VALIDITY OF THE POLAR M430 AMONG FEMALES OF VARYING FITNESS LEVELS, BODY FAT PERCENTAGE, AND REPORTED PHYSICAL ACTIVITY

by

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DEDICATION

This thesis is dedicated to my wife, Julia, and to my son, Riley. They are my motivation. Thank you for your inspiration, encouragement, and love.

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ABSTRACT

Introduction: The Polar M430 is a heart rate monitor that uses a non-exercise prediction method to predict one's $\dot{V}O_{2max}$. Research has revealed that this method will overestimate predicted $\dot{V}O_{2max}$ among females. Studies have investigated the validity of this method, however, these studies have not taken into account how physical activity (PA) levels, body fat percentage, or measured $\dot{V}O_{2max}$ could affect the prediction value. **Purpose:** The purpose of this study was to investigate the validity of the Polar M430 in predicting $\dot{V}O_{2max}$ amongst females of varying PA levels, body fat percentages, and fitness levels. **Methods:** Forty-eight female participants were recruited for this study. After entering age, height, weight, gender, and self-reported PA, into the Polar M430 the *Polar Fitness Test* was started to obtain their predicted $\dot{V}O_{2max}$ (p$\dot{V}O_{2max}$). The test was performed three times: at the participant's self-selected PA category (s$\dot{V}O_{2max}$), and one PA category below the s$\dot{V}O_{2max}$ (s$\dot{V}O_{2max}$ -1), and one category above the s$\dot{V}O_{2max}$ (s$\dot{V}O_{2max}$+1). Measured $\dot{V}O_{2max}$ (a$\dot{V}O_{2max}$) was assessed via indirect calorimetry using a modified Astrand treadmill protocol. To compare fitness level and body fat percentage, data for those values were split into quartiles and a repeated measures (RM) ANOVA was used to detect differences between groups. **Results:** There were no significant differences between mean p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$ values ($p > 0.05$). p$\dot{V}O_{2max}$ was significantly correlated with a$\dot{V}O_{2max}$ (r = .697, $p < .0001$). There was no significant difference between a$\dot{V}O_{2max}$ and p$\dot{V}O_{2max}$ at s$\dot{V}O_{2max}$ - 1 and s$\dot{V}O_{2max}$+1 ($p > 0.05$). There were also no significant differences between quartiles groups for any of the secondary variables ($p > 0.05$). **Conclusion:** Among females, using the Polar M430 is a valid method to predict $\dot{V}O_{2max}$. These results were consistent across different fitness levels, body fat percentages, and PA categories.

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LIST OF ABBREVIATIONS

CRF	Cardiorespiratory Fitness
$\dot{V}O_{2max}$	Maximal Oxygen Consumption
GXT	Maximal Graded Exercise Test
$\dot{Q}$	Cardiac Output
$a\text{-}vO_2$	Arterial Venous Oxygen
SV	Stroke Volume
BMI	Body Mass Index
ECG	Electrocardiography
PPG	Photoplethysmography
EE	Energy Expenditure
PAR-Q	Physical Activity Readiness Questionnaire
SEM	Standard Error Mean
RM	Repeated Measures
ANOVA	Analysis of Variance
$p\dot{V}O_{2max}$	Predicted $\dot{V}O_{2max}$
$a\dot{V}O_{2max}$	Measured $\dot{V}O_{2max}$
RER	Respiratory Exchange Ratio
HR	Heart Rate
HR_{rest}	Resting Heart Rate
HR_{max}	Maximal Heart Rate

$_{ap}HR_{max}$	Age Predicted Maximal Heart Rate
BL	Blood Lactate
PFT	Polar Fitness Test

CHAPTER ONE: INTRODUCTION

Cardiorespiratory fitness (CRF) plays an integral role in health and wellness. Determining CRF can help adults measure their fitness level, assess their risk for cardiovascular or metabolic disease, and can also help athletes evaluate the effectiveness of their endurance training program. Maximal oxygen consumption ($\dot{V}O_{2max}$) is the criterion metric for determining CRF. $\dot{V}O_{2max}$ is the maximum rate a person can yield energy through oxidative energy sources (Ramsbottom, Brewer & Williams, 1998). In relation to the Fick Principle, a person may have a higher level of CRF when their heart has a greater ability to pump blood out to the body, giving the working limbs a higher potential for oxygen utilization (Basset & Howley, 2000). The assessment of $\dot{V}O_{2max}$ has traditionally been used to prescribe exercise intensity, evaluate progress of an exercise program, and evaluate endurance performance potential (American College of Sports Medicine [ACSM], 2018).

Measurement of $\dot{V}O_{2max}$ occurs during a maximal graded exercise test, traditionally on a treadmill or cycle ergometer. As the subject exercises to their maximal capacity during the test, direct gas analysis of oxygen uptake is measured using a metabolic cart. This assessment method is considered to be the gold standard method of measuring $\dot{V}O_{2max}$ (Powers, & Howley, 2009). Despite its high level of accuracy, this assessment can be unreasonable for many people because testing requires expensive equipment, trained specialists, and, in some cases, supervision by a physician (ACSM, 2018). Such an assessment also may not be feasible for people with a cardiovascular or metabolic disease.

Given the drawbacks of performing a maximal graded exercise test, there are other alternative methods to estimate a person's $\dot{V}O_{2max}$. A submaximal exercise test can estimate a subject's $\dot{V}O_{2max}$ based on their heart rate response at a submaximal load along with other measures such as blood pressure, workload, and rating of perceived exertion (ACSM, 2018). When a linear relationship is achieved between variables (such as HR) and the work rate, $\dot{V}O_{2max}$ can then be predicted based off this linear relationship with the upper limit of this relationship being age-predicted heart rate max (ACSM, 2018). While these methods introduce some prediction error compared to a maximal graded exercise test with indirect calorimetry, they are frequently preferred because they are easier to perform, can be managed with lower risks and cost, and can be completed by most populations (ACSM, 2018). Submaximal tests can be performed using varying modes of exercise such as bench stepping (Fitchett, 1985), cycle ergometry (Beekley et al., 2004), and running (Maksud & Coutts, 1971).

Alternative methods are available to predict $\dot{V}O_{2max}$ that do not require exercise. These non-exercise methods use prediction equations to provide an estimation based on factors such as gender, age, resting heart rate (HR) body fat percentage, body mass index, perceived functional ability, and physical activity rating (Heil, Freedson, Ahlquist, Price, & Rippe, 1995; George, Stone, & Burkett, 1997). $\dot{V}O_{2max}$ decreases with age, is lower in females and individuals with a higher percentage of body fat, and may improve with increased physical activity (McArdle, F. Katch, & V. Katch, 2015). The standard error of estimate for these non-exercise prediction models have ranged between 3.09 to 3.63

mL·kg $^{-1}$ min $^{-1}$. (George et al., 1997; George et al., 2009; Bradshaw et al., 2005; McArdle et al., 2015). Multiple studies have shown that non-exercise prediction equations are comparatively accurate and are a means of conveniently and safely predicting one's $\dot{V}O_{2max}$ (Wier, Jackson, Ayers, & Arenare, 2006; Jackson et al., 1990).

With the improvements in technology, HR monitors have been developed to predict $\dot{V}O_{2max}$ using non-exercise prediction equations. Unique to these monitors is the use of HR in their prediction equation. Polar Electro Oy (Kemple, Finland), one of the leaders in HR monitor development, have created a non-exercise test for their HR monitors called the *Polar Fitness Test* (Polar Electro Inc., n.d.). The test consists of the continuous measurement of resting HR and HR variability while the user is rests supine for approximately five minutes. The *Polar Fitness Test* then uses self-reported values for gender, age, weight, height, and physical activity rating in a prediction equation to predict the $\dot{V}O_{2max}$. The $\dot{V}O_{2max}$ value is then presented as the person's *Own Index* (Polar Electro Inc., n.d.).

Given the simplicity of measurements from the Polar HR monitors, this method may be preferred over a maximal graded exercise test that requires an exhaustive effort and may not be available for everyone. However, it is important to establish the validity of this method. Esco et al. (2011) investigated the validity of the Polar Fitness Test using the Polar F11 HR monitor in predicting a person's $\dot{V}O_{2max}$. In this study, 50 male subjects performed the Polar Fitness Test, as described above, followed by a maximal graded exercise test using the Bruce treadmill protocol to obtain the measured $\dot{V}O_{2max}$. A paired t-test showed no significant difference ($p = 0.18$) between the predicted and measured $\dot{V}O_{2max}$ scores (45.4 ± 11.3 mL·kg^{-1}·min^{-1} and 47.4 ± 9.1 mL·kg^{-1}·min^{-1} respectively)

(Esco et al., 2011). In a similar study, Kraft and Dow (2018) examined the validity of the Polar RS300X fitness watch among college students. Each participant performed a maximal graded exercise test using the Bruce treadmill protocol following the Polar Fitness Test. They also found no significant difference between the mean values obtained from the Polar Fitness Test (47.67 $mL \cdot kg^{-1} \cdot min^{-1}$) and indirect calorimetry (44.09 $mL \cdot kg^{-1} \cdot min^{-1}$) ($p = 0.111$) (Kraft and Dow, 2018). These studies suggest that the *Polar Fitness Test* is able to predict one's $\dot{V}O_{2max}$ with no difference to the gold standard of measurement.

In contrast with these two studies, other research has shown the Polar Fitness Test to overestimate predicted $\dot{V}O_{2max}$ values, but only among female participants. Using the Polar S410, Crouter, Albright, and Bassett (2004) found that the predicted and measured $\dot{V}O_{2max}$ values in males were not significantly different ($p > 0.05$) but the monitor overestimated $\dot{V}O_{2max}$ by an average of 10.8 $mL \cdot kg^{-1} \cdot min^{-1}$ in female subjects ($p = 0.001$). When using the Polar FT40, Esco, Snarr, and Williford (2014) also found that predicted $\dot{V}O_{2max}$ was significantly overestimated amongst female collegiate soccer players when compared to the measured values using a Bruce treadmill protocol ($p = 0.008$, Cohen's $d = 0.90$). This pattern was also confirmed in a study by Lowe, Lloyd, Miller, McCurdy, and Pope (2010) who measured the accuracy of the Polar F6 amongst college females who participate in an aerobics dance class. They found that the mean score for the predicted $\dot{V}O_{2max}$ was overestimated by an average of 2.63 $mL \cdot kg^{-1} \cdot min^{-1}$ ($p < 0.01$) (Lloyd et al., 2010).

Previous research has shown that the *Polar Fitness Test* in Polar HR monitors overestimates predicted $\dot{V}O_{2max}$ scores within females (Crouter et al., 2004; Esco et al., 2014; Lowe et al., 2010). Esco Snarr and Williford (2014) discussed that because the prediction equations used to predict $\dot{V}O_{2max}$ in Polar HR monitors are not available to the public, it is challenging to determine which variable is most responsible for the differences between predicted and actual measures. However, they speculated that because PA is self-reported, an exaggerated PA rating could result in an overestimated prediction (Esco et al., 2014). Each of these previous research studies did not take into account the possibility of PA levels, body fat percentage, or measured $\dot{V}O_{2max}$ of the participant could affect the prediction value.

Purpose of the Study

The purpose of this study was to investigate the validity of the Polar M430 in predicting $\dot{V}O_{2max}$ amongst females of varying PA levels, body fat percentages, and fitness levels.

Research Hypothesis

It is hypothesized that measured $\dot{V}O_{2max}$ will not be significantly different than predicted $\dot{V}O_{2max}$ after accounting for differences in PA level, body fat percentage, and fitness level.

Significance of the Study

Examining the effect of PA, body fat percentage, and fitness level on the validity of the Polar M430 to predict $\dot{V}O_{2max}$ can generate valuable information for researchers and clinical exercise physiologists on the use of wearable HR monitors for their clients. This information can also be important for coaches, particularly in areas of measuring fitness status and prescribing workloads for their athletes.

CHAPTER TWO: LITERATURE REVIEW

Introduction

Cardiorespiratory fitness (CRF) is an important component of physical health and wellbeing. The gold standard for determining CRF is the direct measurement of maximal oxygen consumption ($\dot{V}O_{2max}$) during a maximal graded exercise test (GXT). Despite this being the gold standard, directly measuring $\dot{V}O_{2max}$ can be impractical for most people because of the expensive equipment and trained specialists required to perform such tests. For others, performing a GXT is unreasonable because of physical limitations and risk factors. An accurate test requires the participant to work to volitional exhaustion, which is difficult for people with physical limitations to achieve, thus rendering them unable to reach their true $\dot{V}O_{2max}$. To accommodate for these limitations, submaximal exercise tests have been developed to predict a person's $\dot{V}O_{2max}$. These tests require reduced exercise intensity from the subject and do not necessitate expensive equipment. Researchers have gone further to create non-exercise prediction equations, which only require a person to report certain variables such as gender, age, weight, body mass index, perceived functional ability, and physical activity rating. Because of the advancement in technology, heart rate (HR) monitors can use such non-exercise prediction tests to predict one's $\dot{V}O_{2max}$. These monitors make measuring one's CRF accessible to people of all ages and physical conditions. Much research has been done to examine the validity of these monitors, specifically in the monitors from Polar Electro Inc., the leading manufacturer of HR monitors.

