PHYSIOLOGICAL AND PERFORMANCE-RELATED VARIABLES THAT ARE ASSOCIATED WITH FINISH TIME IN OLYMPIC DISTANCE TRIATHLONS

By

Todd Matthew Buckingham

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PUBLIC ABSTRACT

PHYSIOLOGICAL AND PERFORMANCE-RELATED VARIABLES THAT ARE ASSOCIATED WITH FINISH TIME IN OLYMPIC DISTANCE TRIATHLONS

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Triathlon is a growing sport with over 170,000 members – an increase from 15,000 just 20 years ago. Individuals new to triathlon may have difficulty accurately predicting their finish time for a triathlon race. Equations (Schabort et al., Hue) have been developed that predict Olympic distance triathlon finish time based on physical measurements. However, triathletes used in those studies were professionals and studies had low sample sizes, making it uncertain if these findings are applicable to a larger sample of amateur triathletes. An online calculator (QT2) is also available to predict triathlon times, but it has not been validated. Triathletes also utilize wearable technology that allows them to track time, distance, speed, pace, heart rate, power output, and many other variables. This technology could allow individuals to obtain measurements (e.g., stride length, cycling cadence) during an actual triathlon race and determine which are most important for faster finish times in each discipline (i.e., swim, cycle, and run), and overall finish time. Thus, the purpose of this dissertation was to determine the physical and wearable technology measurements that are most important for success in an Olympic distance triathlon for amateur triathletes; specific aims were to: (1) examine how well the scientific equations and online calculator predicted actual finish time of an Olympic distance triathlon for amateur triathletes and; (2) determine which wearable technology measurements are related to faster finish times in each of the disciplines, and overall finish time, during an Olympic distance triathlon for amateur triathletes. **METHODS:** Two sets of methods were used to answer the aims and different participants were used for each aim. However, all participants were amateur triathletes who completed an Olympic distance triathlon. To address aim one, participants completed six exercise tests that involved swimming, cycling, and running, and all tests were performed on separate days. Three of the exercise tests (peak treadmill speed, 4 W/kg cycle, 30-minute cycle/20-minute run) were used in the scientific equations. For these, participants visited the laboratory at Michigan State University or Eastern Michigan University on three separate occasions. Blood lactate was measured for each test. The remaining three exercise tests, which participants completed on their own (400-yard swim, 20-minute cycle, 5km run), were used in the online calculator. These physical measurements were examined for a relationship with the finishing time of an Olympic distance triathlon. To address aim two, participants were recruited via social media and email and completed an online survey which asked about their participation in triathlon. At the end of the survey, each participant uploaded data from his/her wearable technology from a recent Olympic distance triathlon race. This allowed researchers to analyze the measurements – one for each discipline: SWOLF (swim), cycling cadence (cycle), and running stride length (run). These wearable technology measurements were examined for a relationship with the finishing times of an Olympic distance triathlon. **RESULTS:** The first study showed that the online calculator and one of the scientific equations (Hue) predicted overall finishing time very well. The other scientific equation (Schabort) only moderately predicted overall finishing time. The second study showed that the wearable technology measurements for the swim (SWOLF) and run (stride length) were very strongly related to the time taken to complete their individual discipline. Cycling cadence was related to cycle time, but only moderately. Running stride length showed the closest relationship to overall finish time of the three wearable technology measurements. **DISCUSSION:** The studies indicate that the online calculator is simple and easy to use, which may make it preferable over the scientific equations for amateur triathletes. Additionally, running stride length was the most important wearable technology measurement for overall triathlon finishing time. Because of this, triathletes might want to spend more time training for the run to see the biggest improvements in race time.

ABSTRACT

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Triathlon is a growing sport with over 170,000 members – an increase from 15,000 just 20 years ago. Individuals new to triathlon may have difficulty accurately predicting their finish time for a race. Equations (Schabort et al., Hue) have been developed that predict Olympic distance triathlon finish time based on physiological measurements. However, triathletes included in those studies were elite level, and the sample size for the studies was 10 or fewer, making it uncertain if these findings are relevant to a larger sample of amateur triathletes. An online calculator (QT2) is also available to predict triathlon times, but it has not been validated in an independent sample. Many variables could be associated with success in triathlon, and some of them are included in the existing prediction equations. Other variables, such as those captured by wearable technology (e.g., SWOLF), have not adequately been explained in terms of their association with triathlon performance. Thus, the purpose of this dissertation was to determine the physiological and performance-related variables that are associated with faster finish times in an Olympic distance triathlon for amateur triathletes; specific aims were to: (1) assess the criterion and convergent validity of two scientific equations and the QT2 in predicting actual finish time and; (2) determine which multisport watch-measured variables are associated with faster finish times in each discipline and overall finish time. **METHODS:** Two sets of methods were used to answer the aims. All participants were amateur triathletes who completed an Olympic distance triathlon, but different samples were used for each aim. (*AIM 1*)- Participants performed six exercise tests, as close to their race as possible, and all tests were performed on separate days. Three of the exercise tests (peak treadmill speed, 4 W/kg cycle, 30-minute cycle/20-minute run) were used in the scientific equations. For these,

participants visited the laboratory at Michigan State University or Eastern Michigan University. Blood lactate was measured for each test. The remaining three exercise tests, which participants completed on their own (400-yard swim, 20-minute cycle, 5km run), were used in the QT2. Pearson correlations evaluated relationships for criterion and convergent validity. (*AIM 2*)- Participants completed an online survey which asked about their participation in triathlon and uploaded data from his/her multisport watch for an Olympic distance triathlon race. This allowed researchers to analyze the performance-related variables – one for each discipline: SWOLF, cycling cadence, and running stride length. Pearson correlations evaluated relationships between the multisport watch-measured variables and time in each discipline, and overall finish time. A multiple linear regression was performed to determine the contribution of the variables to the total variance explained. **RESULTS:** (*AIM 1*)- Testing was completed by 38 triathletes (20.5 ± 1.8 years, 31.6% female). The QT2 calculator ($r = 0.846$, $p < 0.01$), Hue ($r = 0.832$, $p < 0.01$), and Schabort ($r = 0.359$, $p < 0.05$) were associated with actual finish time. The QT2 calculator and Hue ($r = 0.809$, $p < 0.01$) and Schabort and Hue ($r = 0.329$, $p < 0.05$), were significantly associated with each other. (*AIM 2*)- The survey was completed by 130 triathletes (37.7 ± 10.4 years, 34.6% female). SWOLF ($r = 0.788$, $p < 0.01$), cycling cadence ($r = -0.401$, $p < 0.01$), and running stride length ($r = -0.871$, $p < 0.01$) all showed significant correlations to their respective disciplines. Running stride length showed the strongest correlation to overall finish time ($r = -0.822$, $p < 0.01$) of the three variables. A multiple linear regression determined the performance-related variables significantly predicted overall finish time, $F(5,67) = 32.807$, $p < 0.001$, $R^2 = 0.710$. **DISCUSSION:** (*AIM 1*)- The QT2 calculator involves easily accessible tests, unlike both scientific equations, which require blood lactate testing. Therefore, the QT2 may be preferred by amateurs. (*AIM 2*)- Running stride length was the multisport watch-measured variable that was most closely associated with overall finish time. Triathletes may choose to devote more time training for the run discipline to improve overall finishing time in an Olympic distance triathlon.

