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Predictability of VO2max from three commercially available devices

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Predictability of VO_{2max} From Three Commercially Available Devices

by

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Dedication

Thank you, mother, for being the disciplinarian in my upbringing. Your courage and vigor allowed me to grow to be courageous and vigorous in my endeavors. Words cannot express my gratitude for you being the solid rock in our family and for keeping us together when we were all going in different directions. One of my favorite memories of us, was learning how to ride my bike in Wilshire Ridge. I can picture myself, with bruises and scrapes, riding down that road into the night, knowing my one and only mother was watching me succeed; I eagerly await to feel that again. I love you, ma.

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Abstract

The Polar V800™, A300™, and Garmin Forerunner 235™ predict VO_{2max} from a submaximal effort. **Purpose:** To examine the predictability of VO_{2max} from two heart rate monitors (Device A and V) and a global positioning system (GPS) watch compared to measured VO_{2max}. **Methods:** Forty participants, 22 males and 18 females ages 18 to 55, came to the Running Science Laboratory at Eastern Michigan University. During visit 1, participants completed a maximal graded exercise test (GXT) to determine VO_{2max}. At visit 2, each device's protocol was followed to estimate VO_{2max}. Pearson correlations, repeated measures ANOVA, and a paired samples t-test were utilized to compare estimated VO_{2max} values from the devices to measured VO_{2max} from the GXT ($p < 0.05$). **Results:** Ten participants were excluded. The GPS watch revealed a RMANOVA *p*-value < .001 for participants with > 50 ml/kg/min VO_{2max}. **Conclusion:** Even though there were moderate to strong relationships, all three watches underestimated VO_{2max} compared to measured VO_{2max}.

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Chapter 1:
Introduction and Background

Possessing a commercially available device that accurately predicts VO_{2max} serves as a valuable tool for individuals to learn about their overall cardiorespiratory fitness (CRF). CRF is a health-related component of physical fitness defined as the ability of the circulatory, respiratory, and muscular systems to supply oxygen during sustained physical activity (Lee, 2010). CRF is usually expressed as maximal oxygen uptake (VO_{2max}) measured by exercise tests on a treadmill or a cycle ergometer (Lee, 2010). Since physical inactivity is ever increasing in our modern society, so is the prevalence of fitness-based products attempting to inform the consumer of their overall health. Many relatively inexpensive products on the market today can inform consumers wearing such devices of the individual's calories, steps, heart rate, and now, an estimated VO_{2max}. The purpose of this study was to determine the predictability of VO_{2max} from two commercially available Polar™ devices, the V800™ and A300™, and one Garmin Forerunner 235™ GPS watch, all compared to a laboratory conducted true VO_{2max} test.

Maximal oxygen uptake, or more formally known as VO_{2max}, is defined as the maximal capacity for oxygen consumption by the body during maximal exertion (Kenney et al., 2008). The process of evaluating and estimating VO_{2max} first became popular at the Harvard Fatigue Laboratory in the 1920s by A.V. Bock, D.B. Dill, and A.V. Hill (Kenney, et al., 2008). When these scientists were first experimenting in Harvard Fatigue Laboratory, they were interested in collecting expired air during exercise in pursuit of analyzing that air for levels of oxygen and carbon dioxide specifically. These initial collections would take scientists 20-30 minutes to analyze a single minute of collected expired air from exercise without the aid of computers (Kenney et al., 2008). Today, liters of expired air are captured and analyzed within seconds using equipment such as a spirometer and a metabolic cart. Today's technology also offers equations that can be derived from the collected gases. These equations include the ventilatory equivalent for oxygen (V_E/VO_2), the ventilatory equivalent for carbon dioxide (V_E/VCO_2), and the respiratory exchange ratio (RER; McArdle et al., 2010).

The RER is calculated by the volume of carbon dioxide produced from oxygen during ventilation (VCO_2) divided by the ventilation volume of oxygen consumed (VO_2). This ratio was devised to analyze and quantify what percentage of macronutrient substrates are being utilized to meet the energy demands of the body to sustain a given level of physical activity. A high RER indicates that carbohydrates are predominantly being used, whereas a low RER suggests lipid oxidation (Pendergast et al., 2000; Simonson et al., 1990). An RER value of 1.05 or greater, achievement of 95% of age-predicted maximum heart rate, a plateau in VO_2, and complete volitional exhaustion are all measures that are indicative of a true VO_{2max} (Kline et al., 1987). VO_2 increases linearly with increases in exercise workload, until a workload is reached at which VO_2 no longer increases and plateaus despite further increases in work intensity (Hawkins et al., 2007). The unit for VO_{2max} is comprised of the amount of oxygen consumed in milliliters per kilogram of body weight per minute, noted as ml/kg/min. Every human requires a daily expenditure of calories and must consume oxygen to fuel this process. It is known that an approximate VO_2 of 18 ml/kg/min is required for daily living (Shepard, 2008).

This is an imperative value to understand as we digress to a more sedentary and overweight society in the United States of America.

In 1964, about 46% of adults in the United States fell into the categories of being overweight, obese, and extremely obese (Flegal et al., 2010). Of those, 32% of adults were overweight, 13% were obese, and about 1% had extreme obesity (Flegal et al., 2010). By 2010, the percentage of adults considered overweight, obese, or extremely obese had climbed to approximately 75% (Flegal et al., 2010); 33% were considered overweight, 36% were considered obese, and about 6% were considered extremely obese (Flegal et al., 2010). As these numbers continue to rise in 2017, companies have released products for consumers to track their overall fitness and daily caloric expenditure to curb national obesity levels. As an individual becomes more sedentary, it is understood that there is a massive decrement in physical capability, and an increased risk of cardiovascular disease (CVD). Approximately 638,000 people die every year in the United States of CVD, which equates to one in every four adult deaths (Center for Disease Control and Prevention [CDC], 2019). CVD is the leading cause of death for both men and women (CDC, 2019). CHD is the most common type of CVD, killing over 370,000 people annually (CDC, 2019). Every year about 735,000 Americans experience a myocardial infarction (MI), or heart attack, and of these, 525,000 are a first MI and 210,000 a recurrent MI (CDC, 2019).

With much of our nation's time and devotion to both work and never-ending waves of new and improved technology, exercise is becoming increasingly neglected. Such devices as Garmin Forerunner 235™ and Polar's V800™ and A300™, allow users to monitor their overall VO_{2max} estimation progression in an engaging and convenient way. These devices claim to estimate accurate VO_{2max} values by utilizing both heart rate (Polar™) and distance traveled (Garmin™) for precise predictions. However, there are quite a few physiological factors that influence VO_{2max}. Factors such as age, genetics, gender, preferred method of training, biomechanics of running, hydration, and nutrition all play a pivotal role in an individual's current VO_{2max}, as well as their improvement (McArdle et al., 2010).

Statement of the problem

Amidst the plethora of fitness-based products available on the market today, a handful can predict VO_{2max}. However, most of the products that are available today for consumers haven't been tested for accuracy of predictability for VO_{2max} values. As more products are being released all claiming to predict VO_{2max}, the objective of this study is to compare the predicted VO_{2max} values from three commercially available devices to a true VO_{2max} test.

Purpose

The purpose of this study was to compare predicted VO_{2max} values from the Garmin Forerunner 235™ GPS watch and Polar's V800™ and A300™, respectively, to a true VO_{2max} test conducted in Eastern Michigan University's Running Science Laboratory.

Hypotheses

Based on a review of existing literature and other ongoing laboratory investigations at Eastern Michigan University, the researcher hypothesized that:

1. Polar's most prestigious model utilized in this study, the V800™, will possess the greatest precision in predicting VO_{2max} over the Polar A300™, and Garmin's Forerunner 235™ when compared to an actual VO_{2max}.
2. Garmin's Forerunner 235™ will possess the greatest VO_{2max} estimation capability when participants possess a VO_{2max} greater than or equal to 50ml/kg/min, rather than less than 50ml/kg/min.

Limitations

1. Study participation was not restricted to EMU students in the surrounding area of Ypsilanti, Michigan only.
2. The opportunity to participate in the study were not limited to a specific area. However, all subjects were primarily students at Eastern Michigan University (EMU) and may not be a random sample reflective of the entire population.

Delimitations

1. All subjects were between the ages of 18-55, healthy, and capable of completing a VO_{2max} in conjunction with a 15-minute run without cessation.
2. Subjects were required to be participating in regular physical activity, especially in running, with a minimum cardiovascular fitness level (VO_{2max} 35 ml/kg/min) on a treadmill.

Chapter II:
Review of Related Literature

Based off the present study's review of related literature, there is an apparent paucity of conducted studies with professional data explaining if current wearable devices predict VO_{2max}. Current literature states various ways to predict VO_{2max} via submaximal evaluations such as the Rockport walking test, the 1.5 mile run, the Arizona State University (ASU), Ebbeling and Bruce protocols on a treadmill, the bench step test, and the indirect maximal cycle ergometry test. In 1968, Shepard and colleagues stated that it is unrealistic for VO_{2max} values to be measured directly for entire populations primarily because of prohibitive logistic requirements regarding medical supervision (Shepard et al., 1968). Therefore, each of the various ways of predicting VO_{2max} have been designed and crafted based on the population, or clientele using age and level of fitness as factors for consideration regarding which protocol to administer.

Due to the linear relationship between heart rate, oxygen intake, and workload, VO_{2max} can be estimated. In 1954, Astrand and Rhyming devised a nomogram which "connected the dots" between heart rate and work rate on a stationary cycle. Unbeknownst to the researchers at the time, their discovery would become an ever-expanding pathway into the future of cardiorespiratory fitness estimations. Seventy years following that study, our modern world is currently being bombarded with advancements in wearable devices claiming to simplify what these researchers discovered in 1954---VO_{2max} estimations without the use of gaseous analysis technology.

VO_{2max}

The Lavoisier's experiments in the 1780s illustrated the truth that animals consume O_2 and produce CO_2, as well as heat, during respiration (Bassett, 2002). The maximal volume of oxygen, or VO_{2max}, is formally described as the "highest rate of oxygen consumption attainable during maximal, or exhaustive exercise," (Kenny et al., 2012, p. 122). Also stated as the maximal oxygen uptake, VO_{2max} can be defined as the maximum integrated capacity of the pulmonary, cardiovascular, and muscular systems to uptake, transport and utilize oxygen, respectively (Poole et al., 2008). For nearly a century, scientists have devised and identified appropriate means of estimating VO_{2max} with and without the use of laboratory equipment.