Non-exercise Prediction Models

Accuracy of Non-Exercise Prediction Models

Substantial research has been done to investigate the accuracy of non-exercise prediction models compared to other methods of measuring one's $\dot{V}O_{2max}$. One of the foundational studies to investigate this comes from Jackson et al. (1990), who compared two different non-exercise prediction models to the Astrand, single-stage, submaximal cycling protocol prediction model and direct measurement of $\dot{V}O_{2max}$ using the Bruce treadmill protocol. Both prediction models utilized age, resting heart rate, and physical activity rating. However, each model used a different measure of body mass assessment methods; estimated percent of body fat from skinfolds and body mass index (BMI). Their data analysis showed that both models were significantly more accurate (SE = 5.0 $mL \cdot kg^{-1} \cdot min^{-1}$, SE = 5.3 $mL \cdot kg^{-1} \cdot min^{-1}$ respectively) than the Astrand prediction model (SE = 5.5 - 9.7 $mL \cdot kg^{-1} \cdot min^{-1}$) (Jackson et al., 1990). Similarly, Heil, Freedson, Ahlquist, Price, and Rippe (1995) cross validated their own prediction model to predict VO_{2peak} against measuring $VO_{2\ peak}$ with a treadmill walking protocol. The variables of their non-exercise model included gender, age, percent body fat and physical activity rating. Their study resulted in a correlation coefficient of $r^2 = 0.77$, SEE = 4.90 ml·min, and SEE% = 12.7% demonstrating a high level of accuracy (Heil et al., 1995).

In contrast to these studies, Kolkhorst and Dolgener (1994), investigated the two prediction models derived from the study by Jackson et al. (1990) and found that they largely underestimated VO_{2peak} in college aged students. The differences in the mean values for the non-exercise BMI and percent fat models from the measured VO_{2peak} were 9.77 and 11.73 $mL \cdot kg^{-1} \cdot min^{-1}$ respectively ($p < .0001$) (Kolkhorst & Dolgener, 1994).

Kolkhorst and Dolgener (1994) note that these differences could be either biological or technical, given the fact that their subjects were strictly college aged students and that underestimation in self-reported physical activity rating may have been a limitation. This brings into question if certain variables of a non-exercise prediction model can influence the accuracy of its prediction.

Non-exercise Prediction Variables

Because non-exercise prediction models use different variables, there are discrepancies in the prediction accuracy of each model. For example, Bradshaw et al. (2005) developed a prediction equation using variables that included BMI, gender, age, perceived functional ability (PFA) (to walk, jog, or run given distances at a certain pace), and current physical activity rating (PA-R). Secondary to their purpose was to determine the variable with the largest influence on predicted $\dot{V}O_{2max}$. They found that each independent variable was significant ($p < 0.05$) in $\dot{V}O_{2max}$ prediction, and a β-weight analysis discovered that PFA explained the largest variance, while PA-R accounted for the smallest variance (Bradshaw et al., 2005) By removing PFA from the equation, the correlation coefficient would decrease from 0.93 to 0.89 and the SEE would increase from 3.45 to 4.20 $mL \cdot kg^{-1} \cdot min^{-1}$ (Bradshaw et al., 2005).

Weir et al. (2006) investigated the use of waist girth as a replacement for body fat percentage and BMI, which are commonly used in non-exercise regression models. They also used age, gender, and the NASA Physical Activity Status Scale. They found that replacing BMI or body fat percentage with waist girth in their equation yielded no significant difference in the prediction accuracy of $\dot{V}O_{2max}$ (Weir et al., 2006).

Non-exercise prediction models can be a safe and convenient method of predicting one's $\dot{V}O_{2max}$. However, the validity of these models are inconsistent (Bradshaw et al., 2005; Weir et al., 2006). Much of the validity is most likely dependent on the variables that are used in the equation (Bradshaw et al., 2005). For example, Kolkhorst and Dolgener (1994) showed that even a difference in the sample population can affect the prediction validity. Although they investigated the same prediction models as Jackson et al. (1990), they yielded contradicting results. The authors speculated that the lower age of their participants may have been one reason (Kolkhorst & Dolgener, 1994). Kolkhorst and Dolgener (1994) also considered inaccuracy in the selection of PA as a possible explanation of their contradicting results. They discussed that an over or underestimation in PA could eventually lead to an invalid prediction of $\dot{V}O_{2max}$. Based on the discussion points and conclusions of these previous studies (Bradshaw et al., 2005; Kolkhorst & Dolgener, 1994), the current study fills a need to directly assess the effect on predicted $\dot{V}O_{2max}$ from variables commonly used in prediction equations. Investigating variables such as fitness level, selection of PA, and body fat percentage can further explain the validity of HR monitors to predict $\dot{V}O_{2max}$.

Heart Rate Monitors

In an attempt to optimize training for coaches and athletes, Polar Electro Oy developed the first wireless HR monitor called the Polar PE 2000 (Karvonen, Chwalbinska-Moneta, & Saynajakangas, 1984). This monitor used electric field data transfer (telemetry) between a transmitter that measured HR and a receiver that presented the HR on a screen. The transmitter consisted of disposable electrodes with an elastic belt worn around the chest and the receiver was a monitor worn on the wrist similar to a watch (Karvonen et al., 1984). In addition to coaches and athletes, scientists began using such monitors in their research. Now, people can use commercially available monitors utilizing the same technology for their fitness and health.

Validity of the Chest Strap HR Monitor

The chest strap HR monitor uses electrodes to track one's HR and transmits the signal to a computer or wrist-worn watch (Engström, Ottosson, Wohlfart, Grundström, & Wisén, 2012). The watch then calculates the HR based upon inter-beat intervals (R-R interval) and averages of the HR data (Kingsley, Lewis, & Marson, 2005). To validate this method of HR measurement, researchers have compared it to electrocardiography (ECG), considered to be the gold standard of measuring HR. In a classic study by Karvonen, Chwalbinska-Moneta, and Saynajakangas (1984), 14 subjects performed a maximal graded exercise test, either on a treadmill or cycle ergometer, while HR measurements were taken from an ECG and the PE 2000. The PE 2000 consisted of a transmitter with electrodes wrapped around the subjects' chest with a strap that used telemetry to send the HR to a receiver worn on their wrist. Heart rates recorded from the PE 2000 were significantly higher from the ECG ($p < .01$). Despite the significant difference, HR from the PE 2000 differed by no more than 5 bpm. The averaging rates of HR from both methods were different, with the PE 2000 averaging every 3-4 seconds and the ECG every 12-14 seconds (Karvonen et al., 1984). Thus, the HR recorded by the PE 2000 most represented the changing heart rates during exercise and recovery periods, which explains the difference between the two methods of HR measurement.

Leger and Thivierge (1988) investigated the validity of 13 commercially available HR monitors. Ten subjects simultaneously wore two HR monitors and an ECG during a graded exercise test on a cycle ergometer and treadmill, and a step test. HR measurements were taken every 10 seconds. Correlation with ECG measurement varied among the HR monitors. The investigators separated the monitors into three categories based upon their correlation (excellent r = .93 to .98; good r = .84 to .65; inadequate r < .65). Of the 13 monitors, six were included in the inadequate category (Leger & Thivierge, 1988). However, those monitors used photocell electrodes (which are dependent on a light-sensitive conductor) or “nonconventional electrodes” for their HR measurement. The other monitors that had a good or excellent correlation used conventional electrodes on the chest (Leger, & Thivierge, 1988). Modern Polar HR monitors use an electrode chest strap (Polar Electro Inc., n.d).

The early chest strap HR monitors used radio signals from the electrodes to the receiver watch. Since then, the technology used in such HR monitors has advanced to where information from the chest strap electrodes are sent via sophisticated wireless technologies (Polar Electro Inc., n.d.). Despite these advances, it is still important to examine the validity of chest strap HR measurement. In a study by Engström, Ottosson, Wohlfart, Grundström, and Wisén (2012), 10 participants (3 male, 7 female) performed a graded exercise test on a cycle ergometer while wearing the Polar RS-400 and a 12-lead ECG. The graded test required each participant to bike at 50, 100, and 150 W while the RS-400 measured HR over 5 second intervals and the ECG over 10 second intervals. Data from the last 10 second intervals at 5, 10, and 15 minutes were used for analysis. Correlation coefficients of 0.97-1.0 showed a strong positive correlation between the two methods of HR measurement at all three exercise intensities with a mean difference of 0.7 ± 4.3 bpm (Engström et al., 2012). The authors concluded that the Polar RS-400 showed strong validity against ECG (Engström, Ottosson, Wohlfart, Grundström, & Wisén, 2012).

In a similar study, Kingsley et al. (2005) had 8 participants (6 male, 2 female) perform a maximal graded exercise test on a cycle ergometer while outfitted with the Polar 810 s and a 3-lead ECG. During the test, each participant cycled at 75-85 rpm starting at 60 W with the intensity increasing by 30 W every two minutes until volitional fatigue. R-R interval data was analyzed at exercise intensities of < 40%, 40-60%, 60-80%, and 80-100% $\dot{V}O_{2max}$. A strong relationship was found between the Polar 810 s and ECG during the maximal graded exercise test ($r^2 = 0.927$, $p < 0.001$ to $r^2 = .998$, $p < 0.001$), which lead to the conclusion that the Polar 810 s is a valid tool to measure HR. (Kingsley et al., 2005). From these studies (Engström et al., 2012; Leger & Thivierge, 1988; Karvonen et al., 1984; Kingsley et al., 2005), we see that using a chest strap HR monitor to measure HR can be a trusted and valid alternative to an ECG.

<u>Optical vs. ECG and Chest Strap</u>

Modern wearable HR monitors measure HR using two different technologies: electrocardiography (ECG) and photoplethysmography (PPG), often referred to as "optical" HR monitoring. Optical HR monitoring uses LED lights that emit light into the skin and a photodiode that identifies the amount of light reflected back (Polar Electro Inc., n.d.). As the heart pumps blood, waves of larger volumes of blood pass through the skin. The photodiode detects the lesser amount of light reflected back when a larger volume of blood passes through the skin, thus, determining the heart rate (Polar Electro Inc., n.d).

To assess the accuracy and validity of this method of HR measurement, researchers have compared it to both ECG leads and previously validated chest strap HR monitors. Horton, Stergiou, Fung, and Katz (2017) compared the Polar M600 optical HR sensor against a three lead ECG during various training intensities and activities. HR measurements were taken during activities that included rest, cycle warm up, intervals on the cycle and treadmill, circuit training, and exercise recovery. Accuracy of the M600 was defined and calculated as the percentage of occurrences where the measurement was within ± 5 bpm from the ECG HR value. The M600 had the greatest accuracy in measuring HR during the cycle intervals and was the least accurate during the circuit training (91.8% and 34.5% respectively). There was no significant difference in the average measured HR between the M600 and the ECG during the cycle and treadmill intervals, rest, and during activity transition ($p > 0.05$) (Horton et al., 2017). Similarly, Jo, Lewis, Directo, Kim, and Dolezalal (2016) found that the Fitbit Charge HR, which uses optical HR measurement, was valid at lower intensities, but decreased in accuracy as exercise intensity increased. In this study, each subject wore the Fitbit Charge HR along with a twelve lead ECG while performing activities such as rest, walking, jogging, running, cycling at both 60 and 120 W, lunges, arm raises, and isometric planks. Compared with the ECG, during the lower intensity exercises, the Fitbit Charge HR had a strong correlation ($r = 0.83$) (Jo et al., 2016). However, when the intensity of exercise prompted the HR to reach above 116 bpm, the correlation with the ECG dropped ($r = 0.58$), thus signifying a drop in accuracy (Jo et al., 2016). In addition to the exercise intensity affecting HR measurement, the mode of activity also had an effect. The lowest correlation between the Fitbit Charge and ECG occurred during resisted lunges (r = 0.28) and isometric plank (r = 0.26).

Gillinov et al. (2017) compared the validity of PPG wrist worn monitors with a chest strap monitor. Each subject was randomly assigned to wear two of four PPG monitors which included the Garmin Forerunner 235, Fitbit Blaze, TomTom Spark Cardio, and Apple Watch. Each subject also wore the Polar H7 chest strap and ECG leads. HR was measured at low, moderate, and vigorous intensities on a treadmill, elliptical (both with arms and without), and cycle ergometer. Out of the four PPG monitors, the Apple Watch had the highest agreement with the ECG ($r_c = 0.92$) with the TomTom Spark, Garmin Forerunner, and Fitbit Blaze following behind it in accuracy ($r_c = 0.83$, $r_c = 0.81$, and $r_c = 0.67$ respectively) (Gillinov et al., 2017). However, the Polar H7 chest strap had the highest agreement ($r_c = .99$) during each of the activities and intensities (Gillinov et al., 2017). The authors concluded that the PPG monitors vary in their accuracy and that when HR monitoring is vital, an ECG chest strap should be used. In a similar study, Delgado-Gonzalo et al. (2015) compared the accuracy of the PulsOn HR monitor (PPG) with achest strap, the Polar Electro RS800CX. Each subject walked on a treadmill and cycled at varying speeds, inclines, and resistances while each device measured HR. The PulsOn monitor showed a mean reliability of 94.5% and an accuracy of 96.6% compared to the ECG chest strap (Delgado-Gonzalo et al., 2015).

Stahl, An, Dinkel, Noble, and Lee (2016) compared five different wrist worn HR monitors (TomTom Runner Cardio, Mio Alpha, Basis Peak, Scosche Rhythm, and Microsoft Band) to the Polar RS400 chest strap monitor. The Polar RS400 was previously found to be highly correlated with ECG measurements (Engström et al., 2012). Each subject wore the HR monitors on their wrist in random order and first measured their resting HR for 3 minutes. A graded treadmill protocol for 30 minutes then followed which included walking and running on a treadmill at 3.2, 4.8, 6.4, 8.0, and 9.6 $km \cdot h^{-1}$ for 5 minutes at each speed and a cool down at 4.8 $km \cdot h^{-1}$ for 5 min. HR was recorded from each device every minute. Results showed that four of the five wrist worn monitors were not significantly different ($p > 0.531$) from the chest strap (Stahl et al., 2016). Additionally, a Pearson product-moment correlation demonstrated that all the activity monitors had a strong correlation ranging from 0.87 to 0.96 (Stahl et al., 2016). This study showed that a group of commercially available wrist worn monitors will give comparable HR results to chest strap monitors.