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CHAPTER 1: INTRODUCTION

Triathlon

Swim, bike, run. The sport of triathlon is comprised of these three events and in this order. Triathlon is a burgeoning sport, with the first modern event held in 1974 and its popularity growing rapidly since then. There are various distances in which athletes can compete, ranging from 25km to more than 226km combined among the three disciplines. Over 450,000 triathletes are members of the governing body in the United States, USA Triathlon (1), with over 260,000 more competing in events outside of the USA Triathlon sanctioned races (2). The majority of these triathletes are between the ages of 30 and 50 years and compete primarily in sprint or standard-distance races (1,3). Since there is such a wide range of distances in triathlon races, there are likely to be different factors that influence success for different distance races. Also, because it is a young sport, little information exists on correlates of success in triathlon.

Physiological factors in endurance performance

Several physiologic parameters have been identified as being important in attaining high endurance performance. Perhaps the most important are having a high VO_2 max and lactate threshold (LT) and being more efficient (4). Body composition (lean mass) has also been linked to fast finish times for endurance events (5). However, the body composition and morphology of triathletes appears to differ from athletes in single endurance sports since triathletes compete in three individual sports (each with their own optimal anthropometric values) grouped into one (6–8). For example, when compared to Olympic runners and swimmers, elite female triathletes were taller and heavier than runners, but shorter and lighter than swimmers (6). Furthermore, the triathletes appeared to be more mesomorphic and less ectomorphic than the runners and swimmers (6). While triathletes may exhibit an ideal body composition that does not match one of the individual sports that comprise it, in conjunction with VO_2

max (>69 mL/kg/min for men and >61 mL/kg/min for women) (9), LT (65-85% for men and women) (9), and exercise efficiency (163-191 mL/kg/km for men and women) (10,11), body composition is an important factor in attaining high endurance performance.

Predicting triathlon finish time

Even though the previously mentioned variables have been deemed important for performance, researchers have developed equations to predict short-course (i.e., sprint and standard distance) and long-course (i.e., IRONMAN) triathlon performance from other factors (Table 1.1). Factors include physiological variables like swimming and running velocity at maximal lactate steady state (12), lactate at the end of the cycle in a combined cycle-run test (13), and lactate concentration at a given power output on the cycle (14). Other variables that have been used to predict overall triathlon time include peak sustained power output on the cycle (14), peak running speed on the treadmill (14), and personal best times in a previous standalone event (e.g., marathon when predicting Ironman performance) (15,16). Despite the existence of these equations, there is not a single known factor or group of factors known to definitively be responsible for predicting triathlon performance.

Table 1.1. Prediction equations for triathlon performances of various distances.

Author	Participants	Triathlon Distance Predicted	Prediction Equation	Pros	Cons
Van Schuylenbergh[1, 2]	10	Sprint	Predicted triathlon time (min)= 130 - 9.2x (Vmlss-run) (m/s) - 35.6x (Vmlss-swim) (m/s) + 1.4 BLCmlss-run (mmol/L) R^2= 0.98	• Amateur triathletes • Sprint distance • Very strong R^2 value	• Only 10 participants • Requires blood lactate measurements that are not easily accessible for amateur triathletes
Hue [3, 4, 5]	8	Olympic/international/standard	Predicted triathlon time (s) = -1.128 (distance covered during R of C-R in meters) + 38.8 (lactate at the end of C in C-R) + 13,338 R^2= 0.93	• Olympic distance prediction equation • Use of a treadmill test that is easily accessible • Use of a cycle test that is easily accessible • Very strong R^2 value	• Elite level triathletes • Only 8 participants • Requires blood lactate measurements that are not easily accessible for amateur triathletes
Schabort[6]	10	Olympic/international/standard	Predicted triathlon time (s)= -129(peak TM speed km/h) + 122(lactate at 4 W/kg) + 9456 R= 0.90	• Olympic distance prediction equation • Use of a treadmill test that is easily accessible • Use of a cycle test that is easily accessible • Very strong r value	• Elite level triathletes • Only 10 participants • Requires blood lactate measurements that are not easily accessible for amateur triathletes
Rust	53	IRONMAN (for women)	Predicted triathlon time (min) = 186.3 + 1.595 × (personal best time in an Olympic distance triathlon, min) + 1.318 × (personal best time in a marathon, min) R^2= 0.52	• Amateur triathletes • Over 50 participants • Separate equation for men and women • Easy to use variables to enter in the equation • Moderate R^2 value	• Ironman distance prediction only • Not usable for triathletes who have not run a standalone marathon • Not usable for triathletes who have not completed an Olympic distance triathlon
Rust	184	IRONMAN (for men)	Predicted triathlon time = 152.1 + 1.332 × (personal best time in a marathon, minutes) + 1.964 × (personal best time in an Olympic distance triathlon, minutes) R^2= 0.65	• Amateur triathletes • Over 180 participants • Separate equation for men and women • Easy to use variables to enter in the equation • Moderate R^2 value	• Ironman distance prediction only • Not usable for triathletes who have not run a standalone marathon • Not usable for triathletes who have not completed an Olympic distance triathlon

[1]Vlmss= velocity at maximal lactate steady-state
[2]BLCmlss= blood lactate concentration at maximal lactate steady-state
[3]R= run
[4]C-R= combined cycle-run
[5]C= cycle
[6]Power in W/kg is measured on a cycle

It is important to examine these existing equations for several reasons. One reason is because the aforementioned major factors that previous research has shown to influence performance are not included in the equations themselves. Another is that the studies consisted of elite*, national level triathletes (13,14), physical education students (12), or ultra-distance triathletes who make up a relatively small proportion of all triathletes (3,15,16). Additionally, the number of athletes (10 or fewer) included in the short-course studies (i.e., sprint and standard which are the distances at which the majority of triathletes compete), leaves the validity of these equations in question. Both the sample size and study population could pose a problem because they do not lend themselves to generalization for the amateur triathlete. To allow for an accurate prediction of overall triathlon time, it is important that these equations be validated with a greater number of triathletes who are more representative of the average triathlete population (i.e., triathletes with VO_2 max values <69 mL/kg/min for men and <61 mL/kg/min for women), and not only elite triathletes.

In addition to the published studies that have developed equations to predict triathlon performance, there are also various online commercial calculators which exist to predict performance in a wide-range of triathlon race distances. These calculators use different variables to predict triathlon time than the research-developed equations. These variables include time in each of the three disciplines from standalone events (e.g., a 5km run without prior swimming and cycling), course elevation, bike and helmet aerodynamics, and body weight among others (Table 1.2) (17,18). These could be a great tool for amateur triathletes to use as they are easily accessible, and the input variables are relatively easy to obtain. However, these are not grounded with scientific evidence.

* In the United States, "The main distinction between an elite and amateur athlete is that elite athletes have an elite license issued by USA Triathlon which enables them to compete for prize purses of $5,000 or greater at USA Triathlon sanctioned events." – USA Triathlon, Membership Services, Elite Membership

It is important that these equations and calculators are accurate because setting appropriate goals based on the athlete's current fitness levels can prevent injury and optimize race performance. If the athlete sets a goal that is too ambitious, it could lead to injury from overtraining, burnout, or a poor race performance (19,20), while setting a goal that is not challenging enough could leave the athlete falling short of his/her potential.