Originating in the 1920s, respiratory gas analysis has been a notable subject of interest amongst scholars and researchers alike. Traditionally, expired gases were collected via "Douglas Bags," which received their name from renowned physiologist Dr. Claude G. Douglas in the 1910s (Bassett, 2002). The Douglas Bag method would take previous researchers hours to analyze gas exchange. However, today, this can be completed instantaneously with the use of the PARVO metabolic cart, or a comparable gas exchange analysis system. Following the invention of the Douglas bag, Dr. Archibald V. Hill and his colleagues set out to answer the question of "Is there a relationship between oxygen intake and work rate?" Using himself as the sole participant in his research project, Dr. Hill ran around an 85-meter grass track at Manchester University (Basset, 2002). The expired air samples were collected in a Douglas bag strapped to Dr. Hill's back which in turn required a series of five to six trials at a single running speed, with Dr. Hill opening and closing the three-way valve over a 30 second time interval whilst attempting to minimize air loss (Bassett, 2002). The Douglas bags were then carefully analyzed for percentage of O_2 and CO_2 by use of a Haldane gas analyzer (Bassett, 2002). The bag volume was measured by a Tissot gasometer and O_2 intake was calculated by the Haldane transformation of the respiratory Fick equation (Basset, 2002). By repeating this whole procedure numerous times, they were able to analyze the time course of the increase in O_2 intake at various running speeds (Bassett, 2002). These researchers could quantify what is now referred to as RER, or respiratory exchange ratio. This ratio is used to reflect the balance between hydrogen ion accumulation and bicarbonate buffering in incrementally vigorous exercise (Beltz et al., 2016). During intense levels of physical activity (PA), there is an increase in metabolic acidosis which leads to an increase in CO_2 production, increased ventilation, and thus an increase in RER (Issekutz et al., 1961). This term was coined "excess CO_2" and is used to reflect the change in macronutrient substrate utilization and exercise intensity with the increase in VO_2 (Beltz et al., 2016). Dr. Hill and his colleagues performed 14 trials which produced a series of research journals that became landmark studies in the field of exercise physiology today: "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 cardiopulmonary system as opposed to the need for greater amount of oxygen" (Hill et al., 1924; Pearson, 2017).

Since the late 1940s, protocols have been established to accentuate the effects of intense exercise and the physiological ramifications that accompany such vigorous exercise. The founding father of the "stress test," Dr. Robert A. Bruce, is responsible for enacting his vigorous test properly named the Bruce Protocol. A multistage treadmill exercise protocol lasting 21 minutes in duration with the use of both cardiopulmonary functioning equipment (spirometer) and electrocardiography equipment (ECG) during the evaluation (Bruce et al., 1949). His initial interest was cardiovascular health, and this test was to be conducted in a physician's office. Nonetheless, this evaluation is still revered today and is commonly used in clinical exercise physiology settings.

Researcher Taylor and colleagues in 1955 attempted to use their laboratory for determining not only VO_{2max} but also the potential limitations that accompany the test and how it would and should be utilized in a laboratory setting. These researchers evaluated 73 participants ages 18 to 35 who were relatively "fit" individuals (Taylor et al., 1955). Participants were to be present on initial data collection days for VO_{2max} work rates to be determined which would be used during experimentation (Taylor et al., 1955). The work rates were identified by using the Harvard Fitness Test (Taylor et al., 1955). From the fitness test, participants were instructed to walk between 10 minutes and an hour at 3.5 mph and 10% grade. Subjects proceeded to run at seven miles per hour with 10% grade for three minutes following the completion of the walking portion of the previous stage. Expiratory gases were collected during the running phase to determine VO_{2max}. The third and final day of day of testing resulted in repeating the protocol from the second visit while implementing a run at seven miles per hour and 12.5% grade with the researchers collecting expiratory gasses once more. Attempting to minimize the differences in VO_{2max} values from the two gas collection days, the authors concluded that the most effective method of creating the desired physiological response of VO_{2max} achievement included increasing percent grade until volitional exhaustion, whereas only increasing speed did not provide a proper VO_{2max} achievement even by the same participant (Taylor et al., 1955).

Progressing chronologically throughout the most noteworthy studies regarding determining protocols for VO_{2max}, researcher J. D. George in 1996 was primarily interested in working with college students. Recruiting 126 college students ages 18 to 29 for initial data collection, the participants were divided into two separate groups termed the "test-retest reliability group" and the "validation group" (George, 1996). These groups each completed a maximal GXT on a TM for VO_2 data to be collected and analyzed. Now deemed the Arizona State University (ASU) protocol, the GXT consisted of a "self-selected" pace determined by the participant with percent grade increasing by 1.5 every minute (George, 1996). Participants ran until volitional exhaustion was accomplished with the test average time ranging between four and eight minutes following a six-minute warm up (George, 1996). This protocol was determined by the author as "easy to follow" due to its simplified methods and time effective manner (Pearson, 2017).

However, in 2001, Spackman and colleagues set out to juxtapose the Bruce protocol of 1973 with the "newly" developed ASU protocol (Spackman et al., 2001). These researchers sought to work with college students ages 18 to 29, recruiting 32 participants in total who were students. The participants recruited for this study were completely unfamiliar with VO_{2max} protocols as well as wearing a spirometer (Spackman et al., 2001). After the researchers collected anthropometric data, participants familiarize themselves with the GXT protocols to be enacted in conjunction with the "one-way breathing apparatus," (Spackman et al., 2001). Separated by three to six days, all participants completed both the Bruce and ASU maximal GXT protocols which was followed by an administered questionnaire assessing satisfaction with which protocol was preferred. The questionnaire used in this study was determined off a Likert scale with answers ranging from very unsatisfied to very satisfied and which protocol they would be most likely to repeat, if necessary (Spackman et al., 2001). Conclusions derived from this experimentation primarily pointed to the fact that 93.8% of participants would select the ASU GXT protocol over the Bruce GXT protocol if they were to be required to participate in another maximal GXT two days later attempting to identify VO_{2max} (Spackman et al., 2001). The authors concluded this was due to the ASU protocol's nature of a "self-selected pace" allowing participants to run at a "comfortable pace," granting a more individualized experience. However, reviewing notable VO_{2max} research would only be complete with explanations of the physiological mechanisms these researchers sought to identify and isolate during their experimentation.

VO_{2max} Criteria

Criterion for achieving a "true" VO_{2max} have been scrutinized throughout the past century and as to what particularly constitutes a "maximum." Dr. Bruce et al. (1973) identified five noteworthy criteria for testing a subject / participant for achieving a true VO_{2max}:

> "Firstly, focus on large muscle groups performing dynamic exercise, starting with a submaximal workload that progresses toward maximal effort utilizing incremental stages of increasing workload until volitionally exhaustive effort has been achieved, conducting a test safely which poses minimal risk for the participant, to provide accurate results in a timely manner for both the researcher

and participant alike, and finally, to establish reliable methods and normalized standards for measuring and repeating VO_{2max} evaluations." (Vol. 9 p. 1)

The three traditional physiological variables that should be observed during a VO_{2max} include a plateau in VO_2 consumption (≤ 2ml/kg/min difference) despite an increase in workload, a respiratory exchange ratio (RER) of ≥ 1.05, and ≥ 95% of age-predicted HRmax to identify a maximal oxygen consumption value (Beltz et al., 2016). These values are sought to be observed despite an increase in exercise workload.

An explicit "plateau" in oxygen consumption has been attempted to be identified since the founding fathers of exercise physiology first obtained gases. Minimal changes in oxygen consumption with an ever-increasing workload until volitional exhaustion is the traditional methodological approach. However, today's sampling rate of breath-by-breath and 15 second averages, in conjunction with the plateau threshold criterion may potentially explain much of the variation in prevalence of VO_2 plateau across numerous studies (Beltz et al., 2016).

Respiratory exchange ratio, or RER, has also been a quantified value of interest since the initial gas collection processes by A.V. Hill and colleagues in the 1930s. Substrate oxidation is determined by exercise intensity and differences in skeletal muscle fiber types (Geodecke, 2019). When a greater number of type one skeletal muscle fibers are present, regardless of trained versus untrained, these individuals are more likely to use beta-oxidation and thus the citric acid cycle for fuel utilization varying levels of exercise intensity. Geodecke and colleagues concluded that RER is inversely proportionate to the number of slow-twitch (type one) skeletal muscle fibers (Geodecke, 2019). However, in juxtaposition to fatty acid catabolism supplying energy for exercise, carbohydrate breakdown is indicative of a much greater level of intensity of exercise. During vigorous exercise (approximately 70% VO_{2max}), carbohydrate oxidation (anaerobic glycolysis) from muscle glycogen provides more than two-thirds the energy required for exercise (Geodecke et al., 2000).

The third criterion relevant to the present study is heart rate (HR). Age-predicted heart rate values of 220-age have been the standard estimation since Fox and colleagues placed an arbitrary "best fit line" across 10 studies with maximal heart rate values (Fox et al., 1968). The origination of this ideology of 220-age is still used today and can be used to estimate maximal heart rate for the general apparently healthy population. 95% of this maximal estimated heart rate value is sought to be achieved by the participant to validate a "maximal" bout of exercise thus more closely identifying a VO_{2max}. However, in lieu of the physical collection of gases to identify both RER and a plateau in VO_2 consumption, estimation equations were the primary tool of metabolism estimation, hence submaximal evaluations and PA measurement. These became the primary tool for VO_{2max} estimation from a noninvasive standpoint and are still within the framework of most exercise science courses and academic research settings today.

VO_2 Submaximal Evaluations

As previously mentioned in the introductory section, it is unfeasible to maximally test entire populations for their maximal oxygen uptake capacity due to the safety and logistical restraints. Therefore, researchers have identified and constructed submaximal evaluations to replace the necessity for laboratory equipment and certified technicians to capture an individual's VO_{2max}. The most convenient and reliable submaximal evaluations to estimate VO_{2max} are the 1.5-mile run, 1.0-mile walk, and the Rockport walking test. These alternative field tests were constructed to estimate maximal oxygen consumption with participant safety in mind. Individuals can complete each, or all of these three submaximal evaluations based up on their respective fitness levels. Each of these tests, different in design, can give insight to an individual's fitness level based upon estimated values. There is a certain discrepancy betwixt the three and the differences should be noted.