Boudreaux et al. (2018) compared the HR validity of a chest strap HR monitor (Polar H7) and seven commercial monitors that use optical technology (Polar A360, Apple Watch Series 2, Fitbit Charge 2, Fitbit Blaze, Garmin Vivosmart HR, Bose SoundSport Pulse, Tom Tom Touch) to ECG. The HR measurements of only one of the monitors (the Polar H7) was assessed using a chest strap. Each subject wore the monitors and a six-lead ECG during a graded exercise test on a cycle ergometer, starting at rest and ending at 150 W. The results showed that HR measurement from the monitors had strong relationships with the ECG at rest (R = 0.76 – 0.99) (Boudreaux et al., 2018). However, as the exercise intensity increased, the correlation decreased (R = 0.47–0.90 at 50 W; R = 0.32–0.85 at 100 W; R = 0.11–0.80 at 150 W) (Boudreaux et al., 2018). Three of the eight monitors (Polar H7, Apple Watch Series 2, Bose SoundSport Pulse) maintained a good correlation (R > 0.75) throughout the entire test (Boudreaux et al., 2018). This study suggests that both wrist worn and chest strap monitors can provide valid measures of one's HR at rest, but may begin to worsen as exercise intensity increases.

Rider et al. (2019) examined the accuracy of the wrist worn Polar A360 among 30 athletes. Using the Polar RS400 as a criterion measure for HR, each participant wore both monitors during a series of 2-minute rest intervals while supine, seated, and standing. Each participant then completed a graded maximal exercise test until volitional fatigue, and then performed active and passive recovery. During each stage of rest, exercise, and recovery, HR was measured by both monitors every 30 seconds. Across all stages, the A360 exhibited a strong correlation with the RS400 ($r^2 = 0.98$) (Rider et al., 2019). However, HR measurement was significantly underestimated during a 6.4 kph speed during the graded exercise test ($p < 0.05$) (Rider et al., 2019). Rider et al. (2019) explained that during this stage of the exercise protocol, participants alternated between walking and jogging. They further explained that a change in movement and gait pattern could have been a possible reason why the accuracy of the A360 was impacted at this stage. During the resting stages, the A360 demonstrated the highest accuracy (91%) but decreased during walking (71%) and then increased at running speeds (79%) (Rider et al., 2019).

The results of these studies show that optical HR measurement is a valid alternative to ECG and chest strap monitors (Stahl et al., 2016). However, this is mostly seen during low intensity exercise and begins to vary as exercise intensity increases (Boudreaux et al., 2018; Jo et al., 2016). Other monitors have shown to be significantly different from the gold standard during stages of intensity that change upper body movement and gait patterns (Rider et al., 2019). The mode of exercise can also cause variation in the validity of these monitors (Horton et al., 2017; Jo et al., 2016), as well as the model of the monitor (Boudreaux et al., 2018; Gillinov et al., 2017). Although strong correlations of optical HR measurement with ECG and chest strap monitors have been seen, caution is still advised when using this method. Considering the purpose of this study, it is important to have an accurate and valid HR measure when using a commercially available HR monitor. Given that Polar HR monitors use resting HR in their prediction method, an accurate and valid measure of HR is necessary for a valid prediction of $\dot{V}O_{2max}$. An assessment of the Polar M430's ability to measure HR would be an important factor for this study.

Monitors Using Non-Exercise Prediction Methods

Validity of Heart Rate Monitors that Predict $\dot{V}O_{2max}$

With improvements in technology, HR monitors have been developed to implement non-exercise prediction equations to predict $\dot{V}O_{2max}$. Similar to non-exercise prediction equations, much research has been performed to measure the validity of these devices. Crouter et al. (2004) investigated the accuracy of the Polar S410 in measuring energy expenditure during exercise using both measured and predicted $\dot{V}O_{2max}$.The Polar S410 uses resting HR and HR variability, and self-reported variables such as age, gender, height, weight, and PA level to predict $\dot{V}O_{2max}$. While resting supine in a recliner for 15 minutes, the monitor measured the subject's resting HR and HR variability, and from a proprietary prediction equation, calculated their predicted $\dot{V}O_{2max}$ (Crouter et al., 2004). Each subject then performed a maximal graded exercise test on a treadmill. Before the test began, each subject performed a warm up where the individual found a comfortable running speed during the test. The test was started at the predetermined, self-selected running speed and the grade was increased by one percent every minute until volitional exhaustion. Paired t-tests showed that mean predicted and actual $\dot{V}O_{2max}$ values were not significantly different (p > 0.05) in males, but were significantly different in females (p = 0.001) (Crouter et al., 2004). They also found that $\dot{V}O_{2max}$ was significantly overestimated among the females by an average 10.8 $mL \cdot kg^{-1} \cdot min^{-1}$ (Crouter et al., 2004). Pearson product moment correlation coefficients showed that predicted and actual $\dot{V}O_{2max}$ had a significant correlation in males (r = 0.872, p = 0.001) but not in females (r = 0.477, p > 0.05) (Crouter et al., 2004). Esco, Mugu, Williford, McHugh, and Bloomquist (2011) investigated the validity of the Polar F11 HR monitor to predict $\dot{V}O_{2max}$ among 50 male subjects. Similar to the S410, the F11 HR monitor utilized variables that included age, gender, height, weight and self-reported PA. Given these are the same variables recorded in the Polar S410, it is probable the monitors use the same or similar $\dot{V}O_{2max}$ prediction equations. The test itself is called the *Polar Fitness Test.* With the HR monitor secured, each participant lied on an athletic training table for five minutes while the monitor assessed resting HR and HR variability. The predicted $\dot{V}O_{2max}$ was then automatically displayed on the screen of the monitor. After the prediction test, each participant performed a Bruce treadmill protocol that increased both speed and grade for each 3-minute segment to measure $\dot{V}O_{2max}$. Their results also showed no significant difference between the predicted and measured mean values (p = 0.18; 45.4±11.3 and 47.4±9.1 $mL \cdot kg^{-1} \cdot min^{-1}$ respectively) (Esco et al., 2011).

In contrast to these studies, Snyder, Willoughby, and Smith (2017) found contradictory results. They examined the validity of the Polar V800, and two Garmin Forerunner models: 230 and 235. Each individual followed the same procedure for obtaining the predicted value as the above-mentioned studies for the Polar V800 (Crouter et al., 2004; Esco et al., 2011) followed by a $\dot{V}O_{2max}$ test on a treadmill. Forty-eight hours after the test, each subject completed a 10-min self-paced run, where the Garmin Forerunner 230 and 235 obtained HR values for its prediction measure. Significant differences between predicted and measured values were found for each HR monitor (p = 0.029) (Snyder et al., 2017). Specifically, they found that within both males and females, the values were consistently overestimated by 1.1 to 6.0 $mL \cdot kg^{-1} \cdot min^{-1}$ (Snyder et al., 2017). Johnson and Beadle (2017) investigated the Polar FT60 in predicting $\dot{V}O_{2max}$. Similar to other studies (Crouter et al., 2004; Esco et al., 2011; Snyder et al., 2017), each subject performed a graded maximal exercise test on a treadmill which was compared to the predicted values. They found that the Polar FT60 consistently and significantly overestimated $\dot{V}O_{2max}$ by 9.75% ($p < 0.001$) (Johnson, & Beadle, 2017).

Patterson, Hanzel, Shryack, Willoughby, and Smith (2018) compared the validity of the wrist worn Polar M430 to the Polar V800 (chest strap). Before carrying out the predictions from both monitors, each participant lied supine on a table for 10 minutes to ensure their HR was at resting value. The participants were then fitted to each monitor and then performed the prediction of $\dot{V}O_{2max}$ as previously described (Crouter et al., 2004). From their analysis, the wrist worn, and chest strap predictions showed no significant differences between each other (48.2 ± 13.5 and 48.3 ± 12.9 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively) (Patterson et al., 2018). The same authors (Shyrack, Patterson, Hanzel, Willoghby, & Smith, 2018) followed up with a study that directly compared the predicted $\dot{V}O_{2max}$ of the Polar M430 and the actual $\dot{V}O_{2max}$. Each participant first performed the *Polar Fitness Test* to predict their $\dot{V}O_{2max}$. The subjects then performed a maximal graded exercise test to assess their $\dot{V}O_{2max}$. Their results showed no significant difference between the predicted and measured values (48.2 ± 13.5 and 45.3 ± 9.4 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ respectively) (Shryack et al., 2018). Philips, Ziemba, and Smith (2016) followed a similar protocol but predicted $\dot{V}O_{2max}$ using the Polar V800, M400, and FT60. They also found a significant correlation between the predicted and actual values ($r = 0.718$, $p < 0.01$) (Philips et al., 2016)

By incorporating resting HR and HR variability into a prediction equation, a Polar HR monitor is able to predict an individual's $\dot{V}O_{2max}$ (Crouter et al., 2004; Esco et al., 2011). However, the accuracy of these monitors varies between each model (Snyder et al., 2017; Johnson & Beadle, 2017). It is difficult to explain the possible reasons for this variability, but a limitation shared amongst these studies might clarify these discrepancies. First, not all studies reported if any secondary criteria were used for determining if their subjects reached true $\dot{V}O_{2max}$ (Johnson & Beadle, 2017; Snyder et al., 2017). By not reporting the secondary criteria, it is difficult to determine whether the subjects reached their true aerobic capacity. Not reaching true $\dot{V}O_{2max}$ may affect the statistical significance because the measured value is more distant from the subject's actual value, and may result in an overestimated prediction (Johnson & Beadle, 2017; Snyder et al., 2017). Another reason why it is challenging to explain the differences between these studies is that the prediction equations used in Polar HR monitors to predict $\dot{V}O_{2max}$ have not been publicly released. Because of this, it is difficult to determine the impact that specific variables may have on the predicted $\dot{V}O_{2max}$.

HR Monitor Predictions of $\dot{V}O_{2max}$ Among Different Populations

Fitness Level

Many HR monitors require a self-reported physical activity or fitness level. It is possible that fitness level may affect the $\dot{V}O_{2max}$ prediction accuracy. Montgomery et al. (2009) tested the validity of the Suunto HR monitor to predict energy expenditure and $\dot{V}O_{2max}$ among well trained runners. In their study, they recruited 10 males and 7 females who had been training continuously for six months and had VO_{2peak} values of 65.9 ± 9.7 $mL \cdot kg^{-1} \cdot min^{-1}$ and 57.0 ± 4.2 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively. The prediction of $\dot{V}O_{2max}$ was based on the subject's age, weight, gender, height, and physical activity rating, which were logged into the monitor. The software from the monitor then predicted the HR_{max} and $\dot{V}O_{2max}$. Each subject then completed two treadmill protocols where O_2 consumption was measured. The first was a submaximal series of five 4-minute intervals run below the subject's gas exchange threshold. After the submaximal test, each subject took a 10-minute break with oxygen still being analyzed. The maximal test was performed after the 10-minute break. The initial speed of the max test was the same as the submaximal test but increased by 1 kilometer an hour every minute until volitional exhaustion. Validity of the Suunto HR monitor, compared to open circuit spirometry measured by a metabolic cart, was shown as the standard error of estimate (SEE) and the coefficient of variation (CV), which were expressed with 90 percent confidence limits. Their statistical analysis showed Pearson correlation coefficients of 0.98 (SEE) and 0.98 (CV) (Montgomery et al., 2009). They also found that the Suunto HR monitor underestimated predicted values with a bias degree of -10.9% (Montgomery et al., 2009).

Bradshaw et al. (2005) included 50 males and 50 females between 18-65 years who were classified as low-to-moderate risk for exercise testing. For the prediction equations, the subjects measured and reported their BMI, gender, age, PFA to walk, jog, and run, and PA-R. Each subject then performed a graded maximal exercise test to measure their $\dot{V}O_{2max}$. Mean $\dot{V}O_{2max}$ values ranged between 31-43 $mL \cdot kg^{-1} \cdot min^{-1}$. Cross validation PRESS statistics of their data showed high prediction accuracy ($R_p = 0.91$ and $SEE_p = 3.63$ $mL \cdot kg^{-1} \cdot min^{-1}$) (Bradshaw et al., 2005). In a similar study, Kraft and Roberts (2017) tested the prediction accuracy of the Garmin 920XT fitness watch among college students. The Garmin 920XT predicted each subject's VO_{2peak} from recorded weight, height, and HR during a 10-minute jog around a football field. The next day, each participant performed a maximal graded exercise test following the Bruce Treadmill Protocol. The measured VO_{2peak} average was 45.4 (± 5.6) $mL \cdot kg^{-1} \cdot min^{-1}$. A paired sample t-test found the prediction accuracy of the Garmin 920XT to not be significantly different from the actual measured values ($p = 0.828$) with a Pearson correlation coefficient of r = 0.840 ($p < 0.001$) (Kraft & Roberts, 2017).

From these three studies, the differences in prediction accuracy of wearable HR monitors among diverse levels of fitness can be only assumed. For people who are considered to have a low or moderate fitness level, wearable HR monitors that predict $\dot{V}O_{2max}$ seem to have a high level of prediction accuracy. Both studies from Bradshaw et al. (2005) and Kraft and Roberts (2017) reflect average values for $\dot{V}O_{2max}$ and VO_{2peak} for the age groups in their studies. Both studies resulted with valid predictions from their monitors. One can assume that wearable HR monitors may be a valid tool to make such predictions for those who may be considered at an average fitness level. Montgomery et al. (2009) showed that in well trained runners, the HR monitor underestimated predicted values. By observing these studies as a whole, speculations can be made that as fitness level goes up, prediction accuracy may decrease.