Table 1.2. Online prediction calculators

QT2 Systems (Predicts sprint through IRON distance triathlons)	**TriDot RaceX** (Predicts IRON distance triathlons only)

• Body weight (lbs)
• 400-yard swim time (mm:ss)
• 20-minute cycle power (W)
• 5km run time (mm:ss)
• Swim training yardage (minimum= 1200 yards)
• Bike training mileage (minimum= 25 miles)
• Run training mileage (minimum= 7 miles)
• Years of experience (number of seasons in which the athlete has raced at the distance being estimated, not including this year)
• Race distance for:
  • Swim (mi)
  • Bike (mi)
  • Run (mi)
• Bike course ascent (ft/mile) [hilly bike course = 60 ft/mile, flat bike course = 10 ft/mile]
• Run course elevation gain per mile (ft/mile)
	• How competitive are you as an athlete (1-10 – 10 is most)
	• Have you previously swum competitively on a swim team (yes/no)
	• How proficient are you in the other three strokes (1-10 – 10 is most)
	• Can you swim a 400 without stopping – even for a short rest
	• Do you feel out of breath when you swim (yes/no)
	• Do you swim well in open water relative to the pool (yes/no)
	• Do you swim slower with a pull buoy than without (yes/no)
	• Do you normally breathe to one or both sides (one/both)
	• Estimated stroke rate (seconds per complete cycle – both arms – between 1.0 and 3.0)
	• Which describes your mindset in the pool (anxious, frustrated, neutral, confident)
	• Bike gear weight (lbs)
	• Bike position (tops, hoods, drops, aero recreational, aero intermediate, aero advanced, aero elite)
	• Helmet type (aero, road)
	• Aerodynamic drag (CdA)
	• Rolling resistance (Crr)
	• Drivetrain loss (%)
	• 400 meter swim time (mm:ss)
	• 20-minute cycle power (W)
	• 5km run time (mm:ss)

While these calculators use a time from a specific distance, one of the scientific equations uses the maximal lactate steady state during a consistent speed swim test of 30 minutes (12). It is clear there is no “one-size-fits-all” method for predicting swim performance in a triathlon. However, there appears to be a common theme among these predictors with a swim between 400 yards and 437 yards, possibly due to the fact that this distance tests both the pure speed aspect and speed endurance (a form of anaerobic training lasting longer than 10 seconds) (21), both of which are needed for an Olympic distance triathlon swim of 1500m.

For the cycle, online calculators typically require the time performed from a previous race or just a 20km or 40km standalone cycle time to predict cycling performance in a triathlon (18,22). The problem with this method is that for athletes new to the sport, they do not have any previous race times to use. Furthermore, cycle time over 20-40km can vary greatly depending on the terrain and weather factors with which the athlete must contend.

Instead of using time for a previous race like the online calculators do, multiple scientific studies have used lactate concentration at different workloads during a cycle test to predict overall triathlon performance [lactate concentration at 4W/kg and lactate concentration at the end of a 30-min cycle and prior to a 20-minute run. (13,14)]. The primary problem with this is that the majority of triathletes do not have access to a lactate analyzer to measure lactate concentration.

Using a functional threshold power (FTP) test that can be performed on the athlete’s indoor cycle trainer to predict the 40km cycle time of a triathlon (23), is another way to predict cycling time without having to rely on a previous race performance or a physiological variable that is difficult for typical individuals to measure like lactate concentration. The TriDot RaceX calculator improves upon this by using the FTP and taking into account other variables such as the bike weight, athlete’s position on the bike, the type of helmet the athlete is using, and the course difficulty (18). The Best Bike Split calculator gives more detailed information, such as the power output the athlete should target throughout the bike course and at different points along the bike course. However, this calculator only gives a prediction of time spent on the bike; it gives no output of swim, run, or overall triathlon performance (24). The cycle is arguably the most difficult of the three disciplines for which to predict performance. There are a variety of factors that can influence cycling performance that include course terrain, bicycle set-up (e.g., wheels, tires, rider position), weather conditions, physiological variables, and performance-related variables (25). Because the cycle portion of the race makes up most of the time (>50%) and distance (>77%), there is a greater likelihood that these factors will play a larger role in performance of this discipline. Because of these factors which are outside the athlete's control, using cycling variables to predict overall race performance may be unwise.

Predicting overall triathlon performance from the final discipline, the run, may be the best predictor of the three disciplines. All of the scientific equations (12–16) that predict triathlon performance use a running variable, and peak running speed has been shown to be an even better predictor of running performance than VO_2 max (26). However, that study also used highly trained runners (i.e., VO_2 max >60 mL/kg/min), ignoring those who trend more toward the norm. This highlights the importance of the run discipline of a triathlon and further shows the importance of validating these equations for the "average" amateur triathlete. It appears as though VO_2 max is the most well-defined characteristic of the elite triathletes. Once the threshold for a high VO_2 max has been reached, LT, exercise efficiency, and body composition separate the elites. However, the range of VO_2 max values can be quite wide in amateur triathletes, and higher VO_2 max values have been shown to be related to faster finish times (27).

Wearable technology

In addition to validating the previously developed equations for standard-distance triathlon performance, of further interest is the development of new wearable technology that triathletes use during racing and training. These devices allow athletes to track time, distance, speed, pace, heart rate, power output, and many other variables. The vast majority (80%) (28) of triathletes own and wear these devices during training and racing. This technology could allow researchers to obtain performance-related variables and physiological measurements during each of the three disciplines of an actual race instead of relying on laboratory testing, thus potentially improving ability to determine factors associated with race time.

One of the leaders in the field of wearable GPS technology, Garmin, has developed a metric for swimming to determine efficiency, called SWOLF (a combination of strokes and time to complete 25 meters in the open water, where a lower score is better.) Because the combination of stroke length and stroke frequency is so individualized in producing a given velocity (29), the SWOLF score allows a comparison to be made between those who have different stroke lengths and frequencies. Therefore, the SWOLF score could potentially predict who will have a faster swim during a triathlon race.

Use of in-race technology to assess performance-related variables is particularly important because determining optimal pedaling cadence and power could lead to a faster cycle time (30). Furthermore, the effect of cycling cadence on the subsequent run has yet to be determined. In the standalone sport of cycling, it appears that the faster professional cyclists tend to ride at higher cadences (31) and that cycling efficiency (measured by VO_2 and heart rate) increases with increasing power outputs (30,32). However, multiple studies have failed to observe a significant effect of cycling cadence on the cycling portion of a triathlon (33,34) or the subsequent 10km or 3km run time, respectively (33,35). While the difference in times may not have been statistically significant, it could be significant in race performances where finishing positions are often determined by less than 20 seconds.

Much like the swim, when observing performance-related variables during the run, the combination of stride length and stride frequency in producing a given velocity is highly variable (36). Garmin claims to have researched many runners of all different levels and says that, in general, more experienced runners have a higher cadence (i.e., greater than 180 steps/minute). Furthermore, in a study comparing world-class runners to national and regional level runners, it was found that the stride length values of the world-class runners were significantly greater than those of the other runners (37).