Dating back to the early 1950s with the Astrand & Rhyming study, many exercise physiologists have become renown in their endeavors to reconstruct and simplify these researchers' findings. Cink and Thomas in 1981, attempted to verify the previous researchers devised nomogram and its capacity to predict VO_{2max}. Emulating the nomogram with 40 male students between the ages of 18 and 33, participants completed both a submaximal and maximal cycle ergometer exercise test. These researchers deduced there was indeed no statistically significant difference between the VO_{2max} estimation from the submaximal exercise test and the true maximal exercise test (Cink & Thomas, 1981). Yet even further examination of the Astrand-Rhyming nomogram was verified by MacSween in 2001. This study consisted of 28 participants aged 18 to 50 which performed a maximal graded exercise test, or more informally known as GXT. The participants completed the GXT using the Bruce treadmill protocol (Bruce et al., 1973) and wore a portable gas analyzer and heart rate monitor (MacSween, 2001). Over the course of the next four consecutive weeks, two GXT trials per week were performed with average O_2 consumption being observed at three submaximal heart rates. For females, HRs of 120, 146, and 172 beats per minute and 122, 146, and 170 beats per minute for males respectively (MacSween, 2001). These HR values were used to extrapolate three separate VO_{2max} values using the Astrand-Rhyming nomogram (MacSween, 2001). After conducting this study, MacSween deduced the Astrand-Rhyming nomogram is appropriate for both the academic research community as well as the clinical setting for predicting VO_{2max}.

Another noteworthy submaximal evaluation exercise test which has become widely popularized is the Balke running protocol. Originally developed by the researcher in 1959, the following study consisted of three parts which was designed to test aerobic fitness in the field for the Federal Aviation Agency in 1963 (Balke, 1963). With the researcher's original interest pinpointing "physical conditioning" and its relation to work capacity, Balke used both the cycle ergometer and treadmill to evaluate these performances (Balke, 1963). The 1959 running protocol developed by Balke involved a working treadmill with ever increasing workloads. Balke verified the 1959 protocol in 1963 with eight male subjects running both two and three miles for timed completion and then reexamined after a ten-week training period. The participants then completed several bouts of running at each of these varying work rates allowing for O_2 intake to be calculated and analyzed for each run as the initial phase of the 1963 study. The second portion of the project included nine untrained males completed comparable treadmill evaluations after successfully completing the same two- and three-mile timed trial runs (Balke, 1963). The times completed were utilized to compute velocity and therefore estimate oxygen intake which was then compared respectively to the VO_{2max} from the GXT. The third and final portion of the 1963 study included 34 high school boys who attempted to achieve the greatest distance possible on a treadmill in a matter of 15 minutes (Balke, 1963). The researcher then deduced that there lies a linear relationship between velocity and completed distance during a 15-minute run and VO_{2max} estimation. This equation is still widely used in the field of exercise science today and is considered a "gold-standard" submaximal VO_{2max} field evaluation.

In 1968, Cooper set out to modify the 1963 Balke field testing research utilizing 115 male United States Air Force male soldiers with ages between 17 and 52. Cooper had the participants complete the Balke field test as well as a VO_{2max} derived from a maximal GXT. Instead of Balke's original 15-minute run to extrapolate VO_2, Cooper's participants ran 12-minutes on a flat course exactly one-mile around. Using the maximal GXT protocol presented by Taylor in 1955, Cooper's participants conducted a VO_{2max} (Cooper, 1968). Taylor's protocol consisted of multiple three-minute interval stages with increasing workloads, allowing for 10 minutes of rest between stages with an attempt to exhaust the participant (Taylor, 1955). Cooper's research yielded positive results denoting field testing can be an inexpensive alternative to a laboratory conducted maximal GXT with accurate estimation values relying heavily upon individual participant motivation (Cooper, 1968).

Researcher and influential physiologist Dr. Margaria set out in 1965 to estimate VO_{2max} with an Astrand-Rhyming styled nomogram using a bench-step test. This study evaluated a handful of subjects ages nine to 47 who completed a VO_{2max}. In comparison to the maximal GXT, a bench with a height of 40 centimeters was used to collect data on HR and step frequency of the participants. Using the known height of the bench and HR values of 160, 180, and 200, in conjunction with stepping frequency of either 15 or 25 steps per minute, a VO_{2max} value could be estimated (Margaria et al, 1965). These authors positively deduced that a relatively accurate VO_{2max} value could be estimated based on the variables observed within their research experimentation.

In 1987, Kline and colleagues conducted a study which yielded one of the most important field test evaluations to date. This study presented six equations that took weight, age, sex, and heart rate into consideration to estimate VO_{2max} for adults between the ages of 30 and 69, of which, one is still used today---the one-mile walk test (Kline et al., 1987). The 390 participants consisting of 183 males and 207 females performed a maximal GXT using the exact protocol the present study's protocol emulated – speed remained constant while only grade increased until volitional exhaustion and/or VO_{2max}. The participants completing the one-mile walking bout with HR being recorded every ¼ mile. These four collected heart rate values and times for completing one mile for each participant were then used in a regression equation which calculated estimated VO_{2max} and was compared to each participants' respective maximal GXT VO_{2max} value.

Comparatively, George and colleagues (1993) developed a similar submaximal one-mile track jog protocol which was designed to accurately estimate VO_{2max}. This study consisted of 149 students of college age with 61 females and 88 males with ages ranging from 18 to 29 years old (George et al., 1993). The authors wanted to verify the previous 1.5 mile run in terms of VO_{2max} estimation validity, with both compared to a maximally graded exercise test. The participants of this study completed the submaximal one-mile jog in conjunction with the maximal GXT on the same day with the 1.5 mile run and another GXT on separate days from each other (George et al., 1993). The submaximal one-mile job relied upon a participant selected pace with HR and speed upper limits predetermined by the authors which explicitly stated greater than or equal eight or nine minutes for men and women respectively, and heart rates could not exceed 180 beats per minute. George and his colleagues after instructing the participants to complete the 1.5 mile run as quickly as possible, regarded the one-mile submaximal jog as a "safer and more enjoyable" method when compared to the 1.5 mile run and/or other field tests (George et al., 1993).

One of the most noteworthy of all submaximal treadmill testing would be that of the Ebbeling single stage walking test. This protocol was developed by Dr. Ebbeling and colleagues which factors HR, treadmill speed, gender and age into an equation constructed to estimate VO_{2max} from a single submaximal stage of walking (Ebbeling et al., 1991). With 166 participants of which 89 females and 77 males and ages ranging from 20 to 59 years old, a submaximal walking bout was initiated with grade increasing from 0% to 5% and finally 10% grade. Speed remained constant at two, three, four, or 4.5 miles per hour based on the participants' level of comfortability. HR and gas exchange variables were captured and noted (Ebbeling et al., 1991). After the completion of these three grade percent changes, the single stage walking test transformed into a full maximal GXT. The speed of the treadmill either remained constant or increased per request of the participant and percent grade incrementally increased by 2.5% until volitional exhaustion was achieved (Ebbeling et al., 1991). Ebbeling and colleagues' (1991) conclusion provides a valid and "time-efficient method for estimating VO_{2max}," which has ultimately influenced researchers' endeavors of constructing various submaximal alternatives to this method.

Since the origination of the single stage walking treadmill test developed by Ebbeling and colleagues, Waddoups and colleagues have been amongst some of the researchers attempting to verify its VO_{2max} estimation capacity. These researchers in 2008 wanted to determine if the Ebbeling protocol could accurately predict VO_{2max} - regarding the lower and upper HR echelons of 50% and 70% max heart rate (HRmax), respectively. With 34 subjects consisting of 17 males and 17 females between the ages of 18 and 55, these researchers used all subjects to complete the Ebbeling submaximal exercise test (Waddoups et al., 2008). However, only 22 of the 34 subjects completed the full maximal GXT yielding VO_{2max} values. Waddoups and colleagues (2008) utilized a three-session methodological approach in this study. The first session denoted participant familiarization with the protocols set to administer HR range values and speed of the treadmill during the test. The second session was the initial submaximal treadmill evaluation in which participants completed either the "low intensity" or "high intensity" groups falling into the 50% HRmax and 70% HRmax categories, respectively. Completing the 1991 Ebbeling protocol for all three sessions, the third and final stage of the study was for participants to complete the other remaining intensity in which they were not categorized into for the prior, or second, stage. Waddoups and his colleagues found a statistically significant difference in VO_{2max} values between the two different intensities. The findings in that study stated that lower to middle HR values using the 1991 Ebbeling protocol yielded a greater predictive VO_{2max} value when compared to actual VO_{2max} values for the exact same participants.

The last research journal worth noting regarding submaximal evaluations estimating VO_{2max} would have to fall back onto the shoulders of Dr. George and his colleagues in 2009. Once again, isolating the 1991 Ebbeling protocol, the researchers desired to improve the original protocol to devise a more "inclusive submaximal treadmill test that included jogging and running as options for healthy adults" (George et al., 2009; Pearson, 2017). Participants completed a submaximal treadmill evaluation at a "self-selected" pace whilst progressing through three four-minute stages (George et al., 2009). Increasing in speed from three to four miles per hour to 4.1 to six miles per hour ending with a speed greater than 6.1mph, the evaluation ceased when the participant achieved 70% of their maximal HR. A cooldown of two to five minutes ensued post submaximal exercise test prior to completing a maximal GXT following the authors' own GXT protocol from the 1997 study (George et al., 2009; George et al., 1997). This study resulted in an apparent association between participant selection of walking, jogging, or running, in the Ebbeling submaximal evaluation as it yields an accurate VO_{2max} estimation compared to that individual's actual VO_{2max} (George et al., 2009).

Non-Exercise Models and Estimation Equations

As stated in the introduction by Shepard and colleagues (2008): it is improbable to maximally test all individuals for prohibitive logistical and medical reason. Therefore, various techniques and protocols have been established to estimate VO_{2max} based on non-exercise (NE) data with regression equations derived from PA questionnaires (Jackson et al., 1990; Heil et al., 1995; George, 1997; Bradshaw et al., 2005; Schembre & Riebe, 2011; Pearson, 2017).

At Johnson Space Center in Houston, Texas, Jackson and colleagues (1990) interacted with and tested employees of the National Aeronautics and Space Administration known as NASA. The primary interest of the project was to verify and validate the author created models using NE data to estimate VO_{2max} and laboratory conducted maximal GXTs for VO_{2max} data comparatively (Jackson et al., 1990). The 2009 subjects, primarily male, were recruited for the study and divided into a validation group of 1,532 participants and a cross-validation group containing the remaining 467 (Jackson et al., 1990). Prior to exercise testing, participants completed a questionnaire that was quantified into an "activity code," which would be utilized in one of the four equations the authors created based on gender and other anthropometric variables, such as percent body fat. The GXT was conducted by following the Bruce TM protocol in conjunction with the use of a 12-lead electrocardiography (EKG) unit (Jackson et al., 1990). The initial three stages of the Bruce TM protocol provided data for the submaximal component that would be the foundation of the authors' VO_2 estimation models. During the final 15 seconds of each stage, heart rate and VO_2 data was captured and recorded. From all of this data, the authors could successfully predict VO_{2peak} which was defined in this study as "the highest-full minute of VO_2 uptake observed during the final minute of the test," which was accepted by the authors as the functional aerobic capacity given the participant reached volitional exhaustion and demonstrated an RER value greater than 1.0 (Jackson et al., 1990). The authors concluded the study by stating "these regression models accurately estimate VO_{2peak} from the applied NE models," of course contingent upon the participant's own fitness level (Jackson et al., 1990).

