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Energy Expenditure of Collegiate Golfers in a Competitive Setting

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Abstract: Collegiate golf is physically demanding; however, little research has been done to establish the energy expenditure (EE) and metabolic demand on a golfer during competition. With advances in wearable technology, it has become easier to gain knowledge on physical activities outside the lab. Therefore, the purpose of this study was to determine the amount of EE a collegiate golfer expends during a competitive golf tournament. METHODS: Eight NCAA-caliber golfers (4 males; 4 females) participated (Age: 19.3 ± 2.0 years; WT: 149.5 ± 13.4 pounds; Bag WT: 22.3 ± 2.0 pounds; Bag Wt./Body Wt.: 15.0 ± 1.8%; HT: 67.7 ± 3.6 inches; % Body Fat: 20.0 ± 7.3%). One VO_{2max} and two randomly ordered 6-minute steady-state walk (6MW) tests were performed. One 6MW was completed with a weight vest simulating each golfer's bag weight, and the other was completed without the vest. RESULTS: Phase 1, males had a lower% BF (p=0.03), higher FFW (p=0.03), VO_{2max} (p=0.02), max heart rate (p=0.04), max RER (p=0.03), and max VE (p=0.02) compared to females. Looking at caloric expenditure during all 6MW tests, the Garmin VivoactiveHR™ overestimated calories expended compared to the metabolic cart kcals (+22.4%; p=0.01). For the 6MW without the bag, stepwise regression showed in order of importance heart rate, distance covered, and step count entered the equation (r-squared = 0.966, p=0.0021). Phase 2, females had higher scores (females: 87.5 ± 6.43 strokes; males: 76.75 ± 4.65 strokes), walked a greater distance (females: 7.43 ± 0.23 miles; males: 7.37 ± 0.18 miles), took longer to complete the golf rounds (females: 282:42 ± 37:16 minutes; males: 266:05 ± 11:10 minutes), and had a greater average HR (females: 121.99 ± 15.26 bpm; males: 111.00 ± 4.31 bpm). The Garmin VivoactiveHR™ underestimated the female golfers' kcal expenditure by 6.22% compared to the metabolic predicted kcals; however, the males experienced an overestimation of 5.3% by the Garmin VivoactiveHR™. The stepwise regression conducted on the golf tournament data indicated that calories/hour (p=0.00) and time (p=0.00) affected Garmin VivoactiveHR™ kcal expenditure the most. CONCLUSION: The Garmin VivoactiveHR™ was unable to accurately estimate caloric expenditure during the in-lab and golf tournament testing.

Keywords: Wearables, Energy Expenditure, Steady-State Exercise, Golf

1. Introduction

A collegiate golfer undergoes varying degrees of physical strain during a round of golf, depending on course terrain, weather conditions, and the level of play, amongst other physiological factors [1]. A golf tournament can last between four and a half to five hours [2-4]. Golf can be especially taxing in regard to metabolic cost. For golf, the metabolic rate has to be calculated using the non-calorimetry method which can calculate the amount of energy expenditure (EE) based on physiological responses [5, 6]. According to previous research, collegiate golfers can expend about 1900

kilocalories (kcals) per round of golf [7]; however, little to no research has been done in the field to test a golf tournament setting.

Unfortunately for the sport of golf, calculating EE in the field utilizing the gold standard metabolic cart is not feasible. Therefore, other modes of collecting this data need to be used. Wearable activity trackers have been available to the every-day consumer for many years and even though great advances in this field have been made, there are still improvements needed [8, 9]. Wearable activity trackers have a golf application available, but unfortunately, they only track the sport performance; therefore, individuals must use the walking application in order to collect the physiological and geographical data.

Wearable devices use technology to analyze physiological responses such as heart rate and geographical information such as distance covered to determine EE, which can be collected using a chest strap or a wrist-based monitor [10]. When it comes to golfers, the chest strap may interfere with their playing ability due to the rotational movement of the sport, therefore, the wrist-based heart rate monitor is preferred. Wrist-based heart rate accuracy is best at low-to-moderate intensities [11]; thus, they work well for golf. Even though more validation on this technology needs to be performed, wrist-based heart rate activity trackers allow researchers to perform more in-field EE testing for golf.

The current study examined EE in a competitive tournament setting. This data was compared to the gold standard metabolic cart in order to establish a prediction equation to estimate EE on the course. The activity tracker, Garmin VivoactiveHR™, was used in the field to test the golfer's EE in a competitive golf setting. With knowledge of the metabolic cost on collegiate golfers, it can be seen what steps are needed in the future for each athlete to properly prepare and reach optimal performance.

2. Methods

2.1. Purpose

The primary purpose of this study was to quantify the amount of EE a collegiate-caliber golfer uses while carrying their own golf clubs in a competitive setting. A secondary purpose of this study was to better understand how a golfer's actual tournament play affected his or her overall EE. The study included two data collection phases.

2.2. Subjects

The study consisted of eight subjects, who were recruited by contacting local collegiate golf coaches. The subjects were collegiate-caliber athletes between the ages of 18 and 25. Exclusions include if the subject was unable to carry his or her golf clubs, or the golfer was not willing to wear the Garmin VivoactiveHR™ activity tracker on their wrist.

2.3. Design

The study was composed of two phases including an in-lab testing segment (Phase 1) and a two-round golf tournament (Phase 2). Phase 1 was specifically designed to test the golfers using both the activity tracker, as well as the gold standard metabolic cart. In doing so, a prediction equation was formed to be used in Phase 2 for determining golf play EE. This testing section included the following test items: a VO_2max test, a 6-minute steady-state walking test (6MW) without a weight vest, and a 6MW test with a weight vest to simulate golf bag weight.

Phase 2 was specifically designed to test the amount of energy a golfer expends during each round of competitive golf while they walked and carried their golf bag. Phase 2 testing included each golfer playing two, 18-hole rounds of golf in a tournament setting while wearing the activity tracker.

2.4. Methodology

Prior to starting the study, the subject's age, height, weight, and weight of golf bag were measured on a calibrated BSM170 Stadiometer and scale (In-Body Corporation, Cerritos, CA). The subjects were also asked how many times they have played the study's designated golf course and their 18-hole scoring average. The relevant subject information was then entered into a Garmin VivoactiveHR™ activity tracker.

For Phase 1, the pre-tournament lab testing, each subject was tested at Exercising Nutritionally's Clinical Performance Research Lab (Lisle, IL). Testing included body composition, Garmin VivoactiveHR™ device calibration, two 6MW tests, and a VO_{2max} test. Weight, percent body fat, and fat-free weight were measured was measured using the In Body 570 (In-Body Corporation, Cerritos, CA). The Garmin VivoactiveHR™ device (Garmin, Olathe, KS) was secured on the subject's non-dominant arm. Each subject was accompanied by a researcher to the parking lot where an outdoor flat surface was used to calibrate the global positioning system (GPS), as described by the manufacturer. Once the watch indicated that calibration was complete, the subject returned to the lab to be prepped for the two 6MW tests. All subjects were required to wear a heart rate monitor via a chest strap and a facemask to collect metabolic data, i.e., VE, VO_2, VCO_2, and respiratory exchange ratio (RER).