Male vs. Female

When using a HR monitor to make predictions of $\dot{V}O_{2max}$, a person's sex may possibly affect prediction accuracy. Lowe et al. (2010) investigated the prediction accuracy for energy expenditure (EE) from the Polar F6 among college-age females. Included in their study was a comparison of predicted and measured $\dot{V}O_{2max}$ values. Thirty-two females from a university aerobics class volunteered for the study. To predict $\dot{V}O_{2max}$, each subject wore the Polar F6 and rested for 5 minutes while the watch measured resting HR and made the prediction using the Polar Fitness Test. Each subject then performed a graded exercise test on a treadmill while $\dot{V}O_{2max}$ measured through open circuit spirometry. The mean predicted $\dot{V}O_{2max}$ was significantly different from the measured $\dot{V}O_{2max}$ (44.66 $mL \cdot kg^{-1} \cdot min^{-1}$ and 42.03 $mL \cdot kg^{-1} \cdot min^{-1}$ respectively) ($p < 0.01$) (Lowe et al., 2010). Lowe et al. observed that the predicted values were, on average, overestimated by 2.63 $mL \cdot kg^{-1} \cdot min^{-1}$. Similar results were found in a study by Esco, Snarr, and Williford (2014) who examined the prediction accuracy of the Polar FT40 among female collegiate soccer players. Their study examined whether the Polar FT40 could detect changes in $\dot{V}O_{2max}$ after a period of training, but they also compared predicted values with measured values. The protocol for predicting and measuring $\dot{V}O_{2max}$ was similar to most studies where the participants obtained predicted values from the Polar Fitness Test and then obtained measured values from a maximal graded exercise test on a treadmill. Their results showed mean predicted values to be significantly overestimated when compared to the actual values in both measurements before and after the training period (47.3 $mL \cdot kg^{-1} \cdot min^{-1}$ pre and 49.7 $mL \cdot kg^{-1} \cdot min^{-1}$ post, and 43.6 $mL \cdot kg^{-1} \cdot min^{-1}$ pre and 46.2 $mL \cdot kg^{-1} \cdot min^{-1}$ post, respectively) ($p < 0.001$,) (Esco et al., 2014).

Both studies from Lowe et al. (2010) and Esco et al. (2014) found common results among females. However, these studies did not directly compare those results with males. Crouter et al. (2004) investigated the accuracy of the Polar S410 HR monitor to predict $\dot{V}O_{2max}$ among college age males and females. Their data analysis showed that for males, the average predicted and measured $\dot{V}O_{2max}$ values were not significantly different ($p > 0.05$) and that there was a significant correlation between them ($r = .872$, $P = 0.001$) (Crouter et al., 2004). However, in females there was a significant difference ($p = 0.001$) with no significant correlation ($r = 0.477$, $p > 0.05$) (Crouter et al., 2004). It was also observed that Polar S410 significantly overestimated $\dot{V}O_{2max}$ by 10.8 $mL \cdot kg^{-1} \cdot min^{-1}$ among females. Contrary to this study, Shryack et al. (2018) compared the predicted $\dot{V}O_{2max}$ values from the Polar M430 to actual values measured from indirect calorimetry among both males and females. The Polar M430 predicted the $\dot{V}O_{2max}$ for each subject using the Polar Fitness Test. All subjects then performed a treadmill ramp protocol to measure $\dot{V}O_{2max}$. They found no significant difference in males between predicted and actual values (52.5 ± 13.6 and 50.4 ± 5.8 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively) (Shryack et al., 2018). In females, there was also no significant difference found (41.8 ± 10.4 and 38.1 ± 10.5 $mL \cdot kg^{-1} \cdot min^{-1}$) (Shryack et al., 2018).

From the above mentioned research, males who use wearable HR monitors to predict $\dot{V}O_{2max}$ may achieve an accurate estimation when compared to the gold standard of indirect calorimetry (Crouter et al., 2004 and Shryack et al., 2018). However, this may be different among females. Consistent in the other studies (Crouter et al., 2004; Lowe et al., 2010; Esco et al., 2014), mean predicted $\dot{V}O_{2max}$ values among females were overestimated by the Polar HR monitors when compared to the measured values. This observation may be a result of the prediction equation used by the *Polar Fitness Test*. However, this is difficult to determine given that Polar Electro Oy. has not published the prediction equation used in their test. Amidst these studies are no explanations as to why there are differences between predicted and measured $\dot{V}O_{2max}$ among females. In response to this, it is the purpose of the present study to investigate the validity of $\dot{V}O_{2max}$ prediction using a Polar HR monitor among females.

Summary

Because technology in wearable HR monitors continues to develop, research in this area will continue to progress. Many studies have investigated the prediction accuracy of wearable HR monitors, and much has been learned from the vast information acquired. From this review, it is evident that non-exercise prediction models provide an alternative route to predicting $\dot{V}O_{2max}$ and ultimately CRF. However, there is variability in the prediction accuracy of those models. Variability of prediction accuracy is also evident in wearable HR monitors, but they vary between each model with some showing a high level of accuracy and others that significantly differ from the gold standard. Variability in prediction accuracy of HR monitors may also be present because of the different ways they can be worn, and the different technologies they use. However, from this review, it is evident that both wrist worn and chest strap HR monitors show similar results in prediction accuracy, along with PPG and ECG technology monitors showing a high level of accuracy when compared to an indirect measurement of $\dot{V}O_{2max}$. To date, there are limited data in the literature related to the impact of specific variables, such as gender, body composition, and fitness, on the prediction of $\dot{V}O_{2max}$.

CHAPTER THREE: METHODS

Participants

Women between ages 18-45 were recruited from the Boise community for this study. Participants were not considered for the study if an injury to the lower extremities occurred within the past 6 months or had any physical risk factors such as a metabolic, cardiovascular, or pulmonary disease. Participants were recruited from local running shops and clubs, local triathlon stores, and the Boise State student body. Each participant gave written informed consent and completed a modified Physical Activity Readiness questionnaire (PAR-Q) prior to enrolling in the study. This study was approved by the Boise State University Institutional Review Board for Human Subjects.

Polar M430 GPS

The Polar M430 is a GPS running watch that utilizes optical technology to measure HR. Using GPS and optical technology, the Polar M430 can track distance, running pace, elevation change, calories burned, intensity of exercise, and recovery status (Polar Electro Inc., n.d.). It can also track sleeping patterns using continuous heart rate tracking, and predict/ evaluate fitness, mainly through assessment of cardiorespiratory fitness (Polar Electro Inc., n.d.). For this study, the *Polar Fitness Test,* programmed into the Polar M430 was used to predict each participant's $\dot{V}O_{2max}$. The Polar Fitness Test utilizes self-reported fitness variables including gender, age, height, weight, and self-assessment of physical activity, in addition to measured HR/HR variability using optical technology. The variables are then utilized by a proprietary non-exercise prediction equation to estimate $\dot{V}O_{2max}$

PICTURE 1. The Polar M430 Front and Back Views

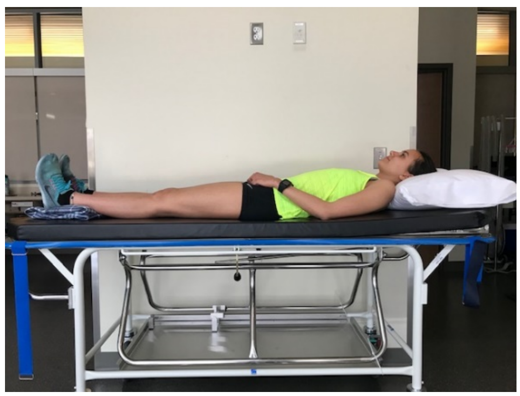
Procedures

Design Overview: Each participant was asked to complete one data collection session. After the completion of the informed consent form and modified PAR-Q, skin tone, weight, height, and body composition was assessed. Following these measures, the resting Polar Fitness Test was performed with the Polar M430. During the test, resting HR was assessed by the Polar M430, Polar V800, and 3-lead ECG. Then, each participant performed a maximal graded exercise test for the assessment of $\dot{V}O_{2max}$. Data collection was performed at Boise State University in the Human Performance Lab.

Polar Fitness Test: Prior to the session, each participant was instructed to refrain from food for two hours prior, avoid the use of substance that may influence heart rate (i.e. alcohol, caffeine, and tobacco) for at least 3 hours before testing, maintain proper hydration levels for 24 hours before testing, get 6-8 hours of sleep the night before, and avoid strenuous exercise 24 hours before testing (Polar Electro Inc., n.d.). First, skin tone was identified using the Fitzpatrick Skin Type Scale (Fitzpatrick, 1988). This scale is a numerical classification of skin color that uses six different skin colors ranging from pale white to a dark brown. Each participant placed their left wrist on a table. The Fitzpatrick Scale was then aligned next to the wrist to identify the skin type. Height without shoes was then measured using a calibrated stadiometer (Seca, Chino, CA). Next, Body composition was measured for each subject using air displacement plethysmography (BodPod; Life Measurement Instruments, Concord, CA) according to the manufacturer's instructions. Body mass assessed by the BOD POD scale was inputted into the Polar M430 and V800 in addition to age, gender, and a self-assessment of the level of long-term physical activity for the past 3 months (Table 1) (Polar Electro Inc., n.d). The chest strap HR monitor, synced with the Polar V800, was fitted to each participant. Electrodes (Covidien LLC., Mansfeild, MA) were also placed in a four-lead configuration at the left and right subclavicular space and left and right costal margin between the 9^{th} and 10^{th} rib. The Polar M430 was then placed on the participant's left wrist according to manufacturer instructions and the participant was asked to lay down in a supine position on a padded table and remained quiet for 5 minutes. To reduce external stimuli that could elevate resting HR, this measurement took place in the Human Performance Laboratory in a shaded room with only the participant and researcher in the room. After 5 minutes of rest, the 5-minute Polar Fitness Test began and was performed using both the M430 and V800. During the test, resting HR was measured using the Polar M430 and V800, and 3-lead ECG from a Q-Stress TM55 (Quinton Cardiology Inc., Bothell, WA). The $\dot{V}O_{2max}$ prediction value was then recorded from both Polar monitors. This test was repeated six times, with each test using a different selection of long-term physical activity.

TABLE 1. Level of long-term physical activity for the past 3 months

Level	Hours per week
1	Occasional 0-1 hr
2	Regular 1-3 hr
3	Frequent 3-5 hr
4	Heavy 5-8 hr
5	Semi-Pro 8-12 hr
6	Pro 12+ hr



PICTURE 2 The Polar Fitness Test Supine Position

Measurement of $\dot{V}O_{2max}$: Each participant performed a graded maximal exercise test on a Woodway treadmill (Woodway USA, Waukesha, WI). A ParvoMedics TrueOne® 2400 metabolic measurement system (ParvoMedics Inc., Sandy, UT) was used to measure oxygen consumption, carbon dioxide production and ventilation. Before these measurements were performed, the metabolic cart was calibrated using the manufacturer's standardized gas and flow meter calibration procedures. Gas calibration was completed using a 2-point calibration of room air and gases of a known concentration (4% carbon dioxide, 16% oxygen, balance nitrogen). The flow meter was calibrated using a calibrated 3-Liter syringe (Sensor Medics, Yorba Linda, CA). A modified Astrand protocol was used for the maximal graded exercise test (Astrand & Rodale, 1970). Before the test began, each participant warmed up at a self-selected pace for 10 minutes followed by a five-minute break for equipment fitting. The participant selected a pace according to what they felt they could sustain during a race of about 30 minutes in duration. The test began with the participant running at the predetermined self-selected pace at a 0% grade for the first minute. Each minute, the grade increased by 1%. Rating of perceived effort and HR were recorded at the end of each one-minute stage. HR during the $\dot{V}O_{2max}$ test was measured using the Polar V800 chest strap and watch. The test continued until volitional fatigue. Once volitional fatigue had been reached, the treadmill was reduced to 2-3 mph for three minutes. At the end of three minutes, blood lactate was assessed using a Lactate Plus lactate meter (Nova Biomedical, Waltham, MA). The tip of the index finger of one hand was first sterilized with a Curad alcohol prep pad (Medline Industries, Inc., Mundelein, IL) that contains 70% isopropyl alcohol. The finger was then lanced using a Perfect Point lancet (Liberty Medical, Port St. Lucie, FL), and the blood drop was applied to the edge of the test strip where it was analyzed by the lactate meter. Successful achievement of $\dot{V}O_{2max}$ was based on achieving a plateau in VO_2. A participant was considered to have reached a plateau if the final two stages of the test were within 2.0 $mL \cdot kg^{-1} \cdot min^{-1}$. If a plateau was not reached then achievement of $\dot{V}O_{2max}$ was based on achieving each of the following criteria: HR within 10 beats of age-predicted max (220 – age), respiratory exchange ratio (R) $\geq$ 1.08, or post exercise blood lactate $\geq$ 8.0 mmol/L (Taylor, Buskirk, & Henschel, 1955; Howley, Bassett, and Welch, 1995).

Data Analysis

Mean and standard error of the mean (SEM) were calculated for descriptive information of the participants. Pearson correlation coefficient was used to investigate the strength of the relationship between predicted $\dot{V}O_{2max}$ (p$\dot{V}O_{2max}$) and measured $\dot{V}O_{2max}$ (a$\dot{V}O_{2max}$) when using the Polar M430 and V800. A repeated measures (RM) ANOVA was used to compare the values between p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$.The first 20 participants performed the *Polar Fitness Test* using both monitors and the remaining 28 used only the M430. Bland-Altman plots were used to identify agreement between the p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$ values from mean values and bandwidths with a mean ± 95% confidence interval. Prediction values closely rated around zero were considered as highly accurate, with values above zero signifying an overestimation and below zero an underestimation. The first 20 participants used the Polar M430, V800, and 3-lead ECG to measure resting HR. The remaining participants used the M430 to measure resting HR. A RM ANOVA was used to compare values across the three methods. The first 20 participants performed the *Polar Fitness Test* six times, with each test using one of the selections of PA. The remaining participants performed the same test 3 times, with one test at the participants selected PA (s$\dot{V}O_{2max}$) and the other tests at one level below (s$\dot{V}O_{2max}$ – 1) and above (s$\dot{V}O_{2max}$+1) their s$\dot{V}O_{2max}$. A RM ANOVA was used to compare the values across the PA selections and a$\dot{V}O_{2max}$. Data for fitness level, age, height, body mass, BMI, fat mass, HR_{rest}, HR_{max}, and $HR_{reserve}$ were split into quartiles based upon their given values. Values for each variable were ordered from least to greatest, and then divided into four even groups of 12. To compare each group, the difference was taken between p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$ (p$\dot{V}O_{2max}$ - a$\dot{V}O_{2max}$) for each participant, and the mean and SEM were calculated. A RM ANOVA was used to compare values across the four groups of each variable. Statistical significance was set at $p < 0.05$ and all statistical analyses were completed using SPSS software version 23 (SPSS Inc., Chicago, Illinois).