Just five years later, researcher Heil and colleagues wanted to improve the accuracy of the 1990 Jackson and company NE regression model equations to predict VO_{2max}. Considering 439 subjects for this experiment, participants were placed into a validation group and a cross-validation group comparative to Jackson's design (Heil et al., 1995). The ages of the subjects ranged from 20 to 79 years old which was determined in conjunction with anthropometric data being obtained. This data included PA levels performed specifically in the preceding month (Heil et al., 1995). Following suit of Jacksons' 1990 study, participants completed a maximal GXT whilst wearing a 12-lead EKG unit for ages greater than 40 and a simple Polar™ HR monitor for individuals younger than 40. Again, using percent body fat as a determining characteristic in these authors' regression model equations, the models created in the study revealed to accurately predict VO_{2peak}. These regression models fail to accurately predict VO_{2max} values roughly greater than 54ml/kg/min in aerobically inclined individuals due to "similar characteristics in fitness levels, gender, and weight" (Heil et al., 1995).

Two years later, another regression model was developed to improve the accuracy of estimating VO_{2max} completed by Dr. George and colleagues in 1997. This questionnaire termed the PFA was designed to "evaluate the subject's perception of maintaining various exercise intensities including walking, jogging, or running over known distances and durations" (George et al., 1997). These distances included both a one-mile and three-mile trial, as well as distance covered in a half hour. The authors recruited 100 subjects evenly divided between males and females aged 18 to 29. These participants agreed to completing the authors' questionnaire, the 1990 Jackson and colleagues NE regression model questionnaire, and a maximal GXT to compare all findings. The results from the study revealed two VO_{2max} prediction equations using multiple linear regression analysis (George et al., 1997). One equation solely relied upon the authors' questionnaire while the other equation incorporated the participants' exercise data and data from the questionnaire (George et al., 1997). George and his colleagues discovered that the data from their devised questionnaire improved the NE

VO_{2max} estimation. However, the authors' alternate prediction equation did not improve in accuracy of VO_{2max} estimation even with the inclusion of the participants' exercise data (George et al., 1997).

Continuing off George's previous works, Bradshaw and colleagues in 2005 established a regression model to estimate VO_{2max} within an older individual sample instead of only young "college aged" participants (Bradshaw et al., 2005). Recruiting exactly 100 participants, evenly divided between men and women 18 to 65 years of age, each performed a maximal GXT. Bradshaw utilizing George's treadmill Protocol from 1996, variables such as age, gender, BMI, and survey data from the initial data collection, the authors quantified a regression model to predict VO_{2max}. With "truthfulness" being the only determinant of survey accuracy, Bradshaw and colleagues deduced the equation is accurate in predicting VO_{2max} for both males and females.

Once more, Dr. J.D. George and colleagues in 2007 desired to expand his research of the ASU protocol. Designing a regression model for VO_{2max} prediction with the idea of VO_{2max} estimation for a broader range of individuals (George et al., 2007). Recruiting exactly 100 participants with ages 18 to 65, each subject performed a warm-up for five to ten minutes followed by George's own ASU protocol developed in 1996 (George et al., 2007). A regression model was constructed by the researchers based on the results of the subjects' VO_{2max} results. This model takes age, gender, body mass index (BMI), TM grade and speed into consideration to estimate VO_{2max}, which yielded an r^2 value of 0.88, denoting a strong association between the equation and actual VO_{2max} values (George et al., 2007). This equation is a means of safely and accurately predicting

VO_{2max} values for a sample worth testing whilst avoiding the necessary safety precautions and laboratory expenses of conducting a maximal GXT.

The International Physical Activity Questionnaire, or IPAQ, was used by Schembre and Riebe in 2011 to estimate VO_{2max}. This study included 80 participants aged 18 to 20 who completed the IPAQ in conjunction with a maximal GXT following the 1949 Bruce Protocol (Schembre & Riebe, 2011). The subjects were randomly selected into groups represented by anthropometric data and fitness levels within the group. From this, a regression equation was developed using the IPAQ responses and physical activity levels per week for the randomly selected group. The authors revealed that VO_{2max} can be accurately predicted from their regression equation using the mentioned factors. Comparable to the present study, Schembre and Riebe stated the equation overestimates VO_{2max} in "unfit" individuals whilst simultaneously overestimating VO_{2max} in aerobically fit participants (Schembre & Riebe, 2011).

Lastly, comparable to the original protocol designed by Maragaria in 1965, Webb et al. in 2014 established and individualized step test which would predict VO_{2max} in college-aged, fit individuals. With a sample of 80 subjects aged 18 to 29 years old, participants completed a submaximal step test in conjunction with a maximal GXT following the 2009 George et al. protocol. The step test was verified to accurately predict VO_{2max} via direct comparison to GXT results. However, a NE model derived from recovery HR and the PFA questionnaire was established to estimate VO_{2max} in healthy college-age individuals (Webb et al., 2014). Finally, the results of this study were used to cross-verify the Astrand-Rhyming submaximal cycle ergometer test-based regression model developed by Jackson and colleagues in 1990, and the model developed by Webb and colleagues proved to be even more accurate than Jackson's model for estimating VO_{2max}, thus further improving the NE approach to safely and accurately estimate VO_{2max} for appropriate populations (Webb et al., 2014).

Predictors of Performance

There are a multitude of physiological factors that influence cardiorespiratory performance. Most notably, cardiac output has a direct relationship with VO_{2max}. Cardiac output (Q) can be defined as the amount of blood pumped by the heart during a one-minute period (Katch et al., 2010). This value, at its maximum represents the functional capacity of the cardiovascular system. Cardiac output can be determined simply by multiplying stroke volume (SV) by heart rate (HR). SV is determined by the quantity of blood ejected out of the left ventricle, through the aorta with each heartbeat, usually denoted in milliliters, or liters per minute (Bassett & Howley, 2000). Arguably, an even greater factor of performance prediction is arterial-venous oxygen difference. In conjunction with the equation of cardiac output, "German mathematician, physiologist, and physicist Adolph Fick" was first to devise a technique to measure both cardiac output in 1870 and quantify the difference in oxygen levels within the blood (Katch et al., 2010). An increased a-VO_2 difference indicates an increased capacity for skeletal muscle oxygen extraction and thus results in aerobic capacity of performance (Cort et al., 1991).

In contrast to evaluating physiological variables regarding running performance implications, brings about the mechanism of running speed. A study completed by Saltin et. al. in 1995 revealed there was no difference found in VO_{2max} between two groups of elite distance runners (Andersen et. al., 1987; Kong, 2008). From these findings, a low moment of inertia from the leg about the hip of these elite distance runners was discovered. Enomoto and Ae's 2005 findings stated that these runners are effective in leg swing, characterized by moving forward faster covering a greater horizontal range, resulting in greater angular velocity and acceleration about the knee joint which could potentially depict what it takes to possess a greater likelihood of success in endurance running (Long, 2000; Saltin, et al. 1999). It can then be assumed that a greater stride length, with less frequent steps, and less time spent in contact with the ground, will result in a net increase of speed, due to less total resistance from contact with the earth, decreasing ground reaction forces, and ultimately improving overall running performance. Recreational runners can only train to implement these mechanical factors to improve overall running performance including VO_{2max}.

One study completed by Goran and colleagues stated that total body fat does not influence maximal aerobic capacity, or VO_{2max}, but that fat free mass is in fact the strongest determinant of VO_{2max} (Goran, et al., 2000). This then revealed that the overweight and obese individuals in their study required a greater proportion of their respective CRF to conduct physically weight-bearing activities (Goran et al., 2000). Individuals with obesity are much more likely to find it physically challenging to participate in activities that require movement of their increased body mass, making weight loss, and/or overall CRF improvement challenging (Goran et al., 2000).

Wearable Technology

The creation and employment of submaximal evaluations and non-exercise equations to estimate VO_{2max} has brought about the presence of wearable technology with pedometers being the most prevalent form of exercise tracking. Modern technology including the Fitbit™, Apple™ watch, Garmin™ product line, and the Polar™ product line devices from the present study all originate from the pedometer. In an effort to identify the founding father of the pedometer, findings were most closely linked to a Japanese physician. He popularized something known as the "manpo-kei" which translates literally to "10,000 step meter." While 10,000 steps appears to be a calculated measurement, it is an arbitrary value roughly equating to five miles (influenced by stride length), that is recognized and respected as a standard by the American College of Sports Medicine as the desired step value for all ambulatory adults.

However, a study conducted by Bravata and colleagues reviewed 2,246 articles with only 26 fitting the researchers' inclusion criteria. These authors were interested in the correlation between physical activity while wearing pedometers and over improvements in outpatient health (Bravata et al., 2007). Concluding the review, these researchers determined there was an implicit correlation between physical activity and the use of pedometers. With variables such as BMI and blood pressure (BP) being lower in the subjects utilizing pedometers frequently, it is understood then that an increase in physical activity can lead to improved overall health, however, further research is necessary to illustrate that these benefits are sustainable over time (Bravata et al., 2007). Following up Bravata and colleagues' research was researchers Kang et al. in 2009. These reserachers conducted a meta-analysis reviewing 32 studies that fit the required criterion. Results from the meta-analysis had comparable findings to the previous study mentioned revealing pedometers can and should be used as an "interventional tool" resulting in a positive effect on PA with an overall average increase of 2,000 steps per day by participants who consistently used pedometers (Kang et al., 2009). However, before GPS based wearable devices, sole accelerometry reigned supreme.

Wearable accelerometers today operate by sensing either physiological or mechanical responses to bodily movement, and then use these signals to estimate variables that reflect PA (Basset et al., 2012). In 1961, Cavagna, Saibene, and Margaria developed the first “strain-gauge accelerometer,” with the original purpose and design to measure vibrations and detect motion within various industrial applications (John & Freedson., 2012). The idea was founded upon the relevance of “quantitative knowledge of the forces acting on the human body during dynamic movement, provides a comprehensive description of any physiological phenomenon” (John & Freedson., 2012).