Even though these performance-related variables have been shown to improve race time in the standalone events of swimming, cycling, and running, respectively, only one study has examined the variables during a triathlon competition and then compared them with performance (38). However, this study only included cycling cadence, stride rate, and stride length as the performance-related variables to compare with performance. The study failed to examine any swimming-related performance-variables (e.g., stroke rate) or pacing during the run portion and found that only stride length had a negative correlation with finish time (i.e., a longer stride length led to a faster finish time in the run portion, and overall race). Furthermore, the study did not examine which performance-related variables are the most important in determining performance in each of the three disciplines individually and overall performance in a triathlon race. Being able to obtain an in-race measurement of which performance-related variables are most important to improving the triathlete's performance, could lead to more efficient training and produce better race results.

Summary

In summary, there are several different issues to consider when examining factors associated with triathlon performance. In the scientific studies that have developed an equation to predict triathlon performance, only three did so for a short-course triathlon (i.e., standard and sprint distance) which is the distance at which the majority of triathletes compete, and 10 or fewer subjects were used. The participants in these studies were elite triathletes, so it is unknown how the equations apply to the amateur triathletes. Additionally, many of the variables involved in the scientific equations (e.g., blood lactate concentration) are difficult for the average individual to measure. The commercial online calculator that predicts triathlon performance has not been verified by scientific research. Finally, we do not know if the online calculator or the scientific equations are better at predicting triathlon performance. By validating these calculators and equations, this will better guide triathletes to using the appropriate method. Thus, the purpose of this dissertation was to determine the physiological and performance-related variables that are associated with faster finish times in an Olympic distance triathlon for amateur triathletes.

Aims

Therefore, the specific aims of this dissertation were to:

1. Assess the criterion and convergent validity of two scientific equations that predict Olympic distance triathlon performance (Hue, Schabort; Table 1.1) and the online calculator (QT2 Systems) in predicting overall finish time of an Olympic distance triathlon.

   Hypothesis 1a (criterion validity): The QT2 Systems calculator prediction time will show a moderate-to-strong ($0.40 \leq r < 0.80$) correlation with actual race time and the following will show a moderate ($0.40 \leq r < 0.60$) correlation with actual race time:

   - Hue equation prediction time
   - Schabort equation prediction time

Hypothesis 1b (convergent validity): There will be a moderate-to-strong ($0.40 \leq r < 0.80$) correlation between the Hue equation prediction time and the Schabort equation prediction time and a moderate ($0.40 \leq r < 0.60$) correlation between the following:

- Hue equation prediction time and QT2 Systems calculator prediction time
- Schabort equation prediction time and QT2 Systems calculator prediction time

2. Determine which multisport watch-measured variables are associated with faster finish times in each the swim, bike, and run disciplines, and overall finish time, during an Olympic distance triathlon for amateur triathletes.

   Hypothesis 2a: There will be a positive correlation between SWOLF and swim time ($r > 0.80$) [i.e., lower SWOLF scores will result in lower (faster) swim times.]

   Hypothesis 2b: There will be a negative correlation between cycling cadence and cycle time ($r < -0.60$) [i.e., faster cycling cadence will result in lower (faster) cycle times.]

   Hypothesis 2c: There will be a negative correlation between stride length and run time ($r < -0.85$) [i.e., longer stride lengths will result in lower (faster) run times.]

   Hypothesis 2d: The multisport watch-measured variable that will be most related to overall triathlon performance will be average stride length during the run portion of the race ($r < -0.80$). [i.e., longer stride length will result in lower (faster) triathlon times.]

CHAPTER 2: REVIEW OF LITERATURE

Introduction: Triathlon

Triathlon is a sport comprised of three different disciplines: swimming, cycling, and running (in that order) and is a new and growing sport with close to three-quarters of a million-people participating each year (1,2). Because it is such a new sport, there is little research about the characteristics that make an athlete successful in a triathlon competition. While there is a multitude of information regarding each of the individual sports (i.e., swimming, cycling, and running), there is little information regarding how performance is affected when combining these sports sequentially. Several studies have observed the relationship between different variables (both physiologic and performance-related) (12–15,33,39–46) and performance, but few have tried to use these variables to predict performance of a triathlon race (12–16). None have tried to predict performance of each individual discipline within the triathlon. Due to the high rate of injury in endurance sports (20,47–49), the chances for burnout (19), and the athlete's desire to perform to the best of his/her ability, it is important that the athlete be able to properly predict his/her finish time for a triathlon. This will help him/her to avoid overtraining, set proper training goal paces, and complete the race to the best of his/her current ability.

One problem with predicting performance of a triathlon is that there are several distances in which athletes compete. The most common distances include: sprint (750m swim, 20km bike, 5km run) (78%), Olympic/standard/international (1500m swim, 40km bike, 10km run) (58%), Half-Ironman (1.2-mile swim, 56-mile bike, 13.1-mile run) (39%), and the full Ironman (2.4-mile swim, 112-mile bike, 26.2-mile run) (3) (17%). With so many different triathlon distances at which athletes can compete, there are likely to be different factors that influence success in each distance. For example, in the sprint and standard distance triathlons, the swim comprises 2.9% of total race distance whereas the in Half- and full Ironman races, it only makes up 1.7% of total race distance. Therefore, predicting performance is likely to be different for each of the triathlon distances.

Within the shorter distance triathlons (sprint and standard distance), there are also draft and non-draft legal races (all half and full iron distance races are non-drafting). Draft legal means that, during the cycling portion of the triathlon, athletes are allowed to cycle behind other athletes and 'draft' off of them, meaning that the individual in the rear position uses the benefit of aerodynamic forces generated by the individual in front (50). For the half and full iron distances races, drafting is not allowed and results in a time penalty for the athletes. Drafting during the cycling portion of a triathlon, as well as during cycling alone, has been shown to significantly reduce energy expenditure, VO_2, heart rate, blood lactate, and expiratory volume during this discipline as well as lead to faster run performances after the bike portion (51–53). Because of the wide range of distances and the drafting or non-drafting style of racing in which athletes can compete, triathlon competitions vary in demands and are complex in nature.

Triathlon is still a young sport, as the first modern event was held in San Diego, California in 1974 (54). The sport of triathlon did not appear in the Olympics until the Sydney games of 2000, with the athletes competing at the standard distance of 1500m swim, 40km bike, and 10km run. Since 1999, participation has more than tripled, and triathlon is one of the most popular endurance sports worldwide (1). The fact that triathlon is such a young and new sport means there are still many emerging factors that are yet to be studied in determining predictors of performance in a triathlon, both in each individual discipline and the overall race itself. This literature review focuses on factors related to triathlon participation, the importance of predicting triathlon finish time, factors associated with endurance performance and finish time, methods for predicting finish time, and technology advances for assessing factors associated with triathlon performance.

Participation in triathlon

In 1999, the membership totals of the United States of America Triathlon (USAT) organization stood at 127,824. By 2005, that number more than doubled to 262,703, and it currently stands at 477,794. This means that almost half a million people participate in a USAT sanctioned race each year. This does not include athletes who participate in races sanctioned by other triathlon organizations (e.g., Ironman, International Triathlon Union) which adds over a quarter of a million more to the total number of triathletes who compete each year (2).

