

Participation will not cost you anything.

You will be responsible for your transportation costs to and from the study.

Will I be paid for participation?

You will not be paid to participate in this research study.

What happens if I am injured while participating in the research?

If you are injured as a result of participating in this study, we will assist you in getting necessary medical treatment. You or your insurance company will be responsible for the cost. Eastern Michigan University does not provide any form of compensation for injury.

Study contact information

If you have any questions about the research, you can contact the Principal Investigator, Andrew Pearson, at apears12@emich.edu or by phone at 734-751-2922.

For questions about your rights as a research subject, contact the Eastern Michigan University Human Subjects Review Committee at human.subjects@emich.edu or by phone at 734-487-3090.

Voluntary participation

Participation in this research study is your choice. You may refuse to participate at any time, even after signing this form, with no penalty or loss of benefits to which you are otherwise entitled. You may choose to leave the study at any time with no loss of benefits to which you are otherwise entitled. If you leave the study, the information you provided will be kept confidential. You may request, in writing, that your identifiable information be destroyed. However, we cannot destroy any information that has already been published.

Statement of Consent

I have read this form. I have had an opportunity to ask questions and am satisfied with the answers I received. I give my consent to participate in this research study.

Signatures

____

Name of Subject

______________________________________ ____________________

Signature of Subject Date

I have explained the research to the subject and answered all his/her questions. I will give a copy of the signed consent form to the subject.

____

Name of Person Obtaining Consent

______________________________________ ____________________

Signature of Person Obtaining Consent Date

Approved by the Eastern Michigan University Human Subjects Review Committee
UHSRC Protocol Number: 985862-1
Study Approval Dates: 11/15/16 – 11/14/17

Appendix B: Physical Activity Readiness Questionnaire

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________________

SIGNATURE OF PARENT ______________________________ WITNESS ______________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

continued on other side...

Appendix C: Health-History Questionnaire

AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire* (Medical History Form)

Assess your health status by marking all true statements

History

You have had:

_______ a heart attack
_______ heart surgery
_______ cardiac catheterization
_______ coronary angioplasty (PTCA)
_______ pacemaker/implantable cardiac defibrillator, or rhythm disturbance
_______ heart valve disease
_______ heart failure
_______ heart transplantation
_______ congenital heart disease

Symptoms

_______ You experience chest discomfort with exertion.
_______ You experience unreasonable breathlessness.
_______ You experience dizziness, fainting, or blackouts.
_______ You take heart medications.

> If you marked any of these statements in this section, consult your physician or other appropriate health care provider before engaging in exercise. You may need to use a facility with a **medically qualified staff**.

Other Health Issues

_______ You have diabetes.
_______ You have asthma or other lung disease.
_______ You have burning or cramping sensation in your lower legs when walking short distances.
_______ You have musculoskeletal problems that limit your physical activity.
_______ You have concerns about the safety of exercise.
_______ You take prescription medication(s).
_______ You are pregnant.

Cardiovascular Risk Factors

_______ You are a man older than of 45 years.
_______ You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal.
_______ You smoke, or quit smoking within the previous 6 months.
_______ Your blood pressure is > 140/90 mmHg.
_______ You do not know your blood pressure.
_______ You take blood pressure medication.
_______ Your blood cholesterol level is > 200 mg/dl.
_______ You do not know your cholesterol level.
_______ You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister).
_______ You are physically inactive (i.e., you get < 30 minutes of physical activity on at least 3 days per week.)
_______ You are > 20 pounds overweight.

> If you marked two or more of the statements in this section you should consult your physician or other appropriate health care provider before engaging in exercise. You might benefit from using a facility with a **professionally qualified exercise staff+** to guide your exercise program.

_______ None of the above

> You should be able to exercise safely without consulting your physician or other appropriate health care provider in a self-guided program or almost any facility that meets your exercise program needs.

+Professionally qualified exercise staff refers to appropriately trained individuals who possess academic training, practical and clinical knowledge, skills, and abilities commensurate with the credentials defined in Appendix F of the ACSM Guidelines 2006.

*Modified from American College of Sports Medicine and American Heart Association. (1998). ACSM/AHA joint position statement: Recommendations for cardiovascular screening, staffing, and emergency policies at health/fitness facilities. *Medicine & Science in Sports & Exercise*: 1018. Reprinted with permission.