Some of the most notable accelerometers which have paved the way throughout the wearable device industry include SenseWear™ Armbands, Caltrac™, both actical and triaxial accelerometers, and the Lifecorder EX™ (LC) and ActiGraph accelerometer™ (AG) devices. The ActiGraph™ was originally designed for military personnel with the intention of capturing raw PA data; however, today the AG is widely used in the medical and scientific communities and academic institutions globally. A study conducted by Bassett and colleagues in 2012 sought to calibrate and validate these devices compared to “gold standard” field evaluations, such as heart rate. The original AG utilized a gyrus which would detect spin and could calculated this frequency in revolutions per minute (RPM; Bassett et al., 2012). Advancements in the newest models use a “direct compression sensor integrated into a solid state which is a micro electromechanical system accelerometer which undergoes digital filtering” in a very advanced method of translating human locomotion into a quantifiable format (Bassett et al., 2012).

Tudor-Locke and colleagues in 2007 contrasted the LC and AG evaluating each devices' respective capability of capturing steps taken in conjunction with "time spent in different categories of PA intensity and assessing the reliability of the LC compared to the AG" (Tudor-Lock et al., 2007; Pearson, 2017). The authors recruited ten individuals evenly split between men and women, requiring them to wear two LCs with each on one hip. The subjects would also wear and AG device on solely the right hip whilst wearing the two LCs. Participants wore these devices for "all waking hours" excluding any activities pertaining to water. Lastly, the participants completed a run that lasted 20 minutes while wearing all three devices simultaneously. The authors then concluded that the LC recorded on average 1,500 steps fewer than the AG and could be considered to possess "high intra-reliability," with both devices being very appropriate for daily PA measurements and monitoring (Tudor-Locke et al., 2007). Emulating the previously mentioned study, Abel and colleagues in 2008 conducted an experiment testing the same the LC and AG. Recruiting 20 participants evenly split between men and women, subjects were place on a TM while step count and energy expenditure (EE) were accounted for. Using a spirometer for indirect calorimetry, resting metabolic rate (RMR) was determined prior to testing and used to capture VO_2 for EE (Abel et al., 2008). Similar methodology used by Tudor-Locke and fellows, two LCs were placed on the subjects with one on each hip and a single AG on the right hip (Abel et al., 2008). Participants then completed six bouts on the TM with three of walking and three of running. Protocol simply increased speed of the TM belt over the course of 10 minutes for each of these trials, all while subjects wore a spirometer for VO_2 data collection (Abel et al., 2008). Comparing steps taken by all three devices, Abel and colleagues concluded not only is further improvement of the devices necessary for improvements in accuracy but also that the "LC and AG are useful devices for clinicians, researchers, and the general public to estimate EE and daily steps taken" (Abel et al., 2008).

The SenseWear Armband™ is a device that has been created for the purpose of estimating VO_2 or EE during resistance training. Liden and fellows researched this device by collecting data from subjects who wore the device during various periods of PA (Linden et al., 2002). The researchers divided 40 subjects evenly into groups based on age, gender, height, and BMI creating four test groups (Linden et al., 2002). The subjects completed two separate trails of PA with the first consisting of walking at slow or fast paces, running, sitting, or biking all the while wearing a spirometer. The second trial operating in nearly same fashion apart from duration and order of PA activities altering (Linden et al., 2002). After analyzing all data collection, the authors concluded that the SenseWear Armband™, while cheaper than comparable market products, this device produced "low error rates as well as accurately assessing levels of PA" (Linden et al., 2002).

The SenseWear Pro Armband™ device has also been proven to accurately estimate EE for indoor rowing in an overweight population by Erdogan and colleagues in 2010. This device was compared to the Polar S810i HRM™ (HR monitor) for EE estimation accuracy of differing activities (Erdogan et al., 2010). Forty-three participants were recruited for this study with 24 being overweight and the remaining 19 considered obese (Erdogan et al., 2010). The authors collected anthropometric data including percent body fat via bioelectrical impedance analysis, or more informally known as BIA. These subjects then completed and indoor rowing exercise that consisted of two-minute stages with increasing levels of intensity followed by 20 seconds of rest between each stage for blood O_2 content to be analyzed (Erdogan et al., 2010). The second and final day of testing included the subjects completing an indoor submaximal rowing protocol whilst wearing the Polar HRM™ and the SenseWear Armband™ devices (Ergodan et al., 2010). Protocol consisted of two consecutive rowing bouts at 50% and 70% VO_{2max} with two minutes of rest between them with VO_2 data captured by a portable metabolic cart identified as the Cosmed K4™. Results from this study yielded the accurate EE estimations from both devices when compared to a the Cosmed K4™ portable gas analyzer (Erdogan et al., 2010). Continuing on the relevant topic of VO_2, the Senswear Armband™ has been proven to also reliably measure EE during resistance training (RT), verified by researchers Reeve and colleagues and the Cosmed K4™ portable gas analyzer in 2014. The 15 subjects utilized in this study completed nine separate exercises with three sets consisting of a 10-repetition count while wearing the Cosmed K4™, the Senswear Armband™, and the BodyMedia FIT™, which ultimately proved the reliability of these devices' ability to estimate EE accurately.

Further expounding upon the research about the SenseWear Armband™, Scheers and colleagues sought to determine just how many days this device requires to become "reliable" in assessing PA measurements and patterns (Scheers et al., 2012). Spanning across seven days of data collection, 313 participants were required to wear the armband for an expected 1,368 - 1,440 minutes per day, or 95%. These subjects were also instructed to record an "electronic diary" when they initiated a new activity

(Scheers et al., 2012). According to the findings of this study, individuals tend to spend Saturdays with slightly higher levels of PA when compared to a "normal weekday," while Sundays indicated lower levels of PA by and large (Scheers et al., 2012).

Global Positioning Systems in Wearable Technology

The Garmin Forerunner 235™ GPS watch as well as the Polar V800™ and A300™ devices, do not display feedback in relation to mechanical locomotion other than distance covered in two dimensions. These new and upcoming wearable devices are intended for everyday use, with their focus on both indoor and outdoor training. Snyder and colleagues in 2017 tested the Garmin Forerunner 235™ and the Polar V800™ for accuracy in predicting VO_{2max}. Pearson et al. (2017) also tested the Garmin Forerunner 235™ Forerunner for the same purpose. Both research groups, unbeknownst to one another, yielded the same results. Both the Garmin Forerunner 235™ and Polar V800™ underestimate VO_{2max} frequently, which emulates similar findings from the present study. The VO_{2max} prediction equation utilized by Garmin is calculated based upon total distance covered during a bout of exercise in conjunction with radial pulse obtained via an infrared light sensor on the back of the face of watch (Garmin Forerunner 235™ Manual, 2017). In juxtaposition to a quantification based upon distance traveled, the Polar A300™ fitness wearable device estimates VO_{2max} from resting cardiac variability (Polar A300™ and V800™ Manual, 2017). It is not well understood how these calculations exact the VO_{2max} measurements they yield as both manufacturers are quite reticent when divulging this information, nonetheless, further evaluation of these devices is required.

However, prior to the modern-day creation of global positioning system (GPS) wearable technology, Schutz and Chambaz in 1997 proposed that satellite technology could be used to potentially record PA measurements on an individual. For these colleagues' research, a single participant was to wear a GPS tracking device while walking, running, and cycling (Schutz & Chambaz, 1997). After completing these exercises around a track, the researchers concluded that GPS technology could in fact be used to determine velocity while walking specifically but would certainly need a greater number of studies to solidify these findings (Schutz & Chambaz, 1997).

A decade later, Le Faucher and colleagues in 2007 documented GPS use in outdoor settings with a healthy, clinical population. Using a predecessor model of the Garmin used within the present study, Le Faucher et al. tested the Garmin 60 GPS™ for accuracy of outdoor walking distance predetermined via an outdoor track. These researchers used a 3-part approach. The first component of the project was for participants to complete six walking bouts ranging between 15 seconds up to eight minutes to which subjects walked at self-selected paces and the GPS device ran constantly for 15 minutes before and after testing for complete data collection (Le Faucher et al., 2007). The second component consisted of subjects following a vocal prompt of walking speed and duration to a local park nearby whilst wearing the GPS device. The third and final component involved subjects walking for 2,000 meters constituted by a series of distances ranging between 100 and 400 meters. The authors confidently deduced the commercially available Garmin 60™ can accurately record distance and speed during exercise by means of global positioning systems, especially for clinical populous and their respective PA levels (Le Faucher et al., 2007).

In a review article conducted by Maddison and Mhurchu in 2009, 36 articles were reviewed for prevalence of GPS in literature during the preceding two decades. In short, the authors concluded that GPS usage for PA evaluation is a “novel method, particularly for activity in free-living conditions” (Maddison & Mhurchu, 2009). Therefore, Wieters and colleagues in 2012 evaluated four different GPS devices and their capacity to measure outdoor PA. The Garmin Forerunner 205™, Garmin Foretrex 201™, Wintec Easy Showily™, and the Globalsat DG-100™ were studied for the accuracy of determining PA via walking a “known route” (Wieters et al., 2012). The researchers were interested in any deviation from the routes’ known distance covered by the participant, any discrepancies based on the wearable devices’ placement on the subjects’ physical body, and “variations of position from a known geodetic point” (Wieters et al., 2012). Considered to be a static reference point on Earth, a geodetic point can be used to illustrate an individuals’ location. These authors deduced from experimentation that the GPS devices studied could serve as valid and reliable tools to for assessing PA and would open the door to more convenient methods of PA data collection in the future (Wieters et al., 2012).

Researcher Duncan and colleagues in 2013 were interested in progression research on GPS wearable devices. These devices included both of Wieters et al. 2012 Garmin™ choices of the Forerunner 205 and Foretrex 201. With five more devices included in the research project, seven devices in total were evaluated for global location acquisition time (Duncan et al., 2013). Once again using a geodetic point for triangulation, the researchers tested all seven devices on three separate occasions. Duncan and fellows discussed the potential issues in urban areas with high-rise buildings causing interference when compared to an “open-sky” setting. In contrast to urban areas can also interfere with GPS signals and therefore influence accuracy of PA measurements, even in greenspace areas. Greenspace is often referred to as parks, playgrounds, and open lots where activities of varying levels of physical exertion can be carried out.

In reference and comparison to Maddison and Mhurchu’s 2009 paper, McCrorie and colleagues (2014) set out to examine a total of 14 papers evaluating GPS, accelerometers, and geographic information systems (GIS) in adolescent individuals aged five to 18. These researchers deduced replicability of the reviewed experiments is challenging due to some “unclear protocols,” which ultimately influences and skews the data reported (McCroie et al., 2014). However, an objective statement produced by the study regards pavement or asphalt as a highly important factor for young individuals to increase PA, specifically when using GPS devices (McCroie et al., 2014). These same young individuals also showed higher levels of PA in “greenspaces.”