To get an accurate metabolic profile of walking with and without the bag as each golfer would do during tournament play, each golfer performed two 6MW tests. One 6MW test was performed with weighted vest and one was performed without weighted vest, which was determined using a random order study design for each subject.

During the 6MW tests, the treadmill was set at 0% grade throughout this test while the subject controlled the speed. The subject was to walk at the fastest speed possible without running. After the first 6MW test was completed, the weight vest with the appropriate amount of weight was then placed and secured on the subject. The switch between the 6MW test with and without the weight vest was done in three minutes. The subject was then instructed to perform the same test following the same protocol. Following the completion

of the second 6MW test, the subject was able to recover. Each subject was given 15 minutes of recovery when they could drink water and rest before starting the VO_{2max} test.

The VO_{2max} test treadmill protocol used a constant speed of 3.5 mph while the grade increased 1% every minute until each subject reached volitional fatigue. Once the subject was prepped for the test, he or she sat and was instructed to relax until their RER level was between.80 and.85. Then the subject positioned themselves on the treadmill and began stage 1 of the VO_{2max} test. During the test, data was collected every minute. Following the completion of the VO_{2max} test, the subject had then completed the in-lab testing required for this research study.

Phase 2 testing consisted on the golf course, Bolingbrook Golf Club (Bolingbrook, IL). Bolingbrook is a links-style golf course with a course rating of 71.4 and a slope of 132. The golfers played from the white tee markers, making the total yardage 6,480 yards. The subjects played two rounds of 18 holes. The subjects followed the rules set by the United States Golf Association (USGA), the NCAA, and the appointed rules committee. They played in an individual stroke play format and carried their golf clubs on their backs. During the study, heart rate, energy expenditure, and distanced travelled were monitored with a Garmin VivoactiveHR™ activity tracker.

Prior to teeing off for each round, the subject's weight and bag weight were measured on a doctor's scale located in the clubhouse at Bolingbrook Golf Club. This information was then placed into the activity tracker to ensure accuracy. The golfers then put the Garmin VivoactiveHR™ device on their non-dominant wrist and were placed into groups of four based on their gender.

Prior to the start of round 1 and round 2, each foursome was called to the tee box to introduce themselves, identify their golf balls, exchange scorecards, and to go over course rules with the starter on duty. Each participant kept track of his or her own score as well as another golfer's. In addition to score, each subject kept track of fairways hit, greens in regulation, and number of putts. Each participant received a blank scorecard and statistics card similar to what would be issued at a collegiate tournament. Prior to their first tee shot, golfers began tracking their activity on the Garmin VivoactiveHR™ watch. During the round, subjects hit the lap button after they putted out every hole and before every tee shot. A research assistant was there to ensure that all golfers followed this protocol throughout the golf testing.

After putting out on hole 18 for round 1 and round 2, subjects stopped tracking their activity. Following the round, each foursome verified their scores with the group and signed the scorecards. All scorecards were signed by the scorer and a witness before they were accepted. The golfers then turned in their scorecards.

Following each round, the scores were tallied. After round 2, a cumulative score from both rounds was calculated. The subject with the overall lowest cumulative score for both days was the winner, with placing following from lowest score to highest score. Following each round, every subject's weight and weight of golf bag were recorded.

The female subjects' round 1 weather was 80 degrees and sunny on the front 9 holes and increased to 85 degrees and sunny on the back 9 holes. On round 2, the front 9 holes was 75 degrees and sunny; then increased to 86 degrees and sunny. For the males, their round 1 weather was 68 degrees and sunny, with a slight breeze on the front 9 holes, changing to 76 degrees and sunny on the back 9 holes. For round 2, the front 9 holes were 62 degrees and sunny and the back 9 holes were 77 degrees and sunny.

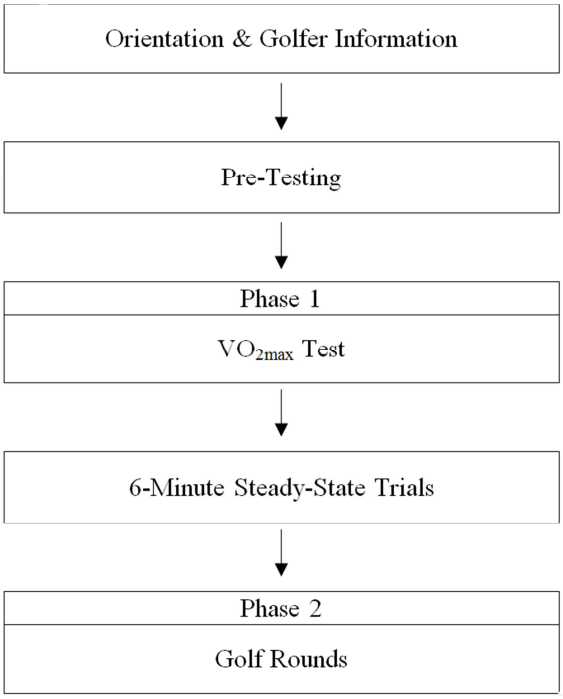

Figure 1. *Study Design Flow Chart.*

2.5. Statistical Analysis

JMP Statistical Discovery Software from SAS Version 12.2.0 (Cary, NC) was used to run paired t test, one-way ANOVA, linear regression, stepwise regression, and bivariate covariance on the data. Data was analyzed with a significance level of <0.05 and a 95% confidence interval.

3. Results

3.1. Phase 1

Table 1 highlights the physical characteristics of the golfers. All golfers were of college age (18 to 25 years old). While males weighed 12.7 pounds more than the female golfers, this difference was not significant. The male golfers were significantly leaner and had 23.4 lbs more fat-free weight (p=0.03). Interestingly, although the male golfer's bag was heavier than the female golfer's, the bag weight to body weight ratio was lower in men.

Table 1. *Physical Characteristics.*

Variable	All Subjects	Females	Males	Males vs Females
Age (years)	19.3 ± 2.0	20.5 ± 2.5	18.0 ± 0.0	NS, 0.14
Weight (pounds)	149.5 ± 13.4	143.2 ± 15.7	155.9 ± 8.0	NS, 0.22
Bag Weight (pounds)	22.3 ± 2.0	21.4 ± 1.3	23.1 ± 2.4	NS, 0.26
Bag Wt./Body Wt. (%)	15.0 ±1.8	15.1 ± 1.9	14.9 ± 2.0	NS, 0.45
Height (inches)	67.7 ± 3.6	66.0 ± 4.6	69.4 ± 1.2	NS, 0.23
% Body Fat (%)	20.0 ± 7.3	24.6 ± 6.0	15.4 ± 5.8	0.03
FFW (pounds)	120.1 ± 17.2	108.4 ± 17.1	131.8 ± 5.4	0.03

Table 2 highlights the results of the VO_{2max} test. These results show that the female golfer's VO_{2max} was 39.7 ± 6.2 mL • kg-1• min^{-1}, and male golfers had a VO_{2max} value of 51.7 ± 3.8 mL • kg-1• min^{-1}. Males had higher max heart rates (Males: 210.8 ± 7.6 bpm; Females: 193.8 ± 13.7 bpm). Males and females displayed similar Max RER (Males, 1.2 ± 0.0; Females, 1.1 ± 0.0). The male golfers had greater maximal VE values (140.9 ± 20.2 L/min) than the female golfers (100.9 ± 9.5 L/min) and males had a significantly greater max TV (2.7 ± 0.2 L) compared to the females (1.8 ± 0.2 L); however, there were no statistical differences in respiratory rates.