CHAPTER FOUR: RESULTS

A total of 48 participants completed the study. Participants included university students, recreational runners, and triathletes. Years engaged in aerobic exercise among participants averaged 5.10 ± 4.5 years (range: 0-15 years). Descriptive data for all participants are presented in Table 2.

TABLE 2. Descriptive Data of Subjects

N = 48	**Mean ± SEM**
Age (yr)	27.39 ± 1.19
Height (cm)	166.49 ± 0.83
Weight (kg)	65.13 ± 1.84
BMI (kg/m^2)	23.44 ± 0.58
% Body fat (%)	24.25 ± 1.12
HR_{rest} (bpm)	58.65 ± 1.37
Ethnicity	98% Caucasian

The criteria for successful achievement of $\dot{V}O_{2max}$ was based upon achieving a plateau in VO_2 ($\leq$ 2.0 mL·kg^{-1}·min^{-1}) (Taylor et al., 1955). If a plateau was not reached, then achievement of $\dot{V}O_{2max}$ was based on reaching each of the following criteria: HR within 10 beats of age-predicted max (220 – age), respiratory exchange ratio (R) $\geq$ 1.08, and post exercise blood lactate $\geq$ 8.0 mmol/L (Howley et al., 1995). Five participants did not reach $\dot{V}O_{2max}$ based on the criteria used for this study. However, a RM ANOVA revealed no significant differences were found between the p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$ for the five participants who did not reach $\dot{V}O_{2max}$ and the 43 participants who met the criteria for achieving $\dot{V}O_{2max}$ ($p > 0.05$). Therefore, data analysis of all 48 participants were completed as one group.

Correlations for $p\dot{V}O_{2max}$ using the Polar M430 and V800 and $a\dot{V}O_{2max}$ for the first 20 participants were r = 0.810 and 0.784 respectively. Figure 1 illustrates the correlation between $p\dot{V}O_{2max}$ using the Polar M430 and V800, and $a\dot{V}O_{2max}$. Figure 2 shows the correlation between $p\dot{V}O_{2max}$ and $a\dot{V}O_{2max}$ as a scatter plot with a line of perfect identity (r = .697, $p < .0001$). A Bland-Altman Plot showing limits of agreement between $p\dot{V}O_{2max}$ and $a\dot{V}O_{2max}$ are presented in Figure 3. Figure 3. displays the differences between $p\dot{V}O_{2max}$ and $a\dot{V}O_{2max}$ against the mean of the $p\dot{V}O_{2max}$ and $a\dot{V}O_{2max}$. There was a mean difference of 1.17 ± 6.82. The 95% limits of agreement ranged between -12.19 and 14.53. All but two values fell between the 95% limits of agreement. Values were wide spread both above and below zero, signifying a large variance of both overestimated and underestimated predicted values.

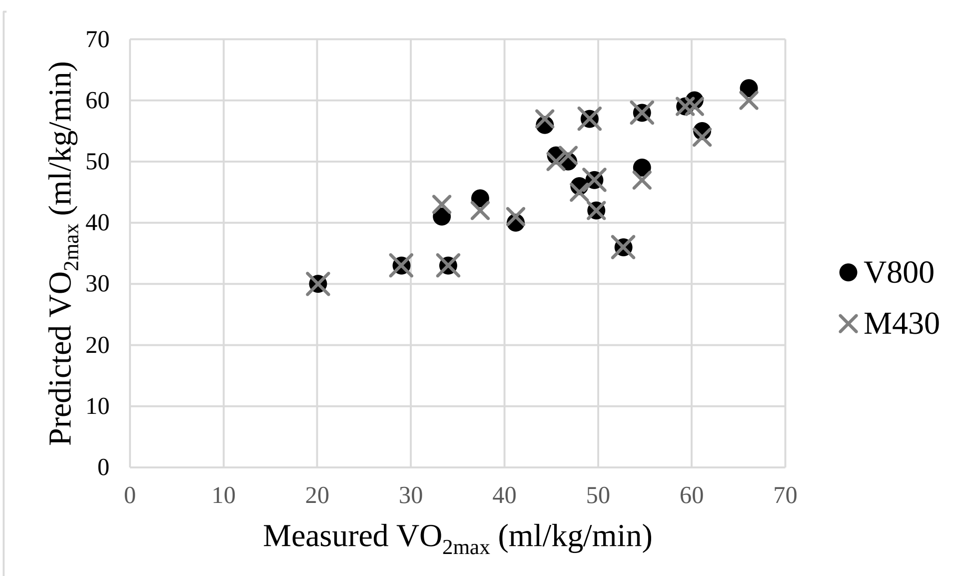


FIGURE 1. Correlation of $p\dot{V}O_{2max}$ between Polar M430 and V800

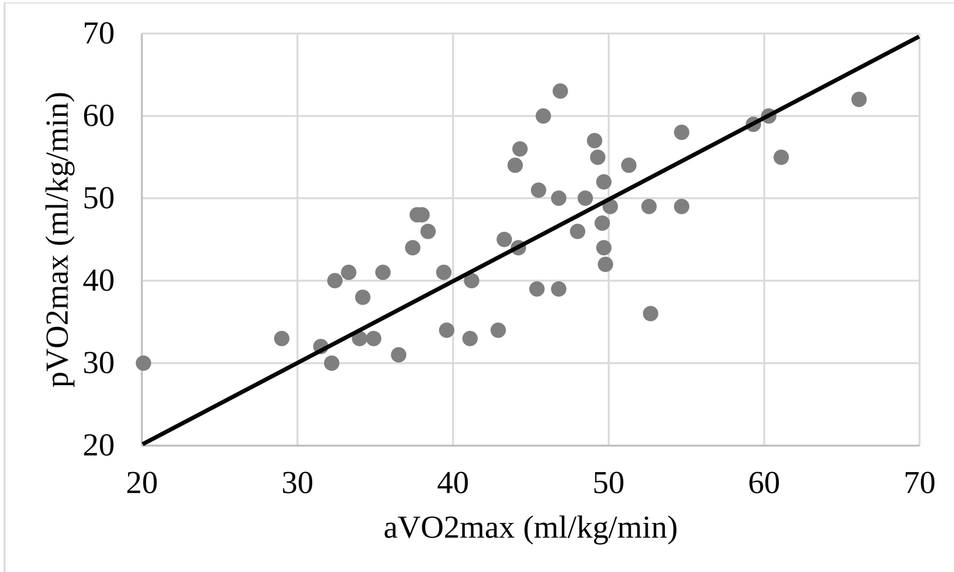


FIGURE 2. Relationship between p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$ With Line of Perfect Identity

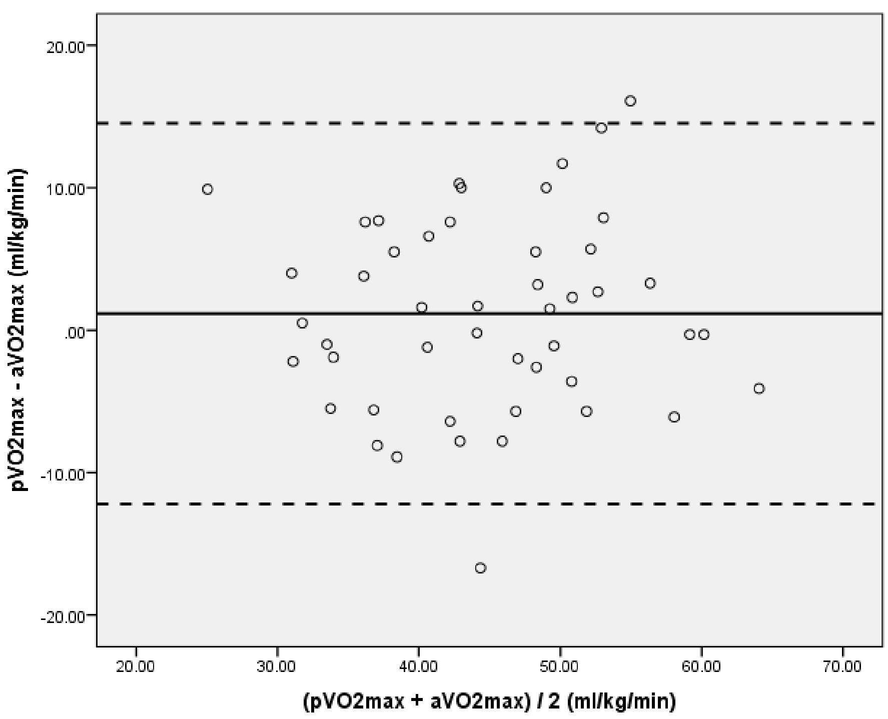


FIGURE 3. Bland-Altman Plot

The solid line represents the mean bias. The two outside dashed lines represent the 95% limits of agreement.

Resting HR measurement using ECG, the Polar V800 and Polar M430 was performed for the first 20 participants. There were no significant differences between the three methods (Figure 4) ($p > 0.05$). For the remaining participants, resting HR was measured by the Polar M30. The first 20 participants performed the *Polar Fitness Test* using all six selections of PA. Mean predicted values for each selection of PA is presented in Figure 5. There was a significant difference across all six PA levels ($p = .001$). Between PA levels 1 and 2 there was no significant difference ($p > 0.05$). PA levels 3, 4, 5, and 6 were significantly different from level 1 ($p < 0.05$) but were not significantly different from each other and level 2 ($p > 0.05$). Measured $\dot{V}O_{2max}$ was only significantly different from PA level 1.

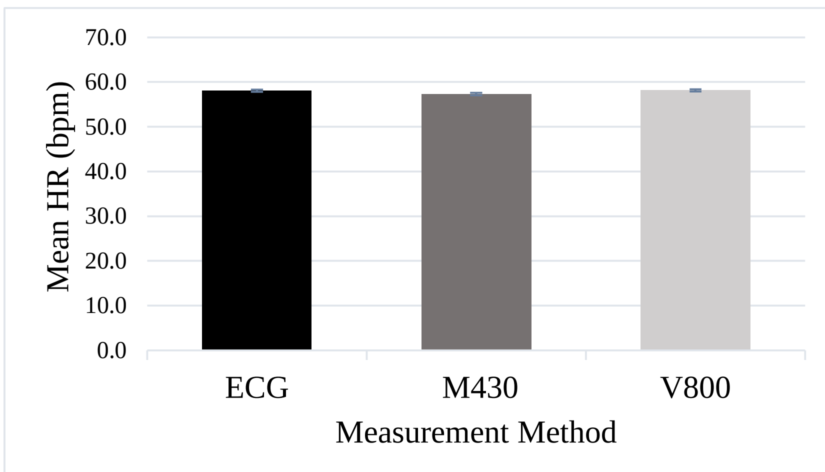


FIGURE 4. Mean HR_{rest} via 3 Methods of Measurement

There were no significant differences between the three methods ($p > 0.05$).

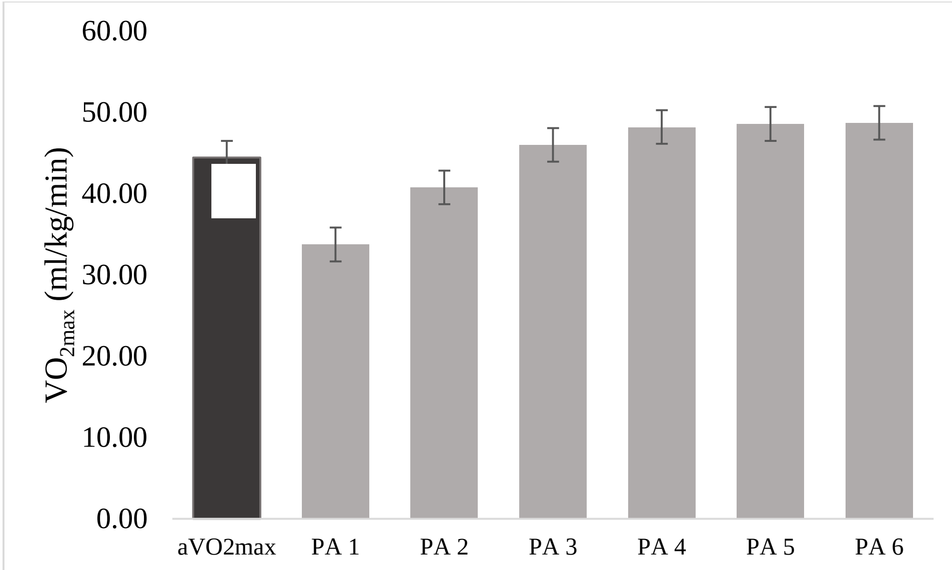


FIGURE 5. Mean a$\dot{V}O_{2max}$ vs. p$\dot{V}O_{2max}$ of 6 PA Selections

*Indicates significant difference with a$\dot{V}O_{2max}$ ($p<0.05$)

Repeated measures ANOVA indicated no significant difference between p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$ ($p > 0.05$). Mean values of p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$ at s$\dot{V}O_{2max}$, s$\dot{V}O_{2max}$+1, and s$\dot{V}O_{2max}$ -1 are presented in Figure 6. p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$ were not significantly different at the participants'Ds$\dot{V}O_{2max}$, s$\dot{V}O_{2max}$+1, and s$\dot{V}O_{2max}$ -1 ($p > 0.05$). There were no differences in p$\dot{V}O_{2max}$ from the participant's original selection of PA and selections above and below their original selection ($p > 0.05$). Data for quartile groups are presented in Table 4. Values for each variable were ordered from least to greatest, and then divided into four groups of 12. For each participant, the difference was taken between predicted and measured $\dot{V}O_{2max}$ (p$\dot{V}O_{2max}$ - a$\dot{V}O_{2max}$). A negative difference signifies an underestimation and a positive difference signifies an overestimation. Repeated measures ANOVAs found no significant differences between quartile groups for each variable ($p > 0.05$). Thus, we fail to reject the null hypothesis. Of the six different skin types in the Fitzpatrick skin type scale, participants in this study were classified in four of the six categories. Similar to the quartile groups, there were no significant differences in $p\dot{V}O_{2max}$ and $a\dot{V}O_{2max}$ between the four skin types (p > 0.05).