The majority of USA Triathlon members are ages 30-49 years which comprises more than 50% of the overall membership. Members are predominantly men (62.9%), and more than 5% of members are older than 60 years of age, with over 900 who are 80 years or older (1). Furthermore, the average income of USAT members is $126,000 (3), and an average of ~$5,000 is spent during one year of triathlon (55). This shows that people are heavily invested in the sport. Therefore, it is important to set appropriate goals for the overall race and during each segment or discipline of the race itself (i.e., swim, bike, and run). Setting appropriate goals is important because setting a goal that is too ambitious could lead to injury, burnout, or a poor race performance (19,20), while setting a goal that is not challenging enough could leave the athlete falling short of his/her potential. This goal setting starts with being able to predict an accurate finishing time for the race and each discipline within the race based on the athlete's current fitness levels.

Importance of accurately predicting finishing time for each discipline and triathlon overall

Setting appropriate goals

Often, athletes choose inappropriate goals (56,57). One of the problems with choosing a goal time that is inaccurate (whether it is too fast or too slow) is that most training plans are based on the goal finishing time. This means the times, distances, and paces that the athlete is prescribed for each training workout have a specific physiological effect to produce a specific physiological change. However, if the athlete is not at that level of fitness, the workouts will not achieve their intended purpose. For example, if an athlete is currently capable of running a 45-minute 10k (7:15/mile pace), but s/he is participating in a training program that is based on his/her best 10km time of 40 minutes (6:27/mile pace), then during training, s/he will be working at intensities that are too difficult for his/her current fitness. Instead of training the aerobic system during a slow, steady- state run, the athlete may be tapping too much into the glycolytic system, preventing the proper adaptations from occurring. Another problem with setting goals that are too fast is that it causes the athlete to train at faster speeds, higher intensities, longer durations, and greater frequencies; all of which dramatically increase the risk of becoming injured (47,58–60). The higher intensity training can also cause an imbalance of training and recovery sessions which can lead to overtraining, injury, and burnout (19,20).

The existence of three sequential events the athlete has to complete during a triathlon race translates into the fact that performance in each event will be diminished compared with performance in the standalone events themselves. Therefore, it is important that athletes pace themselves properly in order to avoid overly fatiguing. Since the run has been shown to be the most important discipline in predicting triathlon performance (and is the final leg of the race), it is important for triathletes to reach this leg of the race with enough energy to put in a good final effort (12,14,38,39,42,44,45,61). One study has shown that running the first mile of a 5km time trial more than 6% faster than goal race pace considerably reduces performance. In fact, when the runners started too fast, they were unable to even finish the time trial (62). Furthermore, from 1912 to 1997, in 21 of 32 and 25 of the 34 world-record performances at 5km and 10km, respectively, the final kilometer has been the fastest of the race (63). This goes to show that pacing oneself in an endurance event is crucial to set up for the fastest possible finish time. This cannot be done if the athlete sets inaccurate goal times, further demonstrating the need to have accurate predictions for triathlon performance.

Avoiding burnout and injury

Several studies have been conducted around the world, and all report very similar rates of injuries in triathletes. In a 2014 survey of USAT members whose membership had expired, more than 75% of respondents indicated that injury or lack of resources (either time or finances) played a role in their decision not to renew their membership (1). Another study conducted with British triathletes found very similar results: 72% sustained an injury over a 5-year period, regardless of the race distance (20). Furthermore, a German study found that at least one injury was experienced by 75% of respondents since they started triathlon 6.7 ± 4.1 years prior (48). It is clear that injuries are a problem in the sport of triathlon, but why are athletes getting injured? A review of the literature found that some of the main causes of injury are training errors and too much intensive training too soon (19). This further highlights the importance for triathletes to set appropriate goals to ensure they are not pushing themselves too hard too fast. If an athlete is injured, his/her training plan will not have the desired effect because s/he will be unable to train.

Factors influencing endurance performance

VO_2 max

The main goal of an endurance training program is to improve one or more of the following: VO_2 max, lactate threshold, and exercise efficiency/economy. These have been shown to be a few of the most important physiological variables that determine success in endurance sports (4). First, having a high VO_2 max seems to set the "upper limit" of endurance performance (64,65). Costill et al. (1973) found a strong, inverse correlation with VO_2 max and time in a 10-mile run. However, the subjects had a wide range of VO_2 max values (54-82 mL/kg/min) (66). In a group of homogenous subjects, such as elite endurance athletes who have VO_2 max values ranging from 70-85 mL/kg/min for men and 63-77 mL/kg/min for women (4), the relationship between VO_2 max and time disappears (64). These high VO_2

max values are approximately one to two times higher than those seen in the average adult male and female (67) which explains the difference in times between a heterogeneous group of non-elite endurance athletes. However, the majority of endurance events are not raced at an intensity high enough to elicit VO_2 max values (4,64,66). In fact, for events lasting longer than 10-15 minutes for elite endurance athletes, most of the competition is performed from 75%-90% of VO_2 max (64,66). Therefore, the ability of endurance athletes to maintain a high percentage of VO_2 max has a significant impact on endurance performance (66). It appears that once VO_2 max reaches a certain “elite” level (62-65 mL/kg/min for females and 70-73 mL/kg/min for males) (44) other factors such as lactate threshold and exercise economy become more important.

Lactate threshold

According to Farrell et al., the speed at lactate threshold explains the vast majority of the variance in performance of distance running races (68). Coyle et al. also found that in cyclists with similar VO_2 max values, those with a high lactate threshold (81.5% of VO_2 max) performed significantly better (60.8 vs. 29.1 min) than those with a lower lactate threshold (65.8% of VO_2 max) in a test completed at 88% of VO_2 max (69). Furthermore, running economy can differ by 30-40% among individuals (65,68,70) and up to 20% between groups of runners with similar VO_2 max values, even in elite runners whose VO_2 max values average 75 mL/kg/min (71). So, while VO_2 max may be important in determining endurance performance in athletes with differing values, lactate threshold and economy can be quite different and account for more of the variation in performance in athletes with similar VO_2 max values.

Body composition

Body composition has also been tied to fast finish times for endurance events. Although body composition does not play much of a role in swimming, particularly in those events where the triathlete is allowed to wear a wetsuit (72), body composition is extremely important in the cycle and run disciplines of the race. Intuitively, it makes sense that an athlete with a lower body fat percentage would be faster than an athlete of the same weight who has a higher body fat percentage. Scientifically, it has been shown that in the standalone sports of cycling and running, the increased body mass and body fat percentage lead to slower race times. In a review by Swain, researchers found that 10-20% of performance variability among elite cyclists is associated with differences in body mass. In the cycle, air resistance is the variable that is most related to performance at speeds greater than 31 mph (50). While many triathletes will not reach speeds this fast during a race, even at speeds of 18 mph, air resistance accounts for more than 80-90% of the total force acting to slow the athlete (50,73). Having a greater body fat percentage will increase body surface area (74) which allows more resistance for the wind and decreases cycling speed. Adiposity hampers run time because it increases the energy demands of an athlete attempting to keep pace with a runner of equal body mass but lower fat mass (75). In multiple studies, researchers have found that faster runners are lighter and have lower skinfold measurements, regardless of race distance (76,77).