VO_{2max} Estimation From Wearable Technology

The essence of the present study has been crafted around the previous research described in this review of literature. Wearable technology is become an ever-increasing element in our society as we move closer towards the idea of singularity with each surpassing year. Regardless, researchers in the past 3 years have been inclined to further understand the capacity of these GPS devices and how they can illustrate VO_{2max} to consumers of both recreational and professional sport. Johnson and Beadle in 2017 were interested in Garmin’s Forerunner 230™ and 235™ as well as Polar’s V800™ and FT60™ for VO_{2max} prediction. Comparable to the present study, the Polar™ devices can estimate VO_{2max} based on resting heart rate, activity level, and the subject's anthropometric data, whereas the Garmin™ devices predict VO_{2max} from heart rate over distance completed during running. The researchers completed all of the device protocols for VO_{2max} prediction compared to a maximal GXT to which they found the devices to be relatively accurate with the most obscure finding to be that of the Polar FT60™ with a discrepancy of 10% (Johnson & Beadle, 2017).

Around the same time, Snyder and colleagues (2017) were interested in the accuracy of VO_{2max} prediction from the same devices as the previous study except the Polar FT60™. Again, all device protocols for VO_{2max} estimation were completed and compared to a maximal GXT for each and all subjects. These researchers found that all the devices overestimated VO_{2max} values for all males and females, while only females possessed instances of underestimation from the devices (Snyder et al., 2017). This ultimately led to a significant difference between values within each other and compared to the maximal GXT (Snyder et al., 2017). Piggybacking off the previous study, Willoughby and colleagues in 2017 tested the Garmin Forerunner 230™ and 235™ with each other. The researchers were interested in EE (kcals), distance covered, pace, average, and maximal HRs during an outdoor run. With discrepancies only existing in HR values between the 230™ and 235™ this yielded a difference in predicted VO_{2max} values (Willoughby et al., 2017). The 230™ predicted significantly lower VO_{2max} values compared to the 235™ potentially due to the mechanism of data collection difference between the two watches.

Finally, the most recent study worth mentioning was completed by Pearson in 2017 regarding the Garmin Forerunner 235™ predictability of VO_{2max} compared to a maximal GXT. When compared to the maximal GXT the researcher found the device underestimates VO_{2max} for the more aerobically inclined individuals and overestimates for the less inclined (Pearson, 2017). Pearson also noted that the Garmin Forerunner 235™ more accurately estimates VO_{2max} for individuals possessing a VO_{2max} greater than 50ml/kg/min. Results from the present study replicate these findings and therefore indicate that further advancements in this technology are necessary for an increase in accuracy and reliability, but also for the less aerobically inclined clientele. Further research regarding the capabilities of these new wearable GPS devices and their capacity to estimate VO_{2max} should be considered as well.

CRF: A Means of Tracking Heart Health

Observing and evaluating human locomotion, and more specifically running from both recreation and performance standpoints reveals an incredibly complex process that requires skeletal muscle contraction, energy expenditure, and depicts how cardiorespiratory fitness (CRF) directly relates to cardiovascular health. In stark contrast to running performance, is the presence of CVD and coronary heart disease (CHD). Recreational runners including those seeking to improve their performance and/or VO_{2max}, are not typically at risk for cardiovascular related diseases and illnesses. Epidemiological studies have displayed an inverse association between physical fitness and the incidence of CHD in healthy participants (Kodoma et al., 2009). It is understood that the most valued means of testing CRF is through an actual VO_{2max}, and yet it is rare for clinicians to consider CRF when evaluating future risk of CHD (Wilson et al., 1998). The primary reason for lack of consideration for CRF as a marker of CVD is due to the unestablished quantitative association of CRF for CVD risk (Kodoma et al. 2009). Also, among the current literature, the degree of risk reduction associated with each incrementally higher level of CRF, as well as the magnitude to which possessing a lower CRF and its relation to increased risk of CVD have been inconsistent among studies. However, an improved CRF was associated with lower risk of CVD and CHD (Kodoma et al., 2009). These findings are congruent with the expectations of cardiovascular health and its overall importance on CRF.

Another study completed by Le Faucher and colleagues in 2008 evaluated patients with peripheral arterial disease (PAD) and the use of GPS devices to evaluate their PA, specifically walking by means of comparing TM walking to "non-TM" walking methods (Le Faucher et al., 2008). The authors recruited 24 participants for the study and specifically evaluated:

> "(a) a walking impairment questionnaire, (b) self-reported maximal walking distance, (c) a TM walking test at 10% grade with increasing speed up to four minutes followed by a maximum of 16 minutes of walking at the capped speed, (d) a six minute walking test, and (e) an unsupervised walking activity using a GPS device (Garmin 60™) of at least 45 minutes in duration to which participants walked freely around a public park," (Le Faucher et al., 2008, p. 898).

Upon conclusion of the study, the researchers discovered maximal walking distance recorded via the GPS device directly correlated with the TM walking distance test and can be a means of an alternative to laboratory setting based walking tests in a clinical population.

Summary

In conclusion, this review of literature is expansive and multifactorial as the subject matter of VO_{2max} is well understood but wearable technology predicting VO_{2max} is not. Previous metabolic estimation equations have heavily influenced today's wearable technology and continue to encourage fitness wearable designers to improve their devices' capability and accuracy. Estimation equations, including ACSM's very own, in conjunction with researchers Dr. Bruce and the late Dr. Ebbeling, have laid foundational work for our current stance today and the direction of future research regarding VO_2 consumption at its varying stages from submaximal to maximal. Research in the years to come should continue to delve into wearable technology and verify its capacity to actual VO_{2max} values, as well as predecessor models. Biomechanics and anthropometry play a piece in influencing running form, overall energy expenditure, and oxygen consumption. If these factors can be changed over time with professional coaching, an individual possesses the capacity to improve not only their maximal oxygen consumption capacity, but the rate at which this oxygen is utilized during bouts of physical activity as well.

Chapter III:
Research Design and Method

Subjects

Forty participants ages 18-55 were recruited for this study. A power analysis was conducted using G* Power 3.1 to determine the sample size. The power analysis was conducted for an "ANOVA: repeated measures, within factors" using an effect size of 0.25, an alpha of 0.05, a power of 0.95 with one group and four measurements. However, this produced a sample size of 36, our final sample size was 40.

Participants were primarily college students from Eastern Michigan University and surrounding areas who consider themselves to be physically active. Participants came to the Running Science Laboratory at Eastern Michigan University on two separate occasions. Upon arrival, participants were required to complete an informed consent form, a health history questionnaire, and a Physical Activity Readiness Questionnaire, or Par-Q, before the evaluation began. Participants that indicated any health conditions that classified them above "low risk" per the American College of Sports Medicine (Risk Factor Guidelines, 2015) were to be excluded from the study. Participants then completed an actual VO_{2max} test. Any participants that did not reach a relative VO_{2max} of at least 35ml/kg/min were excluded from the study.

For the second visit, participants wore all three commercially available watches. The Polar V800™, the Polar A300™, and the Garmin Forerunner 235™, were all worn to determine predicted VO_{2max}. Recordings were gathered by an integrated Polar™ non-exercise model with Garmin's ™ outdoor running protocol, which transpired on Eastern

Michigan University's campus for 15 minutes. After completing both the non-exercise model and the outdoor run, estimated VO_{2max} values were observed and recorded from the two Polar™ devices and the Garmin Forerunner 235™ GPS watch. These values were then be compared to the participants' respective true VO_{2max} value to assess accurate predictability from the commercially available devices.

Visit 1: VO_{2max}:

Prior to participants arriving at Eastern Michigan University's Running Science Laboratory, the PARVO metabolic cart was calibrated 30 minutes before data collection. The calibration of gas and flow was completed with ambient room temperature, relative humidity, and barometric pressure values recorded respective at that time. During this initial visit, participants were required to sign an informed consent along with a Physical Activity Readiness Questionnaire (PAR-Q) and a Health Status Questionnaire prior to participating in any testing procedures to rule out any medical conditions that put them at risk during testing. Participants were required to possess a "low risk" classification per the *Risk Factor Guidelines* (American College of Sports Medicine [ACSM], 2015). ACSM classifies individuals as low risk by those who "do not have signs/symptoms of or have diagnosed cardiovascular, pulmonary, and/or metabolic disease and have no more than one Cardiovascular Disease risk factor" (ACSM, 2015). If any medical conditions were discussed that could limit the participants' participation, they were to be excluded from the study. For example, uncontrolled asthma induced by exercise, uncontrolled hypertension, or any physical ailment that could impair the participant's running capability. Testing procedures and protocols were then explained to the participant. After these procedures were explained, resting heart rate via the radial pulse and blood pressure (BP) were assessed prior to testing. Height in centimeters using the DECTO scale and weight in kilograms using the TANITA BMB-800 scale were used. Height and weight measurements were recorded in duplicate and then averaged to calculate BMI (kg/m^2). Age and gender were also recorded.

After participants were informed of the procedure, the mouthpiece and headgear were constructed and placed appropriately on the participant. Measures that were obtained during the VO_{2max} test included heart rate (HR), Rate of Perceived Exertion (RPE), volume of oxygen (VO_2), volume of carbon dioxide (VCO_2), and the respiratory exchange ratio (RER). The participant then stepped onto the treadmill and stood still for two minutes to allow for baselines measures of VO_2, RER, and HR to be recorded. The chosen protocol to determine true VO_{2max} was as follows: (a) The participant selected a speed at which they could maintain a pace for 30 minutes ~ roughly five to seven miles per hour. The speed of the treadmill was to remain constant throughout the evaluation. For example, if the participant chose 6.5 mph as the self-selected pace, that pace was maintained throughout the entire test. (b) The elevation of the treadmill started at 0% grade and increased by 2% every two minutes until the completion of the test. (c) The participant ran until volitional exhaustion. A plateau in VO_2, a heart rate greater than or equal to 95% of the participant's predicted maximum heart rate, and an RER value of 1.05 or greater, are the three criteria examined for the VO_{2max} (Kline et al., 1987). A participant needed to meet two of three criteria for the VO_{2max} test to be considered "true." The participant was also asked if they reached volitional exhaustion.

After conducting the VO_{2max} test, a five-minute cool down was administered. The participant walked at a self-selected pace of half of one mile an hour to three miles per hour until HR fell below 120 beats per minute. After the participant “felt” comfortable enough to stop walking, the participant was then instructed to sit down and rest for another five minutes. After these five minutes elapsed in the seated position, heart rate and blood pressure were assessed and recorded. The second and final visit required for participation in this study was discussed. Upon agreement of the participant’s time and date for the second visit, the participant was then dismissed.