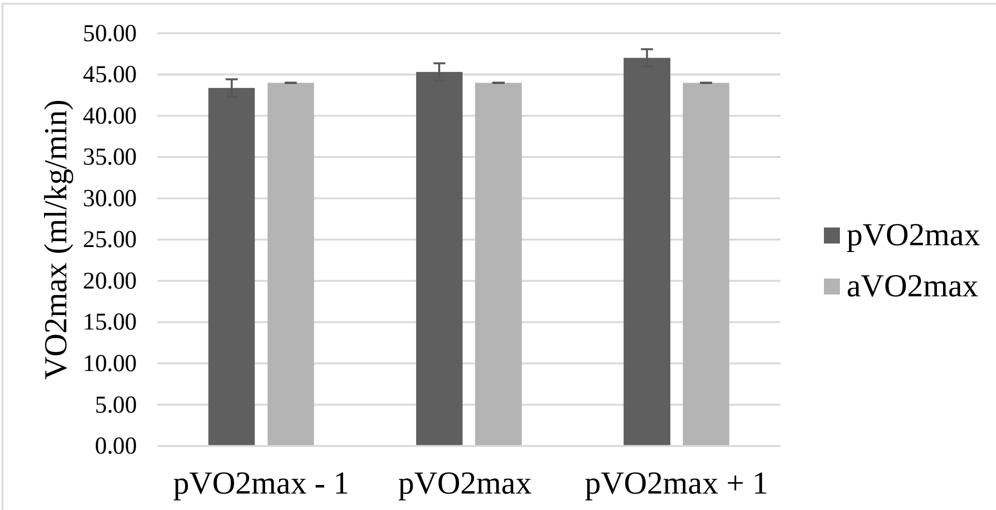


FIGURE 6. Mean Values for Predicted and Actual $\dot{V}O_{2max}$

There were no significant differences between $a\dot{V}O_{2max}$ and $p\dot{V}O_{2max}$ (p > 0.05)

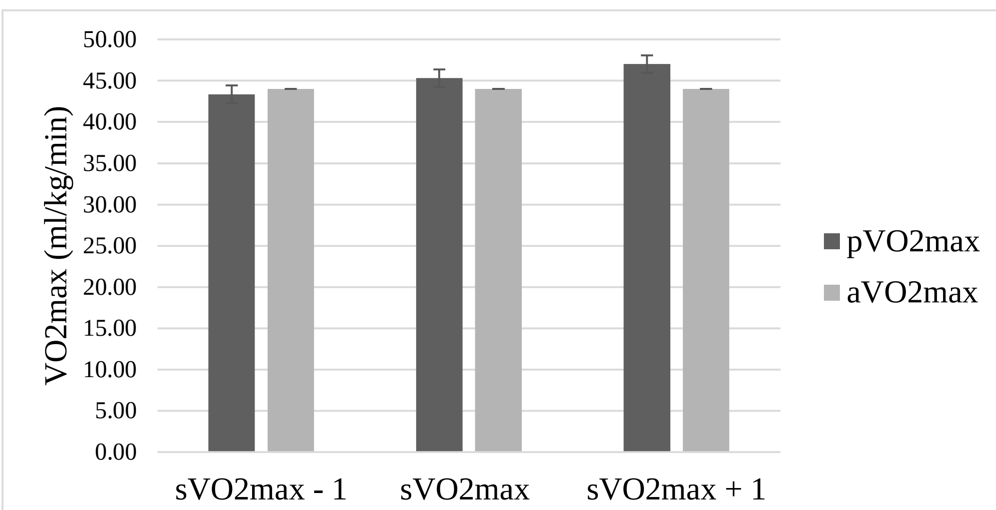


TABLE 3 RM ANOVA Results for Quartile Groups

Characteristic	Group (mean ± SEM)		*p* Value of Main Effect
Age (yr)	18-20	4.08 ± 1.95	0.283
	20-25	1.31 ± 1.95	
	28-34	0.6 ± 1.95	
	35-45	-5.45 ± 1.95	
Fitness Level (ml/kg/min)	20-37	2.92 ± 1.89	0.091
	37-44	2.41 ± 1.89	
	45-49	2.47 ± 1.89	
	49-66	-9.66 ± 1.89	
BMI (kg/m^2)	17-20	1.02 ± 2.02	0.866
	20-21	1.7 ± 2.02	
	22-25	2.12 ± 2.02	
	25-36	-5.36 ± 2.02	
Body Mass (kg)	54-56	3.44 ± 1.98	0.493
	57-59	1.28 ± 1.98	
	61-69	-1.69 ± 1.98	
	71-115	0.86 ± 1.98	
Body fat (%)	12-17	0.53 ± 1.99	0.622
	17-22	1.82 ± 1.99	
	22-28	-0.61 ± 1.99	
	29-48	2.93 ± 1.99	
Height (cm)	157-162	1.93 ± 1.97	0.400
	162-165	-1.45 ± 1.97	
	167-170	0.98 ± 1.97	
	170-178	3.22 ± 1.97	
HR_{rest} (bpm)	41-51	1.59 ± 2.67	0.945
	52-57	0.54 ± 2.67	
	58-66	3.07 ± 2.74	
	67-82	-1.12 ± 2.67	
HR_{max} (bpm)	161-182	2.08 ± 2.59	0.982
	183-190	0.29 ± 2.59	
	190-196	-0.14 ± 2.67	
	197-214	1.77 ± 2.78	
$HR_{reserve}$ (bpm)	106-124	-4.2 ± 2.59	0.847
	125-130	-0.22 ± 2.67	
	131-136	1.25 ± 2.59	
	136-156	2.75 ± 2.76	

CHAPTER FIVE: DISCUSSION

Participants in this study performed the *Polar Fitness Test* using the Polar M430 to obtain a predicted $\dot{V}O_{2max}$, and then performed a GXT using a modified Astrand protocol to directly measure their $\dot{V}O_{2max}$. The results of the present study indicated that there were no significant differences between mean p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$ values ($p > 0.05$). p$\dot{V}O_{2max}$ was significantly correlated with a$\dot{V}O_{2max}$ (r = .697, $p < .0001$). There was no significant difference between a$\dot{V}O_{2max}$ and p$\dot{V}O_{2max}$ at s$\dot{V}O_{2max}$ - 1 and s$\dot{V}O_{2max}$+1 ($p > 0.05$). There were no significant differences between groups among variables that were divided into quartiles ($p > 0.05$).

The current study demonstrated that there was no significant difference between p$\dot{V}O_{2max}$ by the Polar M430 and a$\dot{V}O_{2max}$. Shryack et al. (2018) also found no significant difference between predicted and actual values among females when using the Polar M30. There is, however, previous research that contradicts these results when comparing p$\dot{V}O_{2max}$ against a$\dot{V}O_{2max}$ among females (Crouter et al., 2004; Esco et al., 2014; Lowe et al., 2010; Snyder et al., 2018). The contradiction between the present study and previous studies might come from our use of a newer model (Polar M430) compared to other monitors such as the Polar FT40, S410, F6, and F11 used in previous studies. It is possible that different algorithms to predict $\dot{V}O_{2max}$ were used in the older models, thus, providing a possible reason for the contradicting results. This speculation could be confirmed from our comparison between predicted values from the Polar M430 and V800, in which, there was no significant difference and were strongly correlated. Given these results, it is possible that the Polar M430 and V800 use the same or very similar prediction equations. Another possible explanation of the contradicting results of the present study and previous literature is the statistical power derived from a larger sample of female participants. Previous studies included 10, 20, 32, and 18 females (Crouter et al., 2004; Esco et al., 2014; Lowe et al., 2010; Snyder et al., 2018 respectively). Having a larger sample size of participants increases mean accuracy and statistical power, and decreases the margin of error. It is possible that the previous studies could have yielded different results if their sample sizes were larger.

Although there was no significant difference between mean p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$, figure 2 and the Bland-Altman analysis (Figure 3) indicated a large variance among the participants. The 95% confidence interval lines on the plot show a wide spread with the lower limit at -12.19 mL·kg $^{-1}$ min $^{-1}$ and the upper limit at 14.53 mL·kg $^{-1}$ min $^{-1}$. Looking at individual participants as an example, participant 18 had a predicted value of 36 mL·kg $^{-1}$ min $^{-1}$ while their measured value was 52.7 mL·kg $^{-1}$ min $^{-1}$, making a difference of 16.7 mL·kg $^{-1}$ min $^{-1}$. On the other hand, participant 19 had a difference of -0.3 between p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$ values. In support of these results, a previous study also showed no significant mean difference between p$\dot{V}O_{2max}$ and a$\dot{V}O_{2max}$ using the Polar F11 (Esco et al., 2011). However, large individual differences were also found. Although using the Polar M430 to predict $\dot{V}O_{2max}$ is a valid method, this variability between individuals shows that accuracy is low.

The *Polar Fitness Test* uses age, gender, weight, height, and rating of PA in its prediction equation to predict $\dot{V}O_{2max}$. Given that Polar Electro Oy has not published their prediction equation, it is difficult to determine which variables may have the strongest impact on the prediction value. Thus, a major purpose of this study was to investigate if each of these variables played a role in the validity of the device for predicting $\dot{V}O_{2max}$. As discussed by Esco et al., (2014), self-reported PA can be a source of error because one can easily overestimate or underestimate their own PA. This variable is important given that PA is strongly related to $\dot{V}O_{2max}$ (Jackson et al., 1990). In the present study, the first 20 participants performed the *Polar Fitness Test* using all six PA ratings. Mean p$\dot{V}O_{2max}$ using levels 2-6 showed no significant difference between each other; however, all but levels 3-6 were significantly different from level one. Only PA level one was significantly different from a$\dot{V}O_{2max}$ (Figure 4) This is an interesting finding showing that a PA selection at level 2 will not yield a significantly different result than level 6. This suggests that the selection of PA does not have a strong influence on the p$\dot{V}O_{2max}$. The selection of PA for the *Polar Fitness Test* is based upon the amount of hours spent training per week. There are a few sources of error with this method of reporting PA. First, it may be difficult for one to accurately recall their amount of training hours per week. Multiple studies have demonstrated that people tend to under or overestimate their PA (Fogelholm et al., 2006; Klesges et al., 1990; Washburn, Jacobsen, Sonko, Hill, & Donnelly, 2003). Second, the question of how many hours are spent training per week is vague and easy to misinterpret. This question does not take into account the type or mode of activity, and does not include activities of daily living that could possibly effect one’s actual PA. Because of this, a person may under or overestimate their PA.

To further investigate the influence of self-selected PA, measured $\dot{V}O_{2max}$ was compared with prediction values at the participant’s self-selected s$\dot{V}O_{2max}$, s$\dot{V}O_{2max}$+1, and $s\dot{V}O_{2max}$ -1. $s\dot{V}O_{2max}$, $s\dot{V}O_{2max}$+1, and $s\dot{V}O_{2max}$ -1 were not significantly different from measured $\dot{V}O_{2max}$. This suggests that a slight underestimation or overestimation of PA does not have a significant influence on the predicted $\dot{V}O_{2max}$. However, previous research may not support this. Philips et al., (2016) predicted $\dot{V}O_{2max}$ using the Polar V800, M400, and FT60 among females at their self-selected PA, and at a selection above and below. They found no significant correlation between $p\dot{V}O_{2max}$ and $a\dot{V}O_{2max}$. Interestingly, there was significant correlation with $s\dot{V}O_{2max}$+1. The reason for this contradiction between the present study and the study by Philips et al., (2016) is unknown.

Data for participant fitness level, age, height, body mass, BMI, fat mass, HR_{rest}, HR_{max}, and $HR_{reserve}$ were split evenly into quartiles to examine the influence of lower and higher levels of each variable. A RM ANOVA was used to compare the groups. If a significant difference was found between a group, it would suggest that a variable at a lower or higher level would have an influence on the predicted value. To our knowledge, this is the first study to investigate the influence of these variables on $\dot{V}O_{2max}$ prediction values reported from Polar monitors. Of the above mentioned variables, age, height, body mass, resting HR, and HR variability are recorded into the monitor and directly used in the prediction equation. Previous research may explain why Polar Elector Oy specifically chose to include these variables. Rogers, Hagberg, Martin, Ehsani, and Holloszy (1990) showed that over an 8-year period, $\dot{V}O_{2max}$ in sedentary subjects (age 61.4 ± 1.4 yr) declined by 3.3 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$, which is formulated to be a 12% decline over a full decade. This signifies that as age increases, $\dot{V}O_{2max}$ will decrease. Maciejczyk et al., (2014) found that regardless of body composition, increased body mass will result in a lower $\dot{V}O_{2max}$. Between individuals, body mass can account for 70% of the differences in $\dot{V}O_{2max}$, which explains why $\dot{V}O_{2max}$ is commonly expressed relative to an individual's body mass (McArdle et al., 2015). Kenney (1985) found that due to increased vagal tone, lower resting HR's are strongly associated with individuals who have a higher $\dot{V}O_{2max}$.