Appendix D: IRB Permission Letter

RESEARCH @ EMU

UHSRC Determination: **EXPEDITED INITIAL APPROVAL**

DATE: **November 15, 2016**

TO: **Andrew Pearson, B.S.**
Eastern Michigan University

Re: **UHSRC: # 985862-1**
Category: Expedited category 4
Approval Date: November 15, 2016
Expiration Date: November 14, 2017

Title: **Predictability of VO2max using A GPS sports watch**

Your research project, entitled **Predictability of VO2max using A GPS sports watch,** has been approved in accordance with all applicable federal regulations.

This approval included the following:

1. Enrollment of *40* subjects to participate in the approved protocol.
2. Use of the following study measures: *Garmin VO2 max test sheet; Health History; PAR_Q*
3. Use of the following stamped recruitment materials: *Recruitment Email*
4. Use of the stamped*: Informed consent form*

Renewals: This approval is valid for one year and expires on November 14, 2017. If you plan to continue your study beyond November 14, 2017, you must submit a Continuing Review Form by October 15, 2017 to ensure the approval does not lapse.

Modifications: All changes must be approved prior to implementation. If you plan to make any minor changes, you must submit a **Minor Modification Form.** For any changes that alter study design or any study instruments, you must submit a **Human Subjects Approval Request Form**. These forms are available through IRBNet on the UHSRC website.

Problems: All major deviations from the reviewed protocol, unanticipated problems, adverse events, subject complaints, or other problems that may increase the risk to human subjects **or** change the category of review must be reported to the UHSRC via an **Event Report** form, available through IRBNet on the UHSRC website

Follow-up: If your Expedited research project is not completed and closed after **three years,** the UHSRC office requires a new **Human Subjects Approval Request Form** prior to approving a continuation beyond three years.

Please use the UHSRC number listed above on any forms submitted that relate to this project, or on any correspondence with the UHSRC office.

Good luck in your research. If we can be of further assistance, please contact us at 734-487-3090 or via e-mail at human.subjects@emich.edu. Thank you for your cooperation.

Sincerely,

Joan Cowdery, PhD
Vice Chair
University Human Subjects Review Committee

Appendix E: Proposal Approval Form

EASTERN MICHIGAN UNIVERSITY

Master's Thesis PROPOSAL

Approval Form

Student Name Andrew Pearson Date of Meeting 10-27-16

Program of Study Exercise Physiology ID# E 01474578

TENTATIVE TITLE OF PROPOSED THESIS

Predictability of VO_{2max} using a commercially available GPS sports watch

COMMITTEE REPORT ON THESIS PROPOSAL

After review of the thesis proposal, the Thesis Committee certifies that:

[X] The proposal is satisfactory and the candidate may proceed.

- [ ] The proposed research does NOT involve the use of human or animal subjects
- [X] The proposed research involves human subjects and will be sent to the College Human Subjects Review Committee before data collection
- [ ] The proposed research involves animal subjects and will be sent to the Institutional Animal Care & Use committee (IACUC)
- [ ] The proposed research involves invertebrates (animal subjects that do not require IACUC oversight)

[ ] The proposal is not satisfactory and the following deficiencies must be corrected:[2]

Description of deficiencies ____________________

COMMITTEE SIGNATURES

Chair Name Rebecca Moore Signature [signature]

Member Name Christopher Herman Signature [signature]

Member Name Jeff Schulz Signature [signature]

Member Name ____________ Signature ____________

Member Name ____________ Signature ____________

ACKNOWLEDGEMENT OF PROPOSAL APPROVAL

Date 10-27-16 Program Coordinator/Dept. Head [signature]

Signed original form remains in the student's departmental/program file.