Visit 2: Commercially Available Watches:

During the second visit to Eastern Michigan University’s running science laboratory, the participant completed the second half of the protocol for this experiment. This visit included a non-exercise model with the Polar V800™ and A300™ devices to estimate VO_{2max}, as well as a 15-minute outdoor run wearing the Garmin Forerunner 235™. The recordings of the estimated VO_{2max} values were compared to the laboratory conducted true VO_{2max} test for each respective participant.

When the participant arrived at Eastern Michigan University’s Running Science Laboratory, the participant was instructed to sit down and rest for five minutes prior to heart rate and blood pressure values being obtained and recorded. The participant was then instructed to lie down and relax for one to three minutes whilst wearing the Polar V800™ and A300™ devices; one on each wrist. The researcher then initiated the two Polar™ devices to begin the test. The device will search for heart rate and the “fitness test” (Polar™ Fitness Test Guidelines, 2017) begins as soon as the “training computer” (Polar™ Fitness Test Guidelines, 2017) within the device locates the participant’s heart rate. The participant was instructed to lie still throughout the test, to avoid movement as much as possible, and to refrain from talking (Polar™ Fitness Test Guidelines, 2017). After exactly five minutes, the training computer within the polar devices notified the researcher and the participant with an audible beep. The test results were displayed as an “OwnIndex” (Polar™ Fitness Test Guidelines, 2017) value with an accommodating level of fitness classification, per Polar’s™ “fitness test” (Polar™ Fitness Test Guidelines, 2017) device protocol. The OwnIndex is Polar’s™ depiction of an estimated VO2max value.

After the estimated VO2max values were recorded from the two Polar™ devices, the two watches were removed and replaced by the Garmin Forerunner 235™ GPS watch to compare for accuracy. Garmin’s™ protocol states for the participant to set up the user profile with respective bodily measurements and heart rate zones (calculated from age), and to wear the device correctly with the sensor side facing the wrist (Garmin™: Obtaining VO2max, 2017). The participant and researcher then walked over to an established set route of one half of one mile outdoors on Eastern Michigan University’s campus. This course is flat with minimal elevation change and the participant was instructed to run as many laps as possible in fifteen minutes without cessation. If the participant ceases running, the participant was to be excluded from the study. The desired level of running intensity for the participant per Garmin’s protocol is an achieved HR of 70% or greater than their HR maximum throughout the duration of the fifteen-minute run. Once the run was complete, the data was saved on the watch. The researcher then navigated through the menus on the Garmin watch to find “my stats” and the VO2max value was selected and displayed. This measurement was calculated from heart rate and distance covered (Garmin: Obtaining VO2max, 2017).

The researcher and participant then walked back to the Running Science Laboratory. Upon arrival, the participant sat and rested for five minutes. The final measurements of heart rate and blood pressure were assessed and recorded. The estimated VO_{2max} values obtained from the Polar V800™ and A300™ non-exercise model, and the Garmin Forerunner 235™ after the fifteen-minute run, were then all compared to the true VO_{2max}. The Vo_{2max} results were then explained and discussed with each participant upon dismissal.

Statistics utilized for this study included the descriptive values of means and standard deviations (mean ± SD) for age, height, weight, BMI, true VO_{2max} values, and predicted VO_{2max} values. A Repeated Measures ANOVA analysis was used to determine if there was a significant difference between each predicted VO_{2max} value (Polar V800™, Polar A300™, and Garmin Forerunner 235™) to the participants true VO2max, with Alpha set as $p < 0.05$. Repeated measures ANOVA was most appropriate for this analysis for the present study as it implies all the same participants were used in all conditions (Field, 2016). All three commercially available devices were used as the dependent variables compared to the laboratory conducted VO_{2max} as the independent variable.

Chapter IV:
Results

A total of 10 participants were excluded from this study. Two were dismissed due to having a VO_{2max} less than 35 ml/kg/min, two for not returning for the second visit, and six due to device malfunction. However, utilizing the majority remainder of participants for the study (30), VO_{2max} values for the laboratory conducted VO_{2max} test revealed a mean of 50.6 ± 8.4 ml/kg/min. Polar's V800™ most closely representing that value with an estimation capability of 45.9 ± 5.1 ml/kg/min, Garmin's Forerunner 235™ falling in 2nd with an average estimation of 45.6 ± 5.4 ml/kg/min, and lastly Polar's A300™ yielding the lowest VO_{2max} estimation capability of 44.5 ± 5.3 ml/kg/min (Table 1 and Table 2).

Table 1. Descriptive Statistics of VO_{2max} and device coding with standard

Descriptive Statistics

	Vo2maxlevel	Mean	Std. Deviation	N
LabVO2max	0	44.60	3.534	17
	1	58.44	6.126	13
	Total	50.60	8.430	30
V800	0	43.76	4.956	17
	1	48.69	3.881	13
	Total	45.90	5.095	30
A300	0	42.35	4.987	17
	1	47.31	4.328	13
	Total	44.50	5.264	30
Garmin235	0	43.18	3.712	17
	1	48.85	5.580	13
	Total	45.63	5.353	30

Table 2. Descriptive Statistics including anthropometrics with standard deviation.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
AGE	30	19.00	48.00	26.3667	7.93718
HEIGHT.cm	30	153.00	190.00	169.7833	8.67088
WEIGHT.kg	30	50.50	92.50	72.3200	11.57111
BMI	30	18.97	31.85	24.9927	2.91579
VO2max	30	39.20	69.10	50.5967	8.43002
V800	30	34.00	55.00	45.9000	5.09462
A300	30	34.00	53.00	44.5000	5.26373
GARMIN235	30	36.00	59.00	45.6333	5.35295
Valid N (listwise)	30				

The purpose of this study was to compare predicted VO_{2max} values from the Garmin Forerunner 235™ GPS watch and Polar's V800™ and A300™, respectively, to a true VO_{2max} test conducted in Eastern Michigan University's Running Science Laboratory. It was hypothesized that (a) Polar's most prestigious model utilized in this study, the V800™, will possess the greatest precision in predicting VO_{2max} over the Polar A300™, and Garmin's Forerunner 235™ when compared to an actual VO_{2max}. (b) Garmin's Forerunner 235™ will possess the greatest VO_{2max} estimation capability when participants possess a VO_{2max} less than or equal to 50 ml/kg/min, rather than greater than 50 ml/kg/min.

A repeated measures ANOVA was utilized to quantify if there existed a statistically significant difference between the three commercially available devices' VO_{2max} predictions and the laboratory conducted VO_{2max} for all participants. For the sake of calculations, the subjects were segregated into two distinguishing categories of

VO_{2max} values. Group 0 possessed a VO_{2max} <50ml/kg/min and Group 1 possessed a VO_{2max} >50ml/kg/min (Table 1). Mauchly's test of sphericity and Greenhouse-Geisser were also examined from the results of the repeated measures ANOVA.

Mauchly's Test of Sphericity identifies the relationship between pairs of measurements (Field, 2016). During the present study, the three commercially available devices' VO_{2max} predictions are assumed to be similar for each participant, which denotes the level of dependence between pairs formed by these measurements are somewhat equal. Therefore, if sphericity has been violated, Mauchly's Test of Sphericity results will reveal a loss of statistical power. Conversely, if Mauchly's Test yields a significant finding (p-value < 0.001), then the assumption of sphericity has been met. In the present study, Mauchly's Test of Sphericity yielded, $X^2(30) = 12.023$, $p = .035$, which can be concluded that significant differences exist between variances of differences among pairs (Table 3). The degrees of freedom were corrected utilizing the Greenhouse-Geisser estimations because the conditions of sphericity have been violated.

The Greenhouse-Geisser correction has been used to evaluate the within-subjects effects due to ε being less than 0.75 (Field, 2016). Utilizing this correction, the data from the present study reveals a significant difference among recorded VO_{2max} values from the three commercially available devices, $F\ (2.442, 68.389) = 23.186$, p-value < .01 (Table 3). To distinguish if any of the VO_{2max} recordings were significantly different from each other, group means were evaluated using Bonferroni to adjust for multiple comparisons.

Table 3. Tests of Within-Subjects Effects

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
Test	Sphericity Assumed	784.310	3	261.437	23.186
	Greenhouse-Geisser	784.310	2.442	321.116	23.186
	Huynh-Feldt	784.310	2.789	281.241	23.186
	Lower-bound	784.310	1.000	784.310	23.186
Test * Vo2maxlevel	Sphericity Assumed	416.429	3	138.810	12.310
	Greenhouse-Geisser	416.429	2.442	170.496	12.310
	Huynh-Feldt	416.429	2.789	149.325	12.310
	Lower-bound	416.429	1.000	416.429	12.310
Error(Test)	Sphericity Assumed	947.162	84	11.276	
	Greenhouse-Geisser	947.162	68.389	13.850	
	Huynh-Feldt	947.162	78.085	12.130	
	Lower-bound	947.162	28.000	33.827	

The four VO_{2max} values utilized for the pairwise comparison (Table 4). can be found in Table 1. The laboratory conducted VO_{2max} is the independent variable with Polar's V800™, Polar's A300™, and Garmin's Forerunner 235™ coded as dependent variables. However, a statistically significant difference was not observed (p-value $< .05$) between the laboratory conducted VO_{2max} and any of the three commercially available devices. As for the 2nd hypothesis of this study, a paired samples t-test was analyzed (Table 5). A p-value of < 0.001 was observed for the high laboratory VO_{2max} with high laboratory VO_{2max} Garmin group and a p-value of 0.240 for the low laboratory VO_{2max} with low laboratory VO_{2max} Garmin group. This in turn confirms that a statistical significance exists in the group possessing a VO_{2max} greater than 50 ml/kg/min and the

Garmin Forerunner 235™ estimated VO_{2max} for those participants, resulting in a rejection of the null hypothesis.

Table 4. Pairwise Comparisons

Pairwise Comparisons

Measure: MEASURE_1

(I) Test	(J) Test	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	5.291*	.880	.000	2.791	7.790
	3	6.689*	1.011	.000	3.818	9.560
	4	5.508*	1.025	.000	2.598	8.418
2	1	-5.291*	.880	.000	-7.790	-2.791
	3	1.398	.606	.172	-.323	3.119
	4	.217	.890	1.000	-2.310	2.744
3	1	-6.689*	1.011	.000	-9.560	-3.818
	2	-1.398	.606	.172	-3.119	.323
	4	-1.181	.764	.801	-3.350	.988
4	1	-5.508*	1.025	.000	-8.418	-2.598
	2	-.217	.890	1.000	-2.744	2.310
	3	1.181	.764	.801	-.988	3.350

Based on estimated marginal means

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

b. Adjustment for multiple comparisons: Bonferroni.