Table 2. *VO_{2max} Results.*

Variable	All Subjects	Females	Males	Females vs Males
VO_{2max} (mL/kg/min)	45.7 ± 8.0	39.7 ± 6.2	51.7 ± 3.8	0.02
Max HR (bpm)	202.3 ± 13.7	193.8 ± 13.7	210.8 ± 7.6	0.04
Max RER	1.1 ± 0.1	1.1 ± 0.0	1.2 ± 0.0	0.03
Max VE (L/min)	120.9 ± 25.9	100.9 ± 9.5	140.9 ± 20.2	0.02
Max RR (bpm)	56.0 ± 8.7	57.5 ± 6.0	54.6 ± 11.6	NS, 0.67
Max TV (L)	2.3 ± 0.6	1.8 ± 0.2	2.7 ± 0.2	NS, 0.00

Table 3 highlights the physiological responses in all golfers combined (males and females) for the 6MW tests. Unexpectedly, there were no statistically significant differences observed in oxygen uptake, heart rate, ventilatory responses, and caloric expenditure when comparing walking on the treadmill with and without the golf bag simulated weight vest. It was observed that with the bag, subjects performed at 64.3% of their VO_{2max} and at 61.7% of their VO_{2max} without the bag.

Table 3. *6-Minute Steady-State In-Lab Data.*

Variable	W/Bag	W/Out Bag	Paired T-Test
Mean VO_2 (mL/kg/min)	29.4 ± 2.0	28.2 ± 1.7	NS, 0.24
Mean HR (bpm)	154.7 ± 20.1	152.5 ± 24.5	NS, 0.65
Mean VE (L/min)	57.3 ± 7.4	57.4 ± 11.8	NS, 0.98
Met. Kcals	58.7 ± 5.5	56.6 ± 7.7	NS, 0.29

However, table 4 shows that while females responded similarly across the two 6MW, male golfers showed significantly higher ventilation rates (p=0.02) and Garmin estimated kcals expenditure (p=0.01). Caloric expenditure comparisons were made between the Garmin VivoactiveHR™ energy expenditure prediction equation (the actual gold-standard metabolic cart kcals) and an individualized VO_{2max}-based linear regression equation, which was developed from each participant's heart rate and kcal expenditure during each stage of the max testing.

Table 4. *6-Minute Steady-State In-Lab Data by Gender.*

Variable	W/Bag	W/Out Bag	Paired T-Test
Females			
Mean VO_2 (mL/kg/min)	29.7 ± 2.8	27.3 ± 1.4	NS, 0.26
Mean HR (bpm)	154.9 ± 13.7	147.3 ± 28.4	NS, 0.42
Mean VE (L/min)	60.9 ± 5.0	56.8 ± 15.4	NS, 0.55
Met. Kcals	56.5 ± 5.4	52.3 ± 8.1	NS, 0.29
Garmin Kcals	63.5 ± 19.7	61.8 ± 24.6	NS, 0.61
Variable	W/Bag	W/Out Bag	Paired T-Test
Males			
Mean VO_2 (mL/kg/min)	29.0 ± 1.0	29.0 ± 1.7	NS, 0.93
Mean HR (bpm)	154.5 ± 27.5	157.7 ± 23.0	NS, 0.54
Mean VE (L/min)	53.7 ± 8.2	57.9 ± 9.3	0.02
Met. Kcals	60.9 ± 5.2	61.0 ± 4.6	NS, 0.93
Garmin Kcals	71.0 ± 16.6	88.8 ± 21.8	0.01

Figure 2 displays the data for all eight golfers with the combined mean of both steady-state exercise trials. The data show the Garmin-derived steady-state predicted kcals overestimated the actual kcals recorded with the metabolic cart by 22.4% (p=0.01). Also, using each person's VO_{2max}-based kcal prediction equation, once again, the Garmin device derived steady-state

kcals over predicted the linear regression kcal equation by 15.5% (p=0.03).

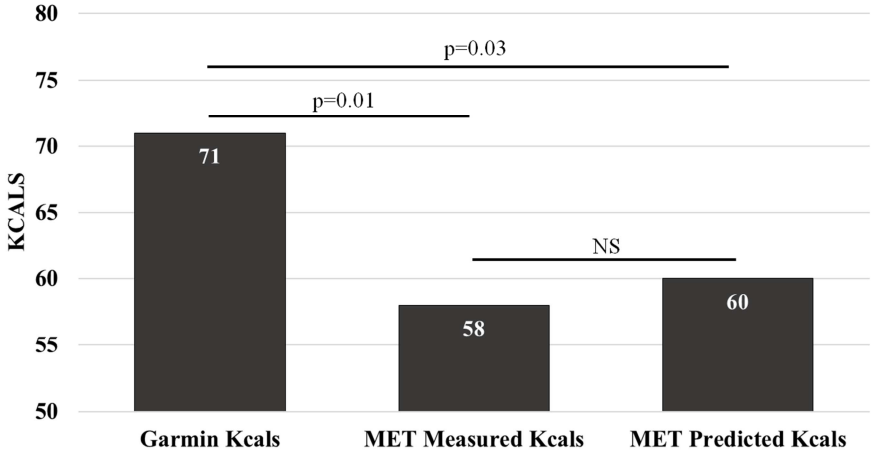

Figure 2. *In-Lab Steady-State Total Kcals Expended (All Subjects With and Without The Bag.*

Figure 3 shows the results in kcal expenditure when each subject walked on the treadmill without the golf bag weight added. Similar to what was shown in Figure 2, the Garmin-derived steady-state predicted kcals expended overestimated the actual calories expended by 24% (p=0.003) and 19% (p=0.01) when compared to prediction equation. Figure 4 shows the comparison of Garmin kcals, metabolic cart kcals, and metabolic predicted kcals for all golfers with the bag. Even though there was no statistical significance, the Garmin VivoactiveHR™ overestimated caloric expenditure by 13.6%.