The fitness level of each participant was determined by their measured $\dot{V}O_{2max}$. There was a large range of fitness levels in this study, ranging from 20.1 to 66.1 $mL \cdot kg^{-1} min^{-1}$. There were no differences found between each fitness level, signifying no influence on the prediction value from the individual’s fitness level. Previous research has shown significant correlations between $p\dot{V}O_{2max}$ and $a\dot{V}O_{2max}$ among those who are considered to be at a low fitness level (Bradshaw et al., 2005), moderate fitness level (Kraft and Roberts, 2017), and high fitness level (Montgomery et al., 2009). The present study and previous studies demonstrate that one’s actual fitness level will not have a significant effect on the predicted $p\dot{V}O_{2max}$ value.

All other variables that were divided into quartiles saw no significant differences between groups in $p\dot{V}O_{2max}$. This suggests that differences in age, height, body mass, BMI, body fat percentage, HR_{rest}, HR_{max}, and $HR_{reserve}$ have no influence on the predicted value given by the Polar M430. It is interesting that variables such as age, body mass, and resting HR did not have significant differences between groups, given that previous research has shown they can effect, or are highly correlated with one’s actual $\dot{V}O_{2max}$ (Kenney, 1985; Maciejczyk et al., 2014; Rogers et al., 1990). Variables such as BMI, fat mass, HR_{max}, and $HR_{reserve}$ may have showed no significant differences between groups because they are not directly recorded into the Polar M430 during the *Polar Fitness Test.*

Since they are not recorded into the Polar M430, it can be assumed that they are not used in the prediction equation itself, thus having little effect on the $p\dot{V}O_{2max}$.

Given that the *Polar Fitness Test* incorporates resting HR in its prediction, and that the Polar M430 uses optical technology to measure resting HR, it was considered important to compare its HR measurement to two other methods. Knowing that the Polar M430 can measure resting HR accurately eliminates that possible limitation. There was no significant difference in resting HR measurement between the Polar M30, V800 chest strap, and ECG. Previous research has confirmed that resting HR measurement using optical technology is not significantly different, and highly correlated with other accurate methods of resting HR measurement. For example, Rider et al. (2019) examined the accuracy of the wrist-worn Polar A360 by comparing it to the Polar RS400 worn as a chest strap. The A360 exhibited a strong correlation with the chest strap (r^2 = 0.98) at rest. Using the Polar M600 optical HR sensor, Horton et al., (2017) compared this method of HR measurement to a 3-lead ECG. They also found no significant difference in resting HR between both methods of measurement. In the present study, we examined all three approaches to resting HR measurement, in which our findings agree with previous research. This eliminates the possibility of optical HR measurement being a limitation in this study.

Optical technology uses LED lights that emit light into the skin and a photodiode that identifies the amount of light reflected back (Polar Electro Inc., n.d.). HR is detected when a lesser amount of light is reflected back as a larger volume of blood passes through the skin (Polar Electro Inc., n.d). Using the Fitzpatrick Scale to identify skin type (Fitzpatrick, 1988), Fallow, Tarumi, and Tanaka (201) examined the influence of skin type on this form of HR measurement. The Fitzpatrick Scale is a numerical classification of skin color ranging from 1 (always burns, palest with freckles) to 6 (never burns, deeply pigmented dark brown) (Fitzpatrick, 1988). LED sensors from a PPG device (Omron Healthcare, Kyoto Japan) were used to measure resting HR. They found no significant differences in HR measurement between skin types 1-4. Skin type 5 showed significantly lower HR measurements than the other skin types ($p < .0001$). Given that skin type could possibly influence the measurement of resting HR, this study examined the influence of skin type on the p$\dot{V}O_{2max}$ using the optical technology from the Polar M430. There was no significant difference between the skin types identified in this study. The participants in the present study were identified as falling within skin types 1-4, the vast majority of the identified skin types being 2 and 3. Because our study did not include a diverse sample of all identifications, we cannot conclude that darker skin type would not influence on the p$\dot{V}O_{2max}$ value from the Polar M430.

In addition to using resting HR in the prediction equation of the *Polar Fitness Test*, HR variability is also used. HR variability was not taken into account in our analysis to see if it had an effect on p$\dot{V}O_{2max}$. Thus limiting another factor that could possibly explain the validity of the Polar M430 to predict $\dot{V}O_{2max}$. However, the use of HR variability could be a source of error in the prediction equation itself. Previous research has shown HR variability to be associated with $\dot{V}O_{2max}$ (Melanson & Freedson, 2001; Yamamoto, Miyachi, Saitoh, Yoshioka, & Onodera, 2001) while others found that it is not significantly associated with $\dot{V}O_{2max}$ (Martinmäki, Häkkinen, Mikkola, & Rusko, 2008; Verheyden, Eijnde, Beckers, Vanhees, & Aubert, 2006). Esco et al. (2013) discussed that HR variability is affected by individual breathing rates, in which, consequently, $\dot{V}O_{2max}$ prediction equations that use HR variability seem to be invalid. Other research has confirmed their point (Turner, Brandenburg, Looney, & Simmons, 2006). Future research should include HR variability in their analysis, but should implement a controlled breathing rate.

Using the Polar M430 to predict $\dot{V}O_{2max}$ can be a safe and convenient way of determining CRF. This method of predicting $\dot{V}O_{2max}$ has unique implications and benefits for certain people such as coaches and their athletes, and exercise physiologists and their clients. Much of the concern for coaches with performing a GXT to measure $\dot{V}O_{2max}$ is that such a test may interrupt their training schedule. Given the simplicity of the *Polar Fitness Test*, having the Polar M430 on hand can provide a convenient measure of fitness without a disruption in training. The Polar M430 may also benefit an athlete who trains on their own and does not have a facility where they can measure their $\dot{V}O_{2max}$. Having the Polar M430 to predict $\dot{V}O_{2max}$ can help an individual athlete identify progress in their training without the assistance of a coach. Patients who have a cardiovascular, metabolic, or pulmonary disease may, for some reason, not be able to perform a submaximal exercise test to estimate their CRF. Using the Polar M430 to predict $\dot{V}O_{2max}$ can be an alternative for exercise physiologists to identify physical risk factors pertaining to their patient's CRF. There are cases where a patient may not be able to periodically attend their appointments with an exercise physiologist. Using the Polar M430 to predict $\dot{V}O_{2max}$ can allow exercise physiologists to track their patient’s progress and make adjustments to a training schedule outside of a clinic. Although the Polar M430 could be a beneficial alternative, future research should investigate the validity of Polar HR monitors to predict

$\dot{V}O_{2max}$ among those who have physical risk factors due to a cardiovascular, metabolic, or pulmonary disease.

There were several strengths to this study. One strength was the large sample of participants. Forty-eight females were included in this study, which increased the statistical power of our results. Our sample size was much larger than previous studies. For example, others included up to 7 (Shryack et al., 2018), 20 (Esco et al., 2014), and 10 females (Crouter et al., 2004).With the possibility that participants could underestimate or overestimate the PA level recorded in the Polar M430, a strength of this study was the investigation of the effect of an under and overestimation of PA. Examining the effect of all the variables used in the *Polar Fitness Test* can also be considered a strength of this study. This is the first study, to our knowledge, that examined the effect of these variables on the predicted value, thus initiating ideas for future research in this area. Another strength to this study is the wide range of values among variables such as age (18-45), fitness level (20-66 $mL \cdot kg^{-1} \cdot min^{-1}$), BMI (17-36 kg/m^2), and body mass (43-115 kg). A wide range in these variables allows for the results of this study to be applicable to a larger population of potential Polar users.

There were some limitations to this study. Despite wide ranges in most variables, one limitation of this study was no full representation of skin types. The Fitzpatrick Scale has 6 different skin types. This study included types 1-4 but the majority of skin types were identified as type 2 or 3. Although skin type was not a vital aspect of our purpose in this study, it was important to include in our analysis of the validity of the Polar M430 because of the possibility of it affecting the resting HR measurement. Not having a full representation of all skin types may be a limitation in our study, but it paves the way for future research to examine the effect of skin type on the validity of the HR monitors to predict $\dot{V}O_{2max}$. Another limitation of this study is the possibility that a participant's HR_{rest} during the *Polar Fitness Test* may not have been their true resting HR. To reduce this limitation, the *Polar Fitness Test* was performed in a controlled environment where light, sound, and other external stimuli could be reduced. A blanket was provided to help each participant feel comfortable in case the temperature of the room was too cold for their preference. Also, each participant was given 5 minutes of rest to ensure their HR reached a resting value before beginning the test. While these accommodations were likely to have reduced the impact of the external factors on HR_{rest}, it is likely that the participants were not at a true HR_{rest} during the testing protocol. Another potential limitation is that five participants did not reach true $\dot{V}O_{2max}$ according to the secondary criteria used in this study. This can be considered a limitation of our study because those who did not achieve a $\dot{V}O_{2max}$ based on the criteria used may have given a submaximal effort during the GXT. Thus, influencing the significance of the differences found in this study. Analyses were performed excluding these five participants and there were no differences between the results of the five participants who did not meet the criteria for $\dot{V}O_{2max}$ and those who did meet the criteria. Correlations between $p\dot{V}O_{2max}$ and $a\dot{V}O_{2max}$ were still significant after the data from the 5 participants were omitted ($r = .697$, $p < .0001$). A RM ANOVA found no differences between the 5 participants and those who reached $\dot{V}O_{2max}$ ($p > 0.05$). Because the results were not significantly changed after omitting the data, it was deemed appropriate to include the participants who reached only $\dot{V}O_{2peak}$.

In conclusion, the current study sought to determine the validity of the Polar M430 to predict $\dot{V}O_{2max}$ among females of varying fitness level, body fat percentage, and PA. Our findings demonstrated that, among females, the Polar M430 is a valid method to predict $\dot{V}O_{2max}$ regardless of the fitness level, body fat percentage, or selection of PA. An underestimation and overestimation of PA did not significantly affect the predicted value given from the Polar M430. There were no differences among other variables such has age, weight, height, fat mass, HR_{rest}, HR_{max}, $HR_{reserve}$, and skin type. Although collectively the Polar M430 demonstrated to be a valid method of $\dot{V}O_{2max}$ prediction, there were large individual differences. Future research in this area should investigate HR variability with a control for breathing rate in their analysis and the effect of a more diverse population of Fitzpatrick skin types on the validity of HR monitors that utilize PPG for HR assessment. Future research should also investigate the validity of Polar HR monitors to predict $\dot{V}O_{2max}$ among those who have physical risk factors due to a cardiovascular, metabolic, or pulmonary disease.

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APPENDIX A

Informed Consent Form

BOISE STATE UNIVERSITY

INFORMED CONSENT

Study Title: Validity of the Polar M430 in Predicting VO2max Among Women of Varying Fitness Levels
Principal Investigator: Dr. Scott Conger **Co-Investigator:** Kevin Miller
Sponsor: N/A

This consent form will give you the information you will need to understand why this research study is being done and why you are being invited to participate. It will also describe what you will need to do to participate as well as any known risks, inconveniences or discomforts that you may have while participating. We encourage you to ask questions at any time. If you decide to participate, you will be asked to sign this form and it will be a record of your agreement to participate. You will be given a copy of this form to keep.

- **PURPOSE AND BACKGROUND**

Aerobic fitness (VO2max) plays an important role in overall health status and fitness. Physical activity monitors, such as heart rate monitors, have been developed to measure aerobic fitness based on resting heart rate measurements. Previous research has shown that these monitors can be inaccurate for some people, especially in women. It is not clear why these monitors are less accurate for women. The purpose of this study is to investigate the ability of the Polar M430 to predict VO2max in women who have different fitness levels.

- **PROCEDURES**

You will be asked to come to the Boise State Human Performance Laboratory on one occasion. Before your visit, you should refrain from intense exercise and ensure that you are well hydrated 24 hours prior to testing. Three hours before testing, you must also refrain from food and substances that could influence heart rate (such as caffeine and nicotine).

Before any exercise testing takes place, you will be asked to complete a modified Physical Activity Readiness Questionnaire (PAR-Q) form. Then, your height, weight, and body fat will be measured. Your body fat will be measured with a system that measures the amount of air your body takes up within a chamber. This is an egg-shaped structure that uses changes in air pressure and your body size to determine your total body composition breakdown.

You will be asked to wear a tight fitting bathing suit or lycra/spandex shorts with a swim cap covering the hair to reduce air blockage. You will enter the system and sit for approximately one minute. You will breathe regularly and remain motionless during the testing procedure. A large window is centered in the front of the system so you may see out into the laboratory and may communicate with an investigator if necessary. An emergency release button is located inside the system should you need to terminate the test at any time and for any reason.

Next, a resting heart rate test will be completed. During this test, three electrodes will be attached to your skin above your left and right collarbone and below your ribcage on the left side. Wires will be attached to the electrodes and connected to a machine that monitors your heart activity. A wrist-worn heart rate monitor will also be placed on your left wrist. You will rest quietly on a padded training table for about 10 minutes while the machine and heart rate watch collect heart rate data.

After completing this resting test, you will then warm up on a treadmill at a self-selected pace for 5-10 minutes. During this warm up, you will be asked to try a few different paces to determine the best pace for you to use during maximal treadmill test. After the warm-up you will be fitted with a mouthpiece and nose clip to be used for VO2max testing. The maximal treadmill test will begin by running at your pre-determined pace at a 0% incline for one minute. Each minute, the incline will increase by 1% while the pace remains the same. The test will end once you feel you have reached your maximal effort and cannot continue the test any longer. Once you have reached this point, you will straddle the treadmill belt, and the incline will be lowered to 0% and the speed will be reduced to a walking pace.

After a 3-minute period, a small amount of blood will be collected from your finger tip to determine the amount of lactic acid in the blood. A safety lancet will be used to prick your finger to obtain a drop of blood. After this, you will be allowed to continue your cool down for as long as you want.

This study can be completed in one session. Your total time commitment for participating in this study will be about 1 to 1.5 hours.