Appendix F: Thesis Defense Approval Form

EASTERN MICHIGAN UNIVERSITY

Graduate School

MASTER'S THESIS

Document Approval Form

Student Name Andrew Pearson

Program of Study Exercise Physiology ID# E 01474578

Academic Department/School Health Promotion & Human Performance

College Health & Human Services

TITLE OF THESIS

Predictability of $\dot{V}O_{2max}$ using a commercially available GPS sports watch

DOCUMENT APPROVAL

COMMITTEE SIGNATURES

Chair [signature] Date 6/22/17

Members [signature] Date 6/22/17

[signature] Date 6-22-2017

Date

Date

ACKNOWLEDGEMENT OF COMPLETED THESIS

Date 6-22-2017 Administrator [signature]

(Department Head/School Director)

GRADUATE SCHOOL

DOCUMENT HAS BEEN SUBMITTED AND EDITED – DEGREE MAY BE CONFERRED

Date ______ Graduate School ______

Signed original goes to Record's student file. Copies/pdf to: Graduate School, chair, and department/college file

Figure 11. **Thesis document approval form.**

Note: some departments use a slightly different form changing the titles for the persons who will sign the document (e.g., English).

Appendix G: Data Collection Sheet

VI

VO_{2max} Pre-test Measurements

Subject number: _____________ **Date: __________________**

Gender ________________ **Date of Birth: ______________** **Age: _____________**

Weight: ________ kg ________ kg Average: __________ kg wt. in lbs._________

Height: ________ cm _________ cm Average: __________ cm ht. inches _______

VO_{2max} Test

Speed: _________ mph

Time	**Work (mph)/ Grade (%)**	**HR**	**VO_2 (ml/kg/min)**
1:00 min. Baseline	0 / 0 %		
2:00 min.	0 / 0 %		
1:00 min. Exercise	/ 0 %		
2:00 min.	/ 0 %		
3:00 min.	/ 2 %		
4:00 min.	/ 2 %		
5:00 min.	/ 4 %		
6:00 min.	/ 4 %		
7:00 min.	/ 6 %		
8:00 min.	/ 6 %		
9:00 min.	/ 8 %		
10:00 min.	/ 8 %		
11:00 min.	/ 10 %		
12:00 min.	/ 10 %		
13:00 min.	/ 12 %		
14:00 min.	/ 12 %		

VO_{2max} : _____________ ml/kg/min

V2

Date	
Ambient Temp	
Relative Humidity	
Predicted VO_{2max} (ml/kg/min)	
Pace (min/mile)	
Time of completion (min.)	
Distance (mile)	

Post V2

Run #1	**Date**
Pace (min/mile)	
Time of completion (min.)	
Distance (mile)	
Run #2	**Date**
Pace (min/mile)	
Time of completion (min.)	
Distance (mile)	
Run #3	**Date**
Pace (min/mile)	
Time of completion (min.)	
Distance (mile)	
Adjusted predicted VO_{2max} (ml/kg/min)	

Appendix H: Curriculum Vitae

Andrew G. Pearson, B.S.

Graduate Assistant, Eastern Michigan University

Ypsilanti, MI 48197

Email: apears12@emich.edu

Phone: (734)-751-2922

Education

M.S. Eastern Michigan University, Health and Human Services – Exercise Physiology

Thesis topic: Predictability of VO_{2max} using a GPS sports watch July 2017

B.S. University of Michigan, Kinesiology – Movement Science 2015

Academic Appointments

Eastern Michigan University

School of Health Promotion and Human Performance

Graduate Assistant

January 2016 – August 2017

Professional Memberships

Midwest Chapter of American College of Sports Medicine (2016-present)

American College of Sports Medicine (2016-present)

Teaching Experience

Eastern Michigan University:

Instructor: SPMD 300/PHED 205: Physiology of Exercise (Lab, 5 sections)

TA: SPMD 410: Laboratory Techniques in Human Performance (3 sections)

Undergraduate Research Experience

University of Michigan

Intern: Physical Activity Lab

Weight Management Program

Fueling Exercise Study – "Investigating the association between exercise capacity, fuel selection and metabolic health using metabolomics."

Awards

Exercise Physiology Graduate Student of the Year – Eastern Michigan University 2017

Travel Award – ACSM Annual Conference Denver, CO May 2017

Publications in progress

Moore, R.W., Pfeiffer, K.A., Aubrey, A.J., Shelton, R., **Pearson, A.G.**, Vielbig, L., Peyer, K., Trost, S.G. Validation of a simultaneous heart rate and motion sensor device during free-living activity in youth.

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