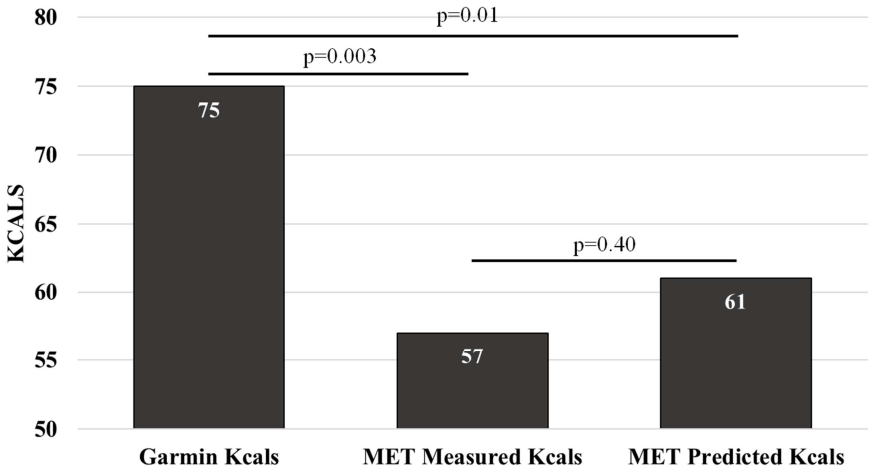

Figure 3. *In-Lab Steady-State Total Kcals Expended (All Subjects Without the Bag).*

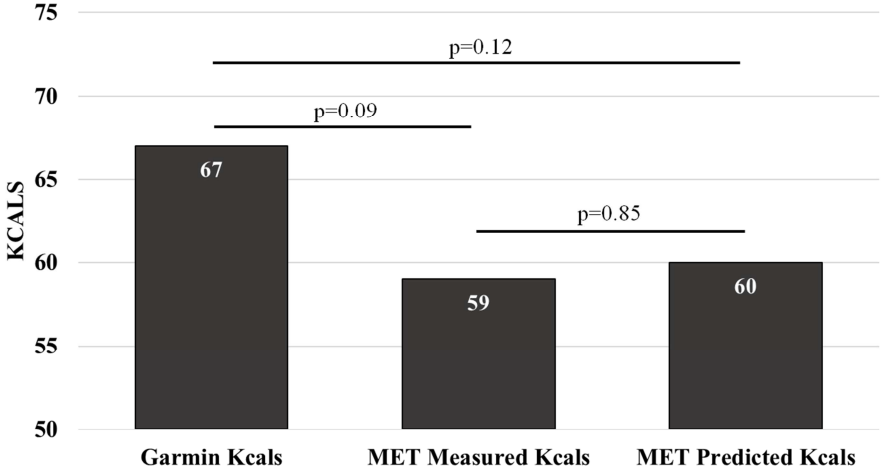

Figure 4. *In-Lab Steady-State Total Kcals Expended (All Subjects With the Bag).*

One can see in Figure 5 (Female Golfers) that during the 6MW with the bag, the female golfers' activity trackers estimated kcal expenditure at 63.5 ± 19.7 kcals, an overestimation of 12.4% compared to the metabolic-cart measured kcals (56.5 ± 5.4 kcals). The overestimation of the Garmin without the bag was even greater at 18.2%. The Garmin estimated EE at 61.8 ± 24.6 kcals; however, the metabolic cart calculated only 52.3 ± 8.1 kcals, a difference of 9.5 kcals. As expected, female golfers experienced a greater metabolic demand walking with the bag compared to without the bag. Mean oxygen uptake was 8.9% greater in female golfers when walking on the treadmill with the bag compared to non-bag walking. Consequently, female golfers' heart rates were lower by 7 bpm, ventilation was reduced by 3.1 liters, and overall kcals expended were lower by 5.8%. Due to the small subject number, these differences were not statistically significant. In Figure 6 (Male Golfers), it can be seen that the activity tracker measured 71.0 ± 16.6 kcals with the bag, compared to the 60.9 ± 5.2 kcals the metabolic cart measured. The is an overestimation of 10.1 kcals. When looking at the 6MW test without the bag, the activity tracker measured 88.8 ± 21.8 kcals, but the metabolic cart only measured 61.0 ± 4.6 kcals. Looking at this comparison, the activity tracker overestimated EE by 27.8 kcals. In stark contrast with the females, metabolic demand between the two 6MW tests in male golfers were very similar (VO_2 = 29.1 mL/kg vs 29.0 mL/kg, with bag vs without bag, respectively). When walking without the bag, male golfers increased their walking speed 6.8% which resulted in three out of four golfers having higher heart rates during the without-bag walk tests. Also, because the male golfers were walking faster, they also had higher ventilations by 6.1%.

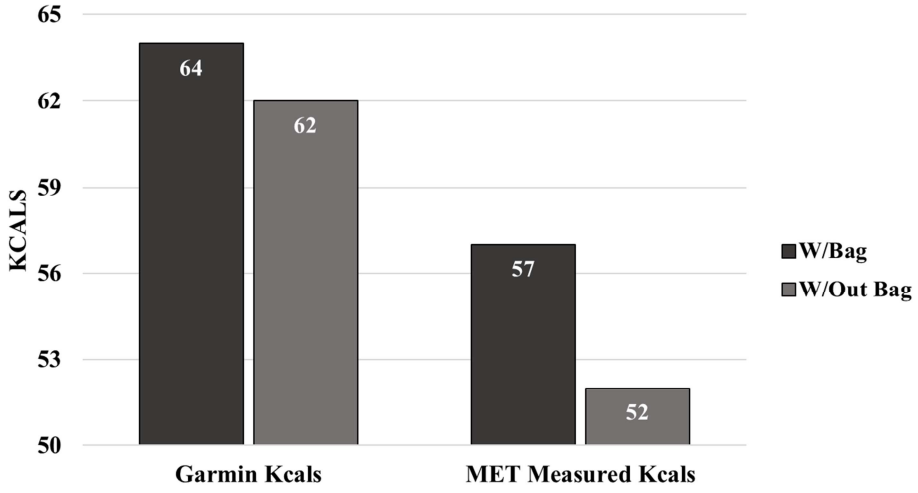

Figure 5. *In-Lab Steady-State Total Kcals Expended (Female Golfers).*

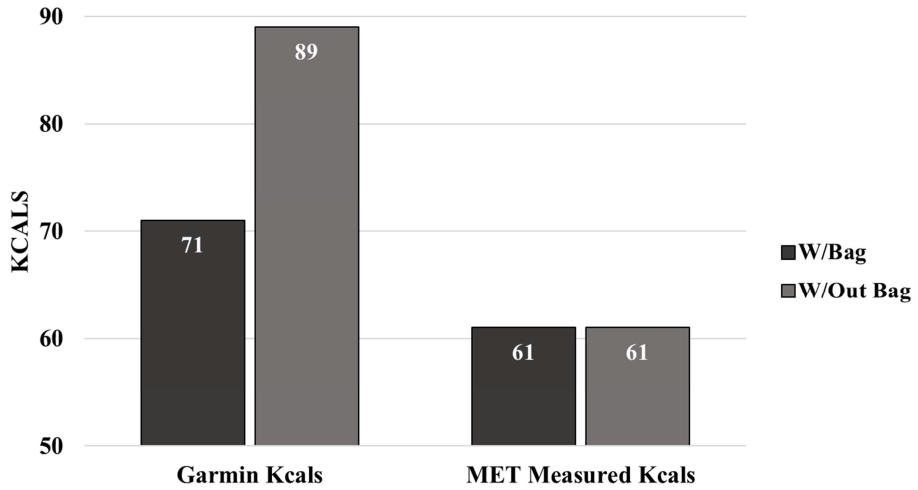

Figure 6. *In-Lab Steady State Total Kcals Expended (Male Golfers).*

In order to better understand the differences that were observed in Garmin-based kcal expenditure values versus the actual metabolic cart kcals, stepwise regression modeling was used. Stepwise multiple regression revealed that the variables that were most relevant in the derived Garmin kcals during both conditions combined (weighted walk and unweighted walk) were in order of importance: Garmin heart rate, body weight, distance, steps/6 minutes, and mph (r-squared=0.98; p=0.0372). When only looking at the Garmin kcals with the added bag weight trials, in order of

importance, Garmin heart rate and steps/6 minutes (r-squared=0.82; p=0.0131) were the only variables to enter the stepwise regression prediction model. For the Gamin kcals without the added bag weight trials, the variables in order of importance were the Garmin heart rate, distance, and steps/6 minutes (r-squared=0.97; p=0.0021). Finally, using a bivariate fit linear regression model looking at the relationship between the actual metabolic kcals expended versus the Garmin-predicted kcals showing these variables were not significantly related for the added bag trials, the r-square value was 0.46 (NS, p=0.06). As expected, the actual metabolic kcals compared to the Garmin-predicted kcals without the bag were highly correlated (r-value = 0.92, r-square value = 0.86 (p=0.0009)).