Specifically, in triathletes, slower total race times and run times are related to higher levels of adiposity in elite level Olympic distance triathletes (5). In addition, Schabort et al. found that the bike, run, and overall finish times in a triathlon were significantly related to body composition in elite South African triathletes competing in a standard distance triathlon (14). Even for athletes who do not compete at the elite level, body composition has a high association with race time. In non-elite male IRONMAN triathletes, body mass and percent body fat were negatively related to total race time (41). In another study, it was found that a lower body mass, lower body fat percent (measured by eight skinfolds), and a lower body mass index had a strong, negative relationship with total race time and with time in the running discipline of a triathlon (42). It has also been found that percent body fat was associated with swim, bike, run, and overall finish time in an ultra-triathlon (40). Of all the anthropometric characteristics, body fat has been shown to be the most important predictor variable for half ironman and full ironman distance race performance (78). These studies show that along with the physiological variables of VO_2 max, LT, and exercise efficiency, body composition also plays an important role in triathlon competitions, regardless of the distance.

When comparing triathletes to single sport endurance athletes, triathletes tend to have higher skinfold thickness values compared with distance runners (8). Furthermore, when taking into account height, weight, and body composition, Ironman triathletes showed a physique most closely related to cyclists than swimmers or runners (7). Leake and colleagues found that female triathletes were closer in body composition (measured via hydrostatic weighing) and somatotype to Olympic swimmers than runners (6). Therefore, the body composition of triathletes appears to differ from other athletes in single sports due to the fact that triathletes compete in three individual sports (each with their own optimal anthropometric values) grouped into one.

Prediction equations

Scientific studies

From the physiologic and anthropometric factors discussed previously, scientific studies have observed the relationship they have with triathlon performance (both overall and within each discipline). These observations have been reviewed in depth (79,80), and it is clear that triathletes who exhibit high VO_2 max and lactate threshold values, are more economical (i.e., use less oxygen to perform the same task), and have lower body mass and fat values, are faster than their counterparts who do not exhibit these traits.

Because of these associations with race performance, researchers have tried to predict finish time for a triathlon from the physiological variables as well as other performance-related variables thought to have a significant impact on finish time (within each discipline and overall.) While correlations have been observed among the aforementioned physiological variables, other performance-related variables, and triathlon finish time (in each discipline and overall), only five scientific studies have successfully developed a prediction equation for triathlon finish time (12–16). Two of these equations (15,16) use previous race performances (i.e., Olympic distance triathlon and marathon personal records) and not physiological or performance-related variables to predict time for an Ironman triathlon. Of the three that use physiological variables, two (13,14) predict Olympic distance triathlon time by using peak treadmill speed and blood lactate concentration at a given cycle intensity (14), or distance covered during a run test and lactate concentration at the end of a cycle test (13). The final equation (12) uses the speed at maximal lactate during steady state swim and run exercise and blood lactate concentration during the run test to predict sprint-distance triathlon time.

- **Rust (IRONMAN)**: Predicted race time (men) = 152.1 + 1.332 × (personal best time in a marathon, minutes) + 1.964 × (personal best time in an Olympic distance triathlon, minutes)
- **Rust (IRONMAN)**: Predicted race time (min) = 186.3 + 1.595 × (personal best time in an Olympic distance triathlon, min) + 1.318 × (personal best time in a marathon, min)
- **Schabort (Olympic)**: Predicted race time (s)= -129(peak TM speed km/h) + 122(lactate at 4 W/kg) + 9456
- **Hue (Olympic)**: Predicted triathlon time (s) = -1.128 (distance covered during R of C-R in meters) + 38.8 (lactate at the end of C in C-R) + 13,338
- **Van Schuylenbergh (sprint)**: Predicted triathlon performance (min)= 130-9.2x (Vmlss-run) (m/s) - 35.6x (Vmlss-swim) (m/s) + 1.4 BLCmlss-run (mmol/**L)**

The equations that contain physiological variables (12–14) used 10 (12,14) or fewer (i.e., 8) (13) subjects to develop their respective equations. The subjects for these studies were also homogenous within studies and vastly different between studies. Schabort and Hue used triathletes competing at the national level (South Africa and France, respectively) while Van Schuylenbergh used college physical education students who had been competing in triathlon for as little as one year and competed in as few as three races (12–14). Additionally, there were only two equations that included women in their predictions (14,16) and only one of those was developed for women alone (16). This small sample size could have played a role in the prediction of triathlon time being very strong (r> 0.90 across studies), but with such a small sample size for each study, it is clear that a validation study is needed to verify the findings.

Online calculators

Non-scientific calculators have also been developed to predict time for the standalone events of swimming, cycling, and running as well as overall triathlon time and time in each discipline of the triathlon. These calculators typically require the time for a shortened version of the particular discipline, as well as variables concerning time and/or distance spent training, and course conditions.

For a standalone swim, calculators exist that rely on times for distances shorter or longer than the race distance. The user inputs time for a certain distance and the calculators then convert that time to the distance for which the athlete desires. (81–83)

Calculators exist for cycling races as well. These calculators can be as simple as the swimming prediction calculators; just enter a time and distance and you will receive a range of times for certain distances (22). However, there are much more complex calculators for the bike as well. Since the bike is dependent on so many outside factors (e.g., course terrain, bike and rider aerodynamics, wind speed and direction, etc.) other calculators try to account for this by including variables such as drag coefficients, rolling resistance of the tires, and the athlete's bike and equipment into the equation (24,84). These are quite complex variables to determine, and even the most advanced athlete may not know or have access to determine these values. It is much more difficult to predict time across different cycling distances because of the wide variation in courses, rider efficiency, aerodynamics of bike and equipment, etc.

Run prediction calculators are also available for athletes, and they are similar to the previous calculators described. The athlete enters a recent race time into the calculator, and the calculator predicts times for other distances (85–88). These times are typically based on a “best case scenario” and assume that the athlete is optimally trained in each of the particular race distances. However, because of genetics and fiber type adaptations, most athletes cannot perform optimally in events on opposite ends of the distance spectrum (e.g., marathon vs. 5km).

In addition to calculators designed for the individual events, prediction calculators have also been designed for triathlons. These calculators require the user to input variables from each of the three disciplines (17,18,89). The inputs are very similar to the previous calculators with a few unique aspects that are specific to the sport of triathlon. It is important that triathlon be viewed as its own sport as opposed to three separate sports when predicting times. Because it requires participation of three subsequent sports that combine to make a singular sport, the athlete will not be able to maintain the same pace for each discipline of a triathlon as s/he would in the standalone event itself. However, none of these calculators takes body composition into account and only two (17,18) account for body mass. As with calculators for standalone events, these triathlon calculators are based on a recent time for a certain distance and give the equivalent for a longer or shorter distance, but they have not been validated. These calculators pose more of a problem than the scientific equations because they are more readily accessible to the public through a quick internet search. If these calculators give the user an inaccurate prediction of time, it could lead to the athlete setting inappropriate goals, getting injured, and losing the ability to compete.

The importance of each discipline on overall triathlon performance

In addition to the importance of physiological and anthropometric variables for endurance performance, the importance of each of the disciplines on overall triathlon performance has also been studied.