Table 5. Paired Samples T-Test: High Laboratory VO_{2max} with High Laboratory VO_{2max} Garmin vs. Low Laboratory VO_{2max} with Low Laboratory

Paired Samples Test

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Significance One-Sided p	Two-Sided p
Pair 1	HIGHLABVO2MAX - HIGHLABVO2MAXGARMIN	9.56429	7.13384	1.90660	5.44533	13.68324	5.016	13	<.001	<.001
Pair 2	LOWLABVO2MAX - LOWLABVO2MAXGARMIN	.93750	3.06657	.76664	-.69656	2.57156	1.223	15	.120	.240

Chapter V:

Summary and Recommendations for Further Investigations

Devices such as Garmin Forerunner 235™ GPS watch, as well as Polar's V800™ and A300™, have been established to encourage those individuals with the pursuit of fitness tracking, performance improvement, and overall progression of health in mind. Manufacturers have continued to improve their algorithmic device potential and have incorporated other tools such as accelerometry, global positioning systems, and heart rate sensors to predict VO_{2max}. Estimated VO_{2max} values were obtained from each device's protocol and were compared to all participants measured actual VO_{2max} data (Pearson, 2017). The discrepancy between estimated VO_{2max} values and measured VO_{2max} was recorded and varied between devices for even the same participant. This led to an inconsistent prediction of VO_{2max} which ultimately impacted the R^2 values for each device.

Ultimately, this study concluded that all three commercially available devices yielded a significant difference between the laboratory conducted VO_{2max} and each devices' VO_{2max} prediction, for both participants with a VO_{2max} greater than and less than 50ml/kg/min. A Pearson correlations test revealed that Device A (r=0.56; p<0.001) (r^2 = 0.31; p<0.05), Device V (r=0.64; p < 0.001) (r^2 = 0.41; p < 0.05), and the GPS watch (r=0.59; p < 0.001) (r^2 = 0.35; p < 0.05), were associated with measured VO_{2max}. A calculated R^2 of 0.41 for the Polar V800™, an R^2 of 0.35 for the Garmin Forerunner 235™ GPS watch, and an R^2 of 0.31 for the Polar A300™. This in turn confirmed the study's hypothesis that Polar's V800™ would possess the greatest capacity to predict VO_{2max}. However, this was not an overtly noticeable quantification for the V800™ as the standard deviation was ± 5.1 ml/kg/min. A significant main effect was found among VO_{2max} values F (2.0, 39.6) = 14.0; $p < 0.05$. Mauchley's test of spherecity yielded a significant difference between the laboratory conducted VO_{2max} and all three commercially available devices $X^2(30) = 12.023$, $p = .035$. Utilizing the Greehouse-Geisser correction, it was denoted once again that a significant difference exists between the laboratory conducted VO_{2max} and the three commercially available devices F (2.442, 68.389) = 23.186, p-value < .01.

The second hypothesis of the study stated the Garmin Forerunner 235™ would be more accurate in estimating individuals' VO_{2max} who were more aerobically inclined (> 50 ml/kg/min). After conducting a paired samples t-test, a statistically significant p-value of < 0.001 was calculated for the group that possessed a VO_{2max} > 50 ml/kg/min for the laboratory conducted VO_{2max} in conjunction with the participant's estimated VO_{2max} by the Garmin Forerunner 235™. This p-value indicates a strong relationship between individuals who possess a VO_{2max} of greater than 50 ml/kg/min and the Garmin Forerunner 235's™ ability to accurately estimate VO_{2max} for the user. Therefore, we can reject the null hypothesis that the Garmin Forerunner 235™ would more accurately estimate individuals with a VO_{2max} greater than or equal to 50 ml/kg/min. In contrast, a non-statistically significant p-value of 0.240 was observed for the group that possessed a laboratory VO_{2max} < 50 ml/kg/min with the participant's estimated Garmin VO_{2max}. Pearson in 2017 found a statistical significance between his participants laboratory conducted VO_{2max} and the same participants adjusted predicted VO_{2max} from the Garmin Forerunner 235™ for the individuals that possessed a VO_{2max} greater than 50ml/kg/min. This researcher's protocol consisted of three 30-minute bouts of running (adjusted predicted VO_{2max}) as well as the Garmin Forerunner 235™ required VO_{2max} protocol for estimating VO_{2max} (Pearson, 2017). The present study filled the gap in this previous literature and revealed a statistical significance from the laboratory conducted VO_{2max} and the Garmin Forerunner 235™ required VO_{2max} estimation within the participant group that possessed a VO_{2max} greater than 50 ml/kg/min.

Limitations in this study included participants being relatively young and healthy, as some were collegiate athletes including wrestling and soccer and did not directly reflect the general populations' current health conditions, as well as a small number of participants that were recruited from outside of Eastern Michigan University. With every study there are these exact limitations, and the present study was no exception. It is impossible to mimic the country's general population current health status with a sample size of 40 participants; however we recruited all participants who were interested. Another noteworthy limitation to this study was the lack of related, pertinent literature regarding wearable technology and VO_{2max}. This is a new field in exercise physiology as researchers and major companies are working in collaboration to develop these devices which in turn revealed a substantially low level of peer reviewed articles to cite and reference to the present study. Polar™ and Garmin™ continuously update their product line with new and improved models, so the results of the present study only reflect the devices that were tested. Some future research ideas should focus on using these exact devices with a clinical population to monitor overall fitness progression by means of estimating VO_{2max} throughout several points in a health-improving program. Other future studies should evaluate these exact devices after software updates have been released as well as newer models to test if these companies are improving their overall capability in predicting VO_{2max}.

The ACSM standard metabolic estimation equation is but none the less equidistant from the actual value such as this scientific hardware. The following figures have been drawn from referenced studies and depict a resembling best fit curve for the results from those studies and to illustrate that VO_{2max} prediction is not a simple, calculable equation that can be applied broadly. The following figures also reveal differences in measured VO_{2max} values for walkers, joggers, and runners and the level of work required to obtain maximal oxygen consumption values. Results from the present study yield an approximate resemblance regarding VO_{2max} estimation and measured actual VO_{2max} discrepancy (Bradshaw et al., 2005).

These tools can and should be utilized with the overweight and obese populations to track fitness progression as to increase patient accountability for their health progression. Devices such as the ones utilized in this study as well as others, should possess the capacity to send their respective data virtually to a hub where an exercise physiologist, or other trained personnel can interpret this data and monitor these patients to send immediate, and/or daily/weekly feedback. Polar™ offers a stationary program with relay devices called the “Polar Pro Team™.” This system offers real-time tracking combining GPS and motion tracking technology in conjunction with HR monitoring which serves as an invaluable tool for coaches to track training data for performance analysis (Polar™ guidelines, 2018). Therefore, this information should inspire our domestic researchers and professionals looking to impact and improve the overall heart health of our nation.

The Polar V800™, A300™, and the Garmin Forerunner 235™ devices were marginally more accurate for estimating VO_{2max} for the less fit individuals in the present study's sample size. This is contrary to their original design purpose and more specifically whom these devices were intended to be used by, perhaps these watches better serve as a marker of cardiorespiratory fitness, with hopeful improvements being monitored and recorded. Scientists and percipient entrepreneurs should collaborate to establish devices that can more accurately predict VO_{2max} to astutely capture consumers concerned with personal cardiovascular health improvements ultimately by providing a noninvasive means of monitoring overall health progression, as cardiorespiratory fitness directly relates to cardiovascular health.

It is understood that CRF is in direct relation to cardiovascular health and can be evaluated as means of monitoring heart health. These devices that are currently on the market today serve as a better indication of cardiovascular health than CRF tracking. CRF is both a diagnostic and prognostic health indicator for patients in clinical settings, as well as healthy individuals and can be adopted as a proxy of cardiovascular and cardiorespiratory health (Lee, 2010). Therefore, CRF is a marker of training status that can be considered one of the most important determinants of health and wellbeing (Altini et al., 2016). While the most recent developments in wearable technologies have improved the accuracy of physical activity monitoring devices in day to day living, almost all solutions focus on primarily behavioral aspects such as steps, activity type, and energy expenditure (Altini et al., 2016). Using pedometery and/or accelerometry gives insight to total steps and energy expenditure which are relevant markers of an individual's health. However, steps and energy expenditure mainly reveal the individual's daily behavior, rather than the individual's health status. CRF estimation using wearable technology could provide more insights on an individual's health status, non-invasively, and therefore help clinicians and individuals coaching or leading a healthier lifestyle (Altini et al., 2016).

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Appendices

Appendix A

Recruitment email

Subject line: Polar™ Heart Rate Monitor and GPS watch running study

To Whom It May Concern:

We are currently recruiting participants for an exercise study at Eastern Michigan University (EMU). We are looking for males and females between 18-55 years old to participate in this study. This study does involve exercise and requires you to come to the Running Science Laboratory at EMU on two separate occasions. Specifically, on the first visit, you will be asked to complete a VO_{2max} test on a treadmill. This involves running on the treadmill for 9-12 minutes at a self-selected speed while grade increases until you can no longer continue. On the second day of testing, you will be asked to lie still for 5-10 minutes to obtain an estimated VO_{2max} value as well as be asked to run outside at a pace you can sustain for 15 minutes while wearing a GPS watch. You may withdraw from the study at any time without negative consequences or losses.

If you would like to learn more information please contact Luke McCormick at lmccorm1@emich.edu or Dr. Rebecca Moore at rmoore41@emich.edu.

Thank you for your time and consideration,

Luke D. McCormick, B.S.

Graduate Assistant

Health Promotion and Human Performance (HPHP)

Eastern Michigan University

Appendix B

RESEARCH @ EMU

UHSRC Determination: EXPEDITED INITIAL APPROVAL

DATE: June 19, 2017

TO: Luke McCormick, B.S.
Eastern Michigan University

Re: UHSRC: # 1078765-1
Category: Expedited Categories *4 and 7*
Approval Date: June 19, 2017
Expiration Date: June 18, 2018

Title: Predictability of VO2max from Three Commercially Available Devices

Your research project, entitled **Predictability of VO2max from Three Commercially Available Devices,** has been approved in accordance with all applicable federal regulations.

This approval included the following:

1. Enrollment of *up to 40* subjects to participate in the approved protocol.
2. Use of the following study measures: *Health History Questionnare and PAR-Q.*
3. Use of the following stamped recruitment materials: *email text.*
4. Use of the stamped consent form.

Renewals: This approval is valid for one year and expires on 6/18/2018. If you plan to continue your study beyond 6/18/2018, you must submit a Continuing Review Form by 5/1/2018 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,

- 1 -   Generated on IRBNet

Sonia Chawla, PhD
Research Compliance Officer