3.2. Phase 2

Table 5 highlights the tournament results for all golfers with means of both rounds combined. It can be observed that male golfers scored lower (76.8 ± 4.65 strokes) overall compared to female golfers (87.5 ± 6.43 strokes). Interestingly, although all golfers played from the same tee markers, female golfers walked farther than the males did during both rounds (females: 7.49 ± 0.27 miles; males: 7.37 ± 0.18 miles) resulting in a longer time to complete the tournament while also having a slower average walking speed. Due to the males being more aerobically fit, as established during the lab testing, they had lower average heart rates (111.00 ± 4.31 bpm) than the females (121.99 ± 15.26 bpm). Looking at caloric expenditure, according to the Garmin VivoactiveHR™ the females burned more calories overall (1,642.33 ± 442.98 kcals) but less calories per hour (348.59 ± 78.09 cal/hour) than the male golfers (1,583.13 ± 145.80 kcals; 357.13 ± 30.21 cal/hour). These results may be related to the increased on-course time and distance traveled for female golfers to play their rounds.

Table 5. *All Rounds for All Subjects.*

Variable	All Subjects	Females	Males
Score (strokes)	82.13 ± 7.76	87.5 ± 6.43	76.75 ± 4.65
Distance (miles)	7.43 ± 0.23	7.49 ± 0.27	7.37 ± 0.18
Time (minutes)	274:23 ± 27:56	282:42 ± 37:16	266:05 ± 11:10
Average Speed (mph)	1.64 ± 0.13	1.61 ± 0.16	1.68 ± 0.09
Average HR (bpm)	115.71 ± 11.46	121.99 ± 15.26	111.0 ± 4.31
Effort Trimp Score	136.64 ± 13.35	141.33 ± 19.37	133.13 ± 5.49
Garmin Kcals	1608.5 ± 296.38	1642.33 ± 442.98	1583.13 ± 145.80
Cal/Hour	353.47 ± 53.45	348.59 ± 78.09	357.13 ± 30.21
Met. Pred. Kcals	1624.92 ± 298.19	1751.29 ± 261.21	1498.56 ± 298.44
Kcal Difference	-193.36 ± 656.43	108.96 ± 445.61	-420.10 ± 722.01

Combining all golfers, the Garmin VivoactiveHR™ calories were overestimating caloric expenditure by only 1.0% compared to the metabolic predicted kcals. However, when separated by gender, the Garmin VivoactiveHR™ underestimated the caloric expenditure by 6.22% compared to the metabolic predicted kcals in female golfers, while for the male golfers, the Garmin VivoactiveHR™ overestimated their calories burned by 5.3% compared to the metabolic predicted kcals. However, these differences did not reach statistical significance. Additionally, during the tournament it was observed that bag weight, body weight, and total bag significantly declined due to body water loss, water bottle content loss or loss of golf balls ($p = \leq 0.009$).

When looking at individual round scoring and performance markers for all golfers independent of gender, only the distance covered between the two rounds were statistically different (p=0.0189; Table 6).

Table 6. *All Subjects Round 1 and Round 2.*

Variable	Round 1	Round 2	Significance
Score (strokes)	83.4 ± 7.9	80.9 ±7.9	NS, 0.14
Distance (miles)	7.6 ± 0.3	7.3 ± 0.1	0.0189
Time (seconds)	17195.5 ± 1986.3	15730.6 ± 919.7	NS, 0.19
Average Speed (mph)	1.6 ± 0.2	1.7 ± 0.1	NS, 0.47
Average HR (bpm)	116.3 ± 11.7	115.1 ± 12.1	NS, 0.38
Effort Trimp Score	141.3 ± 16.6	132.0 ± 7.8	NS, 0.35
Garmin Kcals	1657.7 ± 362.4	1559.3 ± 230.9	NS, 0.41
Cal/Hour	353.2 ± 61.9	353.7 ± 48.5	NS, 0.93
Met. Pred. Kcals	1500.1 ± 667.6	1330.2 ± 562.7	NS, 0.16

Looking at the tournament results for each gender separately, the data shows that males exhibited more between-round variable significant differences (Table 7). Male golfers took less time to play round 1 (15,339.3 ± 35.2 seconds) than round 2 (16,589.8 ± 50.4 seconds; p=<0.0001). They also walked round 1 faster (round 1, 1.8 ± 0.1 mph; round 2, 1.6 ± 0.0 mph; p=0.0138) and had a significantly lower Trimp score effort for round 1 (128.0 ± 0.0) compared to round 2 (138.3 ± 0.5). Interestingly, round 2 showed greater kcal expenditure with the Garmin kcals device (p=0.0017), but when kcal per round was compared using each golfer's individual metabolic cart prediction equation, expenditure between the two rounds was not significantly different. One possible explanation for these kcal estimate

differences may be related to time it took complete each golf round. Based on the fact that round 2 took longer, the Garmin kcal estimates may have calculated more calories burned related to how time played a role in the kcal prediction equation.

Table 7. *Males Round 1 and Round 2.*

Variable	Round 1	Round 2	Significance
Score (strokes)	77.8 ± 4.6	75.8 ± 5.2	NS, 0.29
Distance (miles)	7.4 ± 0.2	7.3 ± 0.1	NS, 0.42
Time (seconds)	15339.3 ± 35.2	16589.8 ± 50.4	<0.0001
Average Speed (mph)	1.8 ± 0.1	1.6 ± 0.00	0.0138
Average HR (bpm)	111.8 ± 4.6	110.3 ± 4.5	NS, 0.29
Effort Trimp Score	128.0 ± 0.00	138.3 ± 0.5	<0.0001
Garmin Kcals	1525.0 ± 150.8	1641.3 ± 133.6	0.0017
Cal/Hour	358.3 ± 36.0	356.0 ± 28.8	NS, 0.61
Met. Pred. Kcals	1472.19 ± 282.61	1524.92 ± 375.13	NS, 0.16

Table 8 shows the female subjects' statistical differences comparing round 1 and round 2. Here one can see that the female golfers walked significantly farther during round 1 compared to the second golf round (Round 1: 7.7 ± 0.2 miles; Round 2: 7.3 ± 0.1 miles, p=0.0069). Consequently, round 2 was significantly faster than round 1 (p=<0.001) and therefore the average round walking speed was faster during round 2 (p=0.0011). Females also exhibited a significantly lower Trimp score effort during round 2 compared to round 1 (p=0.0004), which takes into account heart rate changes during each round. Caloric expenditure was greater for round 1 play looking at both the Garmin and metabolic cart-based equation. However, only the metabolic cart for kcal expended showed that round 1 required a great metabolic demand (Garmin, p = 0.09; Metabolic cart equation, p = 0.02).

Table 8. *Females Round 1 and Round 2.*

Variable	Round 1	Round 2	Significance
Score (strokes)	89.0 ± 6.5	86.0 ± 7.0	NS, 0.37
Distance (miles)	7.7 ± 0.2	7.3 ± 0.1	0.0069
Time (seconds)	19051.8 ± 127.1	14871.5 ± 51.9	<0.001
Average Speed (mph)	1.5 ± 0.1	1.8 ± 0.1	0.0011
Average HR (bpm)	122.3 ± 16.9	121.7 ± 17.2	NS, 0.83
Effort Trimp Score	159.0 ± 1.0	123.7 ± 0.6	0.0004
Garmin Kcals	1834.7 ± 527.0	1450.0 ± 319.1	NS, 0.09
Cal/Hour	346.5 ± 97.2	350.7 ± 76.1	NS, 0.79
Met. Pred. Kcals	1978.0 ± 47.1	1524.6 ± 119.0	0.0181

Table 9 shows a correlation matrix of all golfers for both round 1 and round 2. It can be seen that time and distance has a positive significant correlation (p=0.0082). A negative significant correlation was also observed between average speed and tournament time (p=<0.0001). Effort had a significant correlation with multiple variables for all golfers, such as distance (p=0.0082), time (p=<0.0001), and average speed had a negative correlation (p=<0.0001). The male golfers had a positive correlation between Garmin kcals and average heart rate (p=0.0194). All golfers had a significant correlation between calories/hour and average heart rate (p=0.0205) and calories/hour and Garmin kcals (p=0.0005). There were also multiple significant correlations with metabolic predicted kcals, such as metabolic-cart predicted kcals and time (p=0.0187), metabolic-cart predicted kcals and average speed (p=0.0348), and metabolic-cart predicted kcals and effort (p=0.0178).

Table 9. *All Subjects Correlation Matrix for Both Rounds.*

Variable	By Variable	Correlation	Lower 95%	Upper 95%	Signif. Prob.
Time (minutes)	Distance	0.72	0.25	0.92	0.0082
Average Speed (mph)	Time	-0.92	-0.98	-0.75	<0.0001
Effort	Distance	0.72	0.25	0.92	0.0082
Effort	Time	0.99	0.99	0.99	<0.0001
Effort	Average Speed	-0.92	-0.98	-0.74	<0.0001
Garmin Kcals	Average HR	0.66	0.14	0.89	0.0194
Cal/Hour	Average HR	0.66	0.13	0.89	0.0205
Cal/Hour Kcals	Garmin Kcals	0.85	0.54	0.96	0.0005
Met. Pred. Kcals	Time	0.66	0.14	0.89	0.0187
Met. Pred. Kcals	Average Speed	-0.61	-0.88	-0.06	0.0348
Met. Pred. Kcals	Effort	0.66	0.15	0.89	0.0178

Looking at the female golfers alone (Table 10), they had multiple correlations that were significant. Time and distance had a positive, significant correlation (p=0.0040). Average speed and time had a negative, significant correlation

(p=00003). As for effort, there were three significant correlations: distance (p=0.0028), time (p=<0.0001), and average speed had a negative correlation (p=0.0012). Calories/hour had positive significant correlations with average heart rate (p=0.0325) and Garmin kcals (p=0.0284). Metabolic-cart predicted kcals had many significant correlations. Metabolic-cart predicted kcals were positively correlated with distance (p=0.0002), time (p=0.0296), and effort (0.0050). Metabolic-cart predicted kcals was negatively correlated with average speed (p=0.0296).

Table 10. *Females Subjects Correlation Matrix for Both Rounds.*

Variable	By Variable	Correlation	Lower 95%	Upper 95%	Signif. Prob.
Time (minutes)	Distance	0.88	0.46	0.98	0.0040
Average Speed (mph)	Time	-0.95	-0.99	-0.73	0.0003
Effort	Distance	0.95	0.64	0.99	0.0028
Effort	Time	0.99	0.99	1.00	<0.0001
Effort	Average Speed	-0.97	-0.99	-0.75	0.0012
Cal/Hour	Average HR	0.85	0.12	0.98	0.0325
Cal/Hour	Garmin Kcals	0.86	0.16	0.98	0.0284
Met. Pred. Kcals	Distance	0.99	0.90	0.99	0.0002
Met. Pred. Kcals	Time	0.94	0.55	0.99	0.0051
Met. Pred. Kcals	Average Speed	-0.86	-0.15	-0.15	0.0296
Met. Pred. Kcals	Effort	0.94	0.55	0.99	0.0050

The male golfers alone (Table 11) had fewer variables correlated to each other. Effort was positively correlated with time (p=0.0078). Average heart rate had a negative correlation with score (p=0.0194). Effort was significantly correlated with two variables. Effort was positively correlated with time (p=<0.0001) and negatively correlated with average speed (p=0.0079). The male golfers had a positive correlation between calories/hour and Garmin kcals (p=0.0118). In regards to the metabolic-cart predicted kcals, there was a negative correlation with average heart rate (p=0.0331) and a negative correlation with calories/hour (p=0.0258).

Table 11. *Male Subjects Correlation Matrix for Both Rounds.*

Variable	By Variable	Correlation	Lower 95%	Upper 95%	Signif. Prob.
Average Speed (mph)	Time	-0.93	-0.99	-0.47	0.0078
Effort	Time	0.99	0.98	0.99	<0.0001
Effort	Average Speed	-0.93	-0.99	-0.46	0.0079
Cal/Hour	Garmin Kcals	0.91	0.38	0.99	0.0118
Met. Pred. Kcals	Average HR	-0.85	-0.98	-0.12	0.0331
Met. Pred. Kcals	Cal/Hour	-0.87	-0.99	-0.18	0.0258

Using stepwise multiple regression to account, we investigated what measured variables accounted for either the Garmin-predicted kcals expended or the MET-cart heart rate to kcal regression equation predicted kcals reported for the tournament play while adjusted for these covariant relationships. Looking at the Garmin kcals for all golfers during both round 1 and round 2, the stepwise regression showed that the only variables affecting the Garmin kcals measured were calories/hour (p=0.00) and time (p=0.00) when accounting for variable covariance; together these variables produced an r-squared of 0.99. When separating the golfers by gender, it was found that for the female impact r-squared=0.99. The male golfers showed that only calories/hour had a large effect on Garmin kcals (r-squared=0.99, p=0.00). Looking at the metabolic-cart predicated kcals for all golfers during both rounds, score was the only significant variable (r-squared=0.66, p=0.03) when adjusting for co-variances across all variables. Taking a closer look at how metabolic-cart predicted kcals and score are related for all golfers during both rounds, a regression plot was performed indicating that when covariance was not accounted for, score significantly related to the metabolic-cart predicted kcals (r-squared=0.59, p=0.0013). Separating this data by gender, it was found that the male golfers had a significant correlation between score and metabolic-cart predicted kcals (r-squared=0.78, p=0.0035). However, the female golfers did not have significance relationship (r-squared=0.16, p=0.43). Taking a closer look at the relationship between distance and metabolic-cart predicted kcals for all golfers during both rounds, it was found that there was not a statistically significant correlation (r-squared=0.13, p=0.19).

4. Discussion

4.1. Phase 1

This study's purpose was to determine the amount of energy that was expended for collegiate golfers in a competitive setting and what factors had the most influence while using the wearable device the Garmin VivoactiveHR™. Wearable technology analyzes

physiological responses and body movement throughout physical activity in an attempt to estimate how much energy is expended [10]. For this study, the Garmin VivoactiveHR™ was used in both a controlled environment (the lab) under controlled conditions (6MW with and without the golf bag weight simulation) and during golf play to determine each golfer's physiological responses in context to the lab testing and tournament play.

Recently, in a study by Murakami et al. (2016), the authors determined the total EE of 19 men and women (ages 21-50) in both a controlled setting (whole body metabolic chamber with daily living simulation tasks) and for 15 days in a free-living environment using doubly labeled water. During the metabolic chamber testing and the free-living measurements, each subject also wore 12 different activity tracking devices at the same time. Murakami et al. (2016), found that in the in-lab experiment within the metabolic chamber, energy expenditure was significantly lower than the kcals determined in the true free-living environment using the doubly labeled water technique. Therefore, the study indicates that EE in the metabolic chamber was lower in these golfers compared to their respective free-living conditions possibly because of differences in the subjects' natural ambulatory patterns that were altered in the lab setting. For example, the golfers had 221 kcals higher EE in the free-living portion of the study. These 221 kcals represented approximately two more miles of movement that did not occur under the chamber conditions, which is equal to approximately 4,000 additional daily steps. How well the various activity trackers picked up and reported these changes varied across each of the twelve devices. When measurements are made in the chamber, the lowest estimated EE was 1,814.8 kcals (± 230.3 kcals) and the greatest EE was 2,297.5 kcals (± 345.5 kcals). The devices for the metabolic chamber averaged an EE of 2,245.02 kcals (± 298.18 kcals). This is compared to the gold-standard metabolic chamber of 2,093 kcals, an overestimation of 152.02 kcals.

Our research indicates during the in-lab 6MW tests, the Garmin VivoactiveHR™ significantly overestimated caloric expenditure compared to the gold-standard metabolic-cart measured kcals for all golfers with and without the bag by 22.4% ($p=0.01$). The golfers with the bag recorded a Garmin kcal expenditure of 67 kcals, whereas the metabolic-cart measured kcals were 59 kcals. When the golfers performed the same test except without the bag, the Garmin recorded an estimated EE of 75 kcals but the metabolic-cart measured kcals were only 57, showing that in the controlled environment used in our study, the activity tracking device overestimated EE compared to the gold-standard metabolic cart by an average of 13 kcals. While this deficit is smaller than that of the previous studies due to a smaller subject group and shorter duration exercise, inaccurate estimations of EE were observed from the activity devices in both experiments. These results highlight the potential for real-world EE tracking at rest, light, moderate, and moderately hard activity levels to be inaccurate for a given individual or group of individuals.

In order to better understand the results, the data was separated by gender for the in-lab tests. According to the gold-standard metabolic cart, the female golfers exhibited a decrease in all variables when performing the 6MW test without the bag compared to with the bag. The decrease in mean VO_2, mean heart rate, mean ventilation, and metabolic-cart kcals without the bag indicates that the female golfers were working harder physiologically with the bag. During the 6MW with the bag, the female golfers' activity trackers estimated kcal expenditure at 63.5 ± 19.7 kcals, an overestimation of 12.4% compared to the metabolic-cart measured kcals (56.5 ± 5.4 kcals). The overestimation of the Garmin without the bag was even greater at 18.2%. The Garmin estimated EE at 61.8 ± 24.6 kcals; however, the metabolic cart calculated only 52.3 ± 8.1 kcals, a difference of 9.5 kcals. The Garmin kcals estimated from the 6MW test with the bag was greater than without the bag, following the same trend as the physiological variables indicating that the female golfers were experiencing greater metabolic strain with the bag. Unfortunately, there was no statistical significance due to a small subject number.

In stark contrast, the male golfers did not experience the same physiological responses as the female golfers. The males' mean VO_2 values remained constant from the 6MW test with the bag and without the bag. As for mean heart rate, mean ventilation, and metabolic-cart measured kcals, the values increased. During the 6MW test with the bag, the Garmin estimated kcal expenditure of 71.0 ± 16.6 kcals when the metabolic-cart measured kcals were actually 56.6 ± 5.4 kcals. The Garmin kcals during the without-bag test was estimated at 88.8 ± 21.8 kcals; however, the metabolic-cart measured kcals was only 61.0 ± 4.6 kcals. The male golfers increased their speed by 6.8% when walking without the bag, causing higher heart rates and higher ventilations (6.1%). Consequently, this resulted in the Garmin overestimating male golfers' caloric expenditure by 23.9% ($p=0.02$) when in fact there was no change measured by the metabolic cart. However, because male golfers dramatically increased their walking pace during the without-bag trial resulting in high heart rates, the combined effect of these changes increased the Garmin-estimated kcals.

To gain a better understanding for these observed differences during the in-lab tests, a stepwise regression was used to establish the variables that affected the Garmin kcal estimation during both conditions combined. It was found that the variable that has the largest effect on Garmin kcal estimations was heart rate for both conditions. This was also true for the 6MW with the bag and without the bag. Other variables that affected the Garmin kcals on a smaller level were body weight, steps/6 minutes, mph, and distance. These findings help explain the responses in Garmin kcal expenditure for all golfers during both conditions. As the females' mean heart rates decreased from the with-bag test to the without-bag test, their Garmin kcal expenditure decreased, as well as for the male golfers, as their mean heart rate increased from the with-bag test to the without-bag test, their Garmin kcal expenditure increased. This follows

previous findings from a study by Sell, Abt, and Lephart (2008). In their study, they tested one male subject (43 years old) who performed three rounds of golf using different modes of play. The subject performed one round while walking and carrying clubs, one while walking with a caddy, and one while riding a cart. During all three rounds, the subject was connected to a portable metabolic system, a heart monitor, and a monitor to track distance travelled. The study found that when walking with the golf bag compared to walking without the golf bag there was an increase in heart rate response [14]. With the increase in heart rate, an increase in kcal expenditure was also observed. Just as this study found an increase in energy expenditure with an increase in heart rate response, the female golfers in our study experienced the same response. Even though the male golfers in our study did not experience the same response, the same correlation was linked between heart rate response EE.

4.2. Phase 2

The competitive golf tournament was performed in order to find information regarding the EE and metabolic demand of the sport for collegiate athletes. The in-lab tests performed prior to the golf rounds were used to establish a basis of the aerobic fitness of the golfers in our study, as well as serving as supplemental information to describe the responses observed in the golf tournament. The Garmin kcal expenditure collected on the course was compared to the gold-standard metabolic-cart predicted kcal equations.

Even though all eight golfers played the same course from the same tee markers (white tee markers: 6,480 yards), they exhibited varying results for the variables. In this study, the subjects' VO_{2max} was established during the in-lab testing prior to the golfing to determine the aerobic fitness level of the golfers. Our results showed that the male golfers were more aerobically fit than the female golfers (males: 51.7 ± 3.8 mL • kg-1• min^{-1} [85th percentile]; females: 39.7 ± 6.2 mL • kg-1• min^{-1} [60th percentile]). The male golfers also proved more aerobically fit due to having lower average heart rates (111.0 ± 4.31 bpm) than the female golfers (121.99 ± 15.26 bpm).

Overall, the male golfers recorded lower scores than the female golfers (males: 76.8 ± 4.65 strokes; females: 87.5 ± 6.43 strokes). The difference in distance travelled varied by golfer depending on the location of their golf shots, consequently affecting their total score. Due to the fact that the female golfers had a greater distance than the male golfers (females: 7.49 ± 0.27 miles; males: 7.37 ± 0.18 miles), the female golfers also took longer to complete their rounds (females: 282:42 ± 37:16 minutes; males: 266:05 ± 11:10 minutes). The decreased time to complete the rounds the males experienced can also be explained by the fact that they had a faster average speed than the female golfers (males: 1.68 ± 0.09 mph; females: 1.61 ± 0.16 mph). As found in the research study previously described by Sell, Abt, and Lephart (2008), walking and carrying a golf bag increased the amount of distance walked on the course compared to other modes of play such as utilizing a caddy. According to NCAA regulations, collegiate golfers are not allowed to use a caddy in NCAA tournament play and therefore they travel a longer distance dependent upon the course and playing ability.

Even though the male golfers recorded a greater calories/hour value than the female golfers, the female golfers experienced greater overall tournament Garmin kcals (females: 1642.33 ± 442.98 kcals; males: 1583.13 ± 145.80 kcals). This is due to the fact that the female golfers took a longer time to complete the rounds of golf, travelled a greater distance, and had a higher average heart rate during the rounds. Not only did the extended amount of time on the course increase the females' caloric expenditure, but the increased heart rate increased it as well. As seen from the stepwise regression for the in-lab 6MW, it was established that the variable that affects the Garmin kcal expenditure the most was the Garmin heart rate response, thereby, increasing their total kcal expenditure despite having lower calories/hour values.

Examining the Garmin kcals during the golf tournament testing in greater detail, these values were compared with the gold-standard metabolic-cart predicted kcals. It was found that the Garmin VivoactiveHR™ overestimated the caloric expenditure compared to the metabolic-cart predicated kcals by only 1.0% for all golfers. Separating the golfers by gender, the metabolic-cart predicted kcals were 1,978 for females when the Garmin VivoactiveHR™ estimated 1,834.7 kcals; therefore, during round 1 the Garmin actually underestimated kcal expenditure by 7.2%. Even though the deficit was smaller during round 2 for the female golfers, the Garmin underestimated kcal expenditure by 4.9% compared to the metabolic-cart predicted kcal expenditure. This data is not what we observed during the in-lab testing for the female golfers. As discussed, the Garmin VivoactiveHR™ overestimated kcal expenditure during the in-lab portion. Following the research previously discussed by Murakami et al. (2016), their study found that during the out-of-lab, free-living testing they conducted the golfers had a low estimated EE of 1724.2 kcals (± 229.7 kcals), whereas the highest was an EE of 2245.2 kcals (±359.5 kcals). The EE of the 12 devices during the free living averaged 2009.25 kcals (±319.02). Compared to the gold standard, this is an underestimation of 305.15 kcals. Most importantly, all 12 devices underestimated caloric expenditure compared to the gold standard. This coincides with the results found in our research because for the female golfers' in-lab testing, even though the Garmin VivoactiveHR™ overestimated EE, both studies found that during the in-field testing the activity tracking devices in fact underestimated kcal expenditure compared to gold standards.

The male golfers had they opposite response for Garmin VivoactiveHR™-estimated kcal expenditure during the golf tournament testing. For round 1, the males' metabolic-cart predicted kcals was 1,472.19 ± 282.61 and the Garmin VivoactiveHR™ estimated a kcal expenditure of 1,525.0 ± 150.8 kcals, meaning the activity tracking device overestimated the gold-standard by only 3.5%. The Garmin

VivoactiveHR™ also overestimated the male golfers' second round by 7.1% compared to the metabolic-cart predicted kcals. The trend observed during the golf tournament testing follows what was observed during our in-lab testing for the male golfers. Following the findings of our in-lab testing, the males' results match those found during the 6MW tests' stepwise regression. It was found that the three most important variables affecting Garmin VivoactiveHR™ kcals were Garmin heart rate, body weight, and mph. The male golfers during the golf tournament averaged an effort Trimp score of 133.15, indicating a variance in Garmin VivoactiveHR™ which may have skewed the kcal expenditure data, causing an overestimation. The male golfers also had a greater body weights and a faster average speed than the female golfers leading to the difference in responses for the genders. With the increase in these variables for the male golfers, they could have led to the overestimation of kcal expenditure compared to the metabolic-cart predicted kcals. This overestimation follows the same trend found during the in-lab testing.

In order to better understand the results of the golf tournament testing kcal expenditure data, a stepwise regression was conducted. For both genders during both rounds, the stepwise regression showed that the variables that affect Garmin VivoactiveHR™-estimated kcals were calories/hour and time. This is unlike what the stepwise regression found for the in-lab results. Due to what results were found on the course, and the amount of time increases on the course, the amount of kcals expended will increase.

5. Practical Application

The information gained from this study can positively influence coaches, golfers, and other sport specialists. The knowledge of EE during competitive rounds of golf will help to better prepare golfers for their season through strength and conditioning, practice regimens, and nutrition. Therefore, both the players and the coaches can optimize playing performance through improved training and preparation.

6. Conclusion

In conclusion, during the in-lab tests, the Garmin VivoactiveHR™ overestimated the caloric expenditure. As for the golf tournament tests, the activity tracker overestimated the male golfers' kcal expenditure but underestimated the female golfers' caloric expenditure, showing that there is an inaccuracy in wearable activity tracking devices. The results showed that the main variable affecting the estimation of the kcals was heart rate, leading to the belief that the wearable device does not accurately collect heart rate during activity. Our findings were supported by a statement by Albinali, Intille, Haskell, and Rosenberger (2010), who stated there is an inaccuracy in wearable devices depending on the individual's size, fitness status, as well as placement of the device on the wrist. Therefore, for collegiate golfers who would like to establish the EE and metabolic cost of their sport, it is suggested that using a wearable device is not an accurate way to do so. For future studies, it is suggested that the researchers do not enter the golfer's golf bag weight into the tracking device, rather the study should allow the device to estimate kcal expenditure by accounting for the added load. It is also suggested that more research should be studied in regards to the multiple regression equations and the degree of account the variables have on kcal expenditure.

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