Swim

When looking at the first discipline of the triathlon, the swim, there have been mixed findings of how it influences overall triathlon finish time. Some studies have found that the swim time was significantly related to overall finish time (45,46,90). However, other studies have shown no significant relationship with swim time and overall finish time (39,61,78). The reason for mixed findings could be due to the fact that the swim makes up such a small proportion of total race time (~10-16% depending on total race distance). Finishing time may not be as important as finishing position in the draft legal events where it is key to come out of the water with a group of athletes and work together on the bike.

There are a few important factors in the standalone event of swimming that may predict triathlon swim time. Because swimming speed is a product of stroke frequency and stroke length, improving one or both of these factors will decrease the time it takes to complete the swim portion of a triathlon. Grimston et al. (1985) found that having longer arms and legs and larger hands and feet are just a few factors that have the potential to increase stroke length and stroke frequency (29). However, there is no "magic" stroke length or frequency for an individual. The combination of these performance-related variables in producing optimal swimming velocity is highly individual (91). Because of this, Garmin (a manufacturer of wearable GPS technology) has developed a performance-related variable called "SWOLF". This variable is a combination of the terms "swimming" and "golf" and is obtained by adding together the number of strokes per pool length and the time it took to swim that length, where a lower score is better. In the open water, the SWOLF score is calculated from the GPS pace and distance and is normalized based on a 25-meter pool (92). A similar technique was used by Costill et al. (93) where swimming velocity was multiplied by distance per stroke to obtain a stroke index (SI). The SI assumes that for a given velocity, the swimmer that travels the greatest distance per stroke is the most efficient. SWOLF is similar to SI in that it assumes faster swimming with fewer strokes will yield a faster, more effective swim. Therefore, it is important for an individual to determine his/her personal best for each of these variables (i.e., stroke frequency, stroke length, and SWOLF score) to achieve the fastest and most efficient swim split possible.

Cycle

There are also mixed findings with the second discipline of the triathlon, the cycle (or bike), with regard to overall triathlon time. One study found no significant relationship between average speed during the bike and position after the bike stage (r= -0.17) or overall finish position (r= 0.31) (45). Another study found no relationship between finish time in the bike split and overall finish time for the top 20 finishers in ITU world championships from 2004-2007 (61). On the other hand, there are studies that have found that the time taken to complete the bike leg plays a significant role in overall finish time of triathlon (14,38–40,46). This could be due to the drafting vs. non-drafting rules of certain races. In drafting races, athletes typically finish the bike portion of the race together so they all have the same finishing time and then separate themselves on the run. In non-drafting races, athletes are not allowed to ride together and often separate themselves during the cycling portion of the triathlon. One study that was conducted on a draft legal race found that the most important determining factor of finishing place was the position of the athlete at the end of the cycle discipline (5). This could mean that finishing position of the cycle discipline, not time, is more important in determining overall performance in a draft legal triathlon.

Certain variables have been shown to play a role in determining performance in the standalone event of cycling and could carry over to performance during the cycle of a triathlon. Perhaps the largest of these variables is air resistance. As previously stated, air resistance is the most performance-determining variable in a cycling event and accounts for about 90% of the total resistance the cyclist encounters (50). Because the force of air resistance increases the faster the athlete cycles, the greater the resistance will be, and the greater amount of power the athlete must supply to travel at that velocity. Therefore, reducing the area where the wind can slow down the athlete becomes extremely important in not only standalone cycling events, but in triathlons as well (25). There are multiple methods to achieving this reduction including an aerodynamic bike frame, aerodynamic wheels, and drafting. Using an aerodynamic frame and a set of aerodynamic wheels can reduce energy expenditure by as much as 7%, respectively and drafting and has been found to reduce air resistance by as much as 39% (94). In turn, this reduces heart rate, VO_2, ventilation, and blood lactate values (51,52) during the cycle portion to potentially allow the triathlete to run faster during the subsequent run phase of the race.

While air resistance is the main non-physiological factor that influences performance in a standalone cycle event or the cycling portion of a triathlon, other cycling metrics appear to be related to the finish time as well. Cycling cadence and power output are two variables that cyclists often use to track their performance. However, there mixed findings when it comes to these variables and the influence they have on finish time. In a group of professional cyclists who competed in three ultra-endurance cycling events (Giro d'Italia, Tour de France, and Vuelta a Espana), riders adopted faster cadences (~90 rpm) during flat and time trial stages than those reported in the majority of lab studies as being the most energetically optimal (32,95–97). The authors stated that this high pedaling frequency will decrease the force required by the muscles with each pedal stroke at a given power output (53).

Another study found that the more skilled the cyclist is, the faster his/her optimum pedal frequency (32).

While the faster professional cyclists tend to ride at faster cadences, when predicting performance in a triathlon from these cycling metrics, it appears that cadence does not play a role in cycle finish time or subsequent running performance. However, a faster cycling cadence (>100 rpm) does lead to an increased ventilation, HR, and lactate accumulation (33,34), while a slower cadence (~75 rpm) appears to increase time to exhaustion in cycling and running (98) when compared to fast (>100 rpm) and normal (~94 rpm) cadences. Furthermore, in the subsequent run after the bike, VO_2 recorded during the run of the slow cadence (60 rpm) cycling trial was significantly higher than during the normal (80 rpm) and fast (100 rpm) sessions (33). The values represented 92.3% of cycle VO_2 max compared with 85.1 and 87.6% for 80 and 100 rpm, respectively.

Potentially even more important than cadence on cycling performance is average power during the cycle portion. As noted when discussing the effect of air resistance on cycling performance, the faster the athlete cycles, the more power s/he must supply in order to travel at the increased speeds. Peak power output (PPO) from a lab test has been shown to be significantly related to the bike split and overall finish time of a triathlon (where PPO is the peak sustained power output of the last exercise intensity completed for 3 minutes) (14). However, no studies have assessed a triathlete's power during an actual triathlon and related it to split or finish time.

Run

For the final discipline of a triathlon, the run, the findings have been much clearer. Time and again, performance in the run has been shown to be one of (if not the most) important factors in triathlon performance (5,12,14,39,44,45,61,78). Furthermore, no studies have showed a non-significant relationship between the run and overall finish time in a triathlon. Saunders and colleagues (2004) reviewed the factors affecting running economy in standalone running events of distances ranging from 800m to the marathon (99). As mentioned previously, running economy is one of the major determinants of endurance performance (4,65), so distinguishing the factors that influence this aspect are important. Performance-related variables such as stride length and stride cadence appear to be among those factors that influence running economy. However, it appears that runners naturally adopt the most efficient stride length and frequency through repeated training. By trying to change an athlete's stride length or cadence, submaximal VO_2 increases curvilinearly (99).

When looking at the performance-related variables during the cycle and swim and their relationship with triathlon performance, only one study has reported the effect of stride length and stride frequency on running velocity. Hausswirth et al. observed the effects of an alternating draft versus a continuous draft on the cycle portion and the role it played on subsequent running performance. The researchers found that stride rate was significantly higher and stride length was significantly shorter during the first kilometer of the alternating draft run compared with the first kilometer of the continuous draft run (51). Because running velocity is a product of stride rate and stride frequency, an increase in one will result in a concurrent decrease in the other and would result in maintenance of velocity. However, in this study, stride length decreased to a greater degree than stride frequency increased which resulted in a slower running velocity in the first kilometer and the overall 5km.

When determining the effect of previous cycling on running, there have been few studies examining this relationship. As mentioned previously, drafting on the cycle has been shown to greatly benefit the subsequent run. The reason is that drafting during the cycle portion of a triathlon yields a lower heart rate, oxygen consumption, expiratory flow, and blood lactate during the bike discipline (51,52). This is important for the run portion of the triathlon because it allows the athlete to run at a higher percentage of his/her heart rate and VO_2 max. In studies that have observed the effect of cycling cadence on subsequent run performance, there was no statistically significant effect on finish time for the subsequent run with each of the three cadences (60 vs. 72 rpm; 80 vs. 84 rpm; 100 vs. 97 rpm. Bernard and Tew, respectively) (33,35). However, there may still be a clinically significant effect in choosing one cadence over another because competitions are often decided by less than one minute. The importance of this is shown in Table 2.1.

Table 2.1. Influence of cadence on subsequent running performance.

Cadence	Tew (10km)	Bernard (3km)	Vercruyssen (time to exhaustion at 85% of maximal TM velocity)
Slow	49:58	10:26	14:54
Preferred	49:09	10:30	10:51
Fast	49:28	10:33	10:24

The cadence a triathlete chooses while cycling and the effect it has on subsequent running performance is important because finish time for the run has been shown to be the most important determinant in finish time of a triathlon, regardless of distance (5,12,14,39,41,44,45,61). By cycling at a cadence that will elicit the fastest possible run time or increase the time to exhaustion when running near maximal velocity, the athlete will be able to finish the run portion of the triathlon faster which is likely to determine how well s/he finishes the race overall.

Technology

In order to measure these performance-related variables during training and racing, the athlete must have some sort of technology to do this. While cycling computers and running watches have been around for several decades, the technology to measure performance during a triathlon is still very much developing. As one of the leaders in the field of wearable GPS technology (100), Garmin released their first multisport watch in 2006. This finally allowed users to seamlessly switch between sports (i.e., swim to bike, bike to run) while also including a transition time with the simple push of a button. Although this technology was able to include a transition between sports, it lacked a swim specific mode and the ability to measure specific performance-related variables (e.g., running cadence). This technology is only a decade old and still evolving, and in 2012, Garmin released a watch designed specifically for triathletes. This watch came with the swim specific mode that automatically tracks distance and strokes, even when swimming indoors. However, it still did not have the ability to measure any running-specific performance-related variables. Finally, in 2014, Garmin released a watch that had the ability to measure performance-related variables across all three disciplines while still assessing the transition from one sport to the next. With the evolution of this technology, triathletes have a plethora of data available to them. However, there may be an over-abundance of information for the athlete to consider. By determining which variables are the most important to performance in the individual disciplines and overall triathlon finish time, triathletes can focus on improving those factors.

Only one study has compared any of these factors with performance during an actual triathlon competition (38). However, this study only compared cycling cadence, stride rate, and stride length with performance, and the authors found that only stride length had a negative correlation with finish time (i.e., a longer stride length led to a faster finish time in the run portion and overall race). Furthermore, the study by Landers et al. failed to examine any swimming-related performance-variables (e.g., stroke rate) or power during the cycling portion. If a triathlete can focus on only a few key variables to improve his/her performance in each discipline and overall, it could lead to more efficient training and produce better race results.

Directions for future research

Validating the equations of the studies that used laboratory tests is important for two reasons. First, to make sure that these are accurate methods of predicting race time for a triathlon. Second, to extend the generalizability of the predictions to a wider range of triathletes. These equations were developed using elite, professional triathletes, but it is unknown if they are applicable to the typical triathlete who makes up the vast majority of those who compete in the sport.

Validating the non-scientific calculators is also extremely important because of the increased opportunity for the non-elite triathletes to access these. These could be a particularly useful tool for triathletes to use since they do not require the extensive lab testing that the others do. The majority of triathletes do not have access to this type of lab testing and it is important that they are able to set appropriate goals based on the tools they have available to them.

In addition to validating the existing equations, it is also important to obtain swim, bike, and run performance-related variables from participants during an actual race and not in a laboratory situation, to see if there is a particular factor, or factors, that lead to a faster finish time for any of the 3 disciplines or for the total race. The performance-related variables of interest include swimming SWOLF; cycling cadence, power, and heart rate; and running stride length, heart rate, and consistent pacing.

Final summary

Hundreds of thousands of people participate in triathlon and invest thousands of dollars into the sport each year. Therefore, it is important to set appropriate goals, so the athletes are able to stay healthy and avoid burnout. There are many factors that influence performance in endurance events and specifically triathlon. VO_2 max, exercise economy, lactate threshold, and body composition are some of the physiological factors that are most highly related to endurance performance. There are also factors within each of the three disciplines of triathlon that play a role in not only that discipline, but the subsequent disciplines of the race as well. In terms of the influence that each discipline has on the overall outcome of a triathlon, there are mixed findings. It appears that swim and bike time may not be as important as the position in which the athlete finishes these disciplines. What is clear is that running performance shows a strong relationship with the overall outcome of the triathlon.

Because of these relationships, researchers have developed equations to predict overall triathlon performance. These equations are primarily based on laboratory assessments which require the athlete to undergo extensive testing (e.g., VO_2 max and blood lactate tests). They also were developed based on sample sizes of 10 or fewer and with either elite or novice triathletes. Most triathletes have been competing for several years, but do not race at the elite or professional level. Nor do they have access to lab testing required to predict triathlon time, so it would not be possible for them to do so based on these studies. There are prediction calculators that exist online, but they are not grounded in scientific research, they do not take body composition into account, and they are based on a recent time for a certain distance and give the equivalent for a longer or shorter distance.

No studies have observed the relationship with performance-related variables in each of the three disciplines and how those may contribute to finish time within each of the disciplines and with the overall triathlon, during an actual race. Only one study (38), has observed how a few performance-related variables (i.e., cycling cadence, stride length, stride frequency) are related to performance in a subsequent run. From the available evidence, it appears that the run is the most important and well-grounded variable in predicting overall finish time in a triathlon. Therefore, it is important to look more closely at the performance-related variables during the run portion of a triathlon to see where improvements can be made for the triathlete.

By validating the scientific equations and online calculators that predict triathlon performance, it will allow triathletes to set more appropriate goals for finishing a triathlon. This will also allow them to target the correct intensity levels in training, so their workouts are accomplishing the desired effect on the specific energy system and thus, improving performance of the athlete. Furthermore, by examining the performance-related variables that are associated with improved triathlon performance, it will allow triathletes to focus on these specific factors during training and the race itself to finish the race and each of the three disciplines as fast as possible.

CHAPTER 3: METHODS

There were two sets of methods used to answer the questions posed in the aims.

In order to answer questions from specific aim 1, the following methods were used:

STUDY 1

Participants

All participants (n= 40) were non-professional, age-group triathletes who were aged 18-30 years. Participants were recruited through social media (e.g., Facebook, Twitter), email