- **RISKS**

The potential risks that may occur with participating in this study include those associated with any exercise. These include muscle/joint soreness, lightheadedness, nausea, and in rare instances, fainting, and heart attack. However, the possibility of serious events happening in people who have no previous history of heart, respiratory, or muscular disease are low. The Human Performance Laboratory has a planned response to an emergency and all testing personnel are CPR certified.

- **BENEFITS**

There are no direct benefits from your participation in this study. However, you will be provided with the results of your body composition and VO2max tests.

- **EXTENT OF CONFIDENTIALITY**

Reasonable efforts will be made to keep the personal information in your research record private and confidential. Any identifiable information obtained in connection with this study will remain confidential and will be disclosed only with your permission or as required by law. The members of the research team and the Boise State University Office of Research Compliance (ORC) may access the data. The ORC monitors research studies to protect the rights and welfare of research participants.

Your name will not be used in any written reports or publications which result from this research. Data will be kept for three years (per federal regulations) after the study is complete and then destroyed.

For this research project, the researchers are requesting demographic information. Due to the make-up of Idaho's population, the combined answers to these questions may make an individual person identifiable. The researchers will make every effort to protect your confidentiality. However, if you are uncomfortable answering any of these questions, you may leave them blank.

- **PAYMENT**

You will not be paid for your participation in this study.

- **PARTICIPATION IS VOLUNTARY**

You are free to make a decision to participate in this study, and if you should choose to participate, you may withdraw from the study at any time without penalty. If you withdraw from the study, your data will be given to you or destroyed.

- **QUESTIONS**

If you have any questions or concerns at any time during the course of the study or after completion of the study, you may contact the Principal Investigator, Kevin Miller (kevinmiller@u.boisestate.edu) or Dr. Scott Conger (208-426-4271 or scottconger@boisestate.edu).

If you have questions about your rights as a research participant, you may contact the Boise State University Institutional Review Board (IRB), which is concerned with the protection of volunteers in research projects. You may reach the board office between 8:00 AM and 5:00 PM, Monday through Friday, by calling (208) 426-5401 or by writing: Institutional Review Board, Office of Research Compliance, Boise State University, 1910 University Dr., Boise, ID 83725-1138.

DOCUMENTATION OF CONSENT

I have read this form and decided that I will participate in the project described above. Its general purposes, the particulars of involvement and possible risks have been explained to my satisfaction. I understand I can withdraw at any time.

______________________ ______________________ __________

Printed Name of Study Participant　　**Signature** of Study Participant　　Date

______________________________________ __________

Signature of Person Obtaining Consent　　Date

APPENDIX B

Modified Physical Activity Readiness Questionnaire

HEALTH HISTORY QUESTIONNAIRE

NAME: ____ AGE: _______ DATE OF BIRTH: __________

First Last

ETHNICITY: __________

TELEPHONE: _________________________ E-mail address: ______________________________

Person to contact in case of an emergency: _________________________ Phone # _________________

(relationship) _____________________

Physical Activity Readiness Questionnaire (PAR-Q)

Please read the questions carefully and answer each honestly:

YES NO

_____ _____ 1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

_____ _____ 2. Do you feel pain in your chest when you do physical activity?

_____ _____ 3. In the past month, have you had chest pain when you were not doing physical activity?

_____ _____ 4. Do you lose your balance because of dizziness or do you ever lose consciousness?

_____ _____ 5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?

_____ _____ 6. Have you had any physical injuries to your lower extremities in the past 6 months?

_____ _____ 8. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

_____ _____ 9. Do you know of any other reason why you should not do physical activity?

Do you currently engage in aerobic exercise? Yes ____ No ____

If so, what type(s)?____

How long have you been engaged in aerobic exercise? _________________

How much aerobic exercise do you complete in a typical week (in miles, hours, or minutes)?

____

Do you participate in any other types of exercise? Yes___ No ____

If so, what type(s)? ____

If you do not currently engage in aerobic exercise, have you ever exercised regularly? Yes___ No ____

How long has it been since you exercised consistently (at least twice per week)? ____________________

If applicable, report recent race times for the given distances:

5K _________

6K _________

10K ________

Half Marathon ________

FOR STAFF USE:

____

____

____

____

APPENDIX C

Photo Release Form

Photo/Video Release Form

I, the undersigned, grant Boise State University permission to obtain and use my image, likeness, voice, name, written testimony, and/or biographical information for the promotion and advancement of the university. I understand that the photos, videos, or materials created or commissioned by Boise State which include my image, likeness, or voice are the property of Boise State and I waive the right to inspect or approve those materials prior to distribution or to receive compensation for the use of those materials. This permission applies to all markets and in any media.

Date____

Signature____

Print Name____

☐ Please check this box if you are at or over the age of 18

NOTE: If you are under the age of 18, the signature of your parent or guardian is also required to grant permission

Date____

Parent/ Guardian Signature_________________________________

Print Name____

Revision 11/2/2018

BOISE STATE UNIVERSITY

APPENDIX D

Recruitment Flyer

RESEARCH STUDY VOLUNTEERS NEEDED

Prediction of Cardiorespiratory Fitness Using the Polar M430 Among Women

Eligibility:

1. You need to be a woman between ages of 18 and 40 yrs.
2. In good physical health, and no previous lower body injuries in the past 6 months.

What do I need to do?

- Complete a resting measurement of your heart rate while lying down.
- Perform a maximal-effort treadmill running test lasting about 8 to 12 minutes.

What's in it for me?

- Free testing of cardiorespiratory fitness
- Free assessment of body composition

For more information, send an email to kevinmiller@u.boisestate.edu

Treadmill Exercise Study kevinmiller@u.boisestate.edu	Treadmill Exercise Study kevinmiller@u.boisestate.edu	Treadmill Exercise Study kevinmiller@u.boisestate.edu	Treadmill Exercise Study kevinmiller@u.boisestate.edu	Treadmill Exercise Study kevinmiller@u.boisestate.edu	Treadmill Exercise Study kevinmiller@u.boisestate.edu	Treadmill Exercise Study kevinmiller@u.boisestate.edu	Treadmill Exercise Study kevinmiller@u.boisestate.edu	Treadmill Exercise Study kevinmiller@u.boisestate.edu	Treadmill Exercise Study kevinmiller@u.boisestate.edu

APPENDIX E

Fitzpatrick Skin Type Scale


THE FITZPATRICK SKIN TYPE SCALE
TYPE 1
Light, Pale White
Always burns, never tans.
TYPE 2
White, Fair
Usually burns, tans with difficulty.
TYPE 3
Medium, White to Olive
Burns mildly, tans gradually.
TYPE 4
Olive, Moderate Brown
Rarely burns, tans with ease.
TYPE 5
Brown, Dark Brown
Very rarely burns, tans very easily.
TYPE 6
Black, Very Dark Brown to Black
Never burns, tans very easily.

APPENDIX F

Mean Anthropometric Data

	Mean ± SD
Age	27.39 ± 8.16
Height (inch)	65.54 ± 2.24
Total Weight (lbs)	143.45 ± 27.79
% Fat	24.24 ± 7.70
% Lean	75.75 ± 7.70
Fat Weight (lbs)	36.23 ± 19.12
Lean Weight (lbs)	107.21 ± 13.93
N = 48	

APPENDIX G

Subject Rating of PA, Skin Type, HR, and p$\dot{V}O_{2max}$

Subject	Rating of PA	Skin Type	rHR 430	rHR V800	rHR ECG	PFT 1	PFT 2	PFT 3	PFT 4	PFT 5	PFT 6
1	2	1	63	62	62	39	44	51	58	58	58
2	4	3	46	47	46	40	42	55	60	58	58
3	5	2	56	57	56	47	49	54	62	62	62
4	4	3	57	59	60	36	44	51	55	54	54
5	4	2	53	55	54	33	41	44	46	44	44
6	6	1	77	77	76	33	39	41	40	41	42
7	2	2	62	62	63	36	40	46	47	47	46
8	3	2	52	54	53	35	42	50	53	54	52
9	2	2	76	78	76	28	30	30	29	29	29
10	2	2	51	54	52	32	41	45	43	43	43
11	4	3	51	50	53	32	40	49	47	49	51
12	3	2	55	56	55	27	32	33	30	30	30
13	1	3	68	67	69	33	40	42	42	42	42
14	3	3	41	43	42	29	39	51	59	58	58
15	2	3	51	51	50	44	49	54	59	58	60
16	3	3	58	59	61	40	50	56	62	63	62
17	4	2	47	49	48	36	45	51	58	57	58
18	4	3	70	68	71	30	36	39	36	36	36
19	4	2	54	55	55	32	44	53	59	61	61
20	4	2	58	60	59	38	44	49	57	59	59
21	4	2	45	-	-	-	-	54	55	57	-
22	4	2	50	-	-	-	-	41	39	37	-
23	5	3	42	-	-	-	-	-	60	60	60
24	3	3	54	-	-	-	32	33	27	-	-
25	3	2	58	-	-	-	44	50	52	-	-
26	2	2	60	-	-	36	38	36	-	-	-
27	4	2	60	-	-	-	-	44	44	44	-
28	4	3	49	-	-	-	-	38	32	33	-
29	2	2	66	-	-	33	41	43	-	-	-
30	3	2	62	-	-	-	41	44	46	-	-
31	3	3	71	-	-	-	41	48	51	-	-
32	4	2	62	-	-	-	-	47	54	55	-
33	1	2	60	-	-	30	39	45	-	-	-
34	4	2	68	-	-	-	-	36	31	32	-
35	1	1	52	-	-	41	45	50	-	-	-
36	3	2	67	-	-	-	42	48	50	-	-
37	1	1	69	-	-	34	41	40	-	-	-
38	3	2	56	-	-	-	43	40	37	-	-
39	3	2	69	-	-	-	40	46	52	-	-
40	3	3	70	-	-	-	42	45	50	-	-
41	4	2	57	-	-	-	-	41	34	36	-
42	6	3	55	-	-	-	-	-	54	54	54
43	3	4	58	-	-	-	44	49	56	-	-
44	4	2	46	-	-	-	-	50	49	49	-
45	4	3	57	-	-	-	-	54	63	61	-
46	5	4	73	-	-	-	-	-	32	33	33
47	2	2	82	-	-	33	39	39	-	-	-
48	4	3	51	-	-	-	-	50	52	52	-

APPENDIX H

$\dot{V}O_{2max}$ Criteria Data

Subject	VO2max	Plateau	BL	Y/N	Hrmax	apHRmax	Y/N	RER	Y/N	Achieved VO2max?
1	37.4	y	8.9	y	194	198	y	1.05	n	Y
2	60.3	n	5.3	n	183	184	y	1.02	n	N
3	66.1	n	11.6	y	192	199	y	1.10	y	Y
4	61.1	y	8.6	y	182	186	y	1.06	n	Y
5	48.0	n	6.4	n	184	183	y	1.04	n	N
6	49.8	y	7.8	n	190	191	y	0.97	n	Y
7	41.2	y	10.2	y	189	186	y	1.08	y	Y
8	46.8	y	4.9	n	169	179	y	1.02	n	Y
9	20.1	y	6.0	n	205	191	y	1.10	y	Y
10	33.3	n	8.6	y	183	185	y	1.07	n	N
11	49.6	y	4.8	n	174	185	n	1.02	n	Y
12	29.0	y	6.5	n	161	182	n	1.12	y	Y
13	34.0	y	8.1	y	201	199	y	1.06	n	Y
14	45.5	y	9.8	y	168	189	n	1.01	n	Y
15	54.7	y	9.7	y	183	192	y	1.06	n	Y
16	44.3	y	9.8	y	180	187	y	1.07	n	Y
17	54.7	y	3.6	n	174	190	n	1.00	n	Y
18	52.7	y	8.2	y	184	178	y	1.01	n	Y
19	59.3	n	8.1	y	184	191	y	1.04	n	N
20	49.1	y	10.6	y	214	202	y	1.08	n	Y
21	49.3	y	9.1	y	180	183	y	1.06	n	Y
22	46.8	y	7.8	n	178	183	y	1.06	n	Y
23	45.8	y	16.0	y	176	200	n	1.10	y	Y
24	34.9	y	8.2	y	193	182	y	1.02	n	Y
25	48.5	y	10.4	y	196	195	y	1.09	y	Y
26	34.2	y	8.9	y	190	192	y	1.04	n	Y
27	44.2	y	10.0	y	180	186	y	1.12	y	Y
28	31.5	y	7.9	n	170	175	y	1.06	n	Y
29	35.5	y	9.6	y	195	199	y	1.03	n	Y
30	49.7	y	8.9	y	207	192	y	1.03	n	Y
31	37.7	y	9.0	y	186	199	n	1.17	y	Y
32	44.0	y	8.5	y	198	199	y	1.06	n	Y
33	32.2	y	10.1	y	192	197	y	1.12	y	Y
34	36.5	y	6.1	n	194	176	y	1.07	n	Y
35	39.4	y	11.9	y	193	201	y	1.13	y	Y
36	38.0	y	8.4	y	204	201	y	1.01	n	Y
37	39.6	y	9.6	y	202	202	y	1.05	n	Y
38	32.4	y	9.7	y	199	201	y	1.10	y	Y
39	38.4	y	14.1	y	191	201	y	1.16	y	Y
40	43.3	y	8.3	y	194	201	y	1.02	n	Y
41	42.9	y	10.4	y	189	200	n	1.06	n	Y
42	51.3	y	7.0	n	185	199	n	1.02	n	Y
43	52.6	y	9.6	y	204	200	y	1.05	n	Y
44	50.1	y	11.8	y	194	199	y	1.13	y	Y
45	46.9	y	10.6	y	189	201	n	1.09	y	Y
46	41.1	y	6.6	n	197	202	y	1.07	n	Y
47	45.4	y	11.1	y	211	201	y	1.09	y	Y
48	49.7	n	7.2	n	201	201	y	1.06	n	N

VO2max was based on either a plateau of VO2max or achievement of the three secondary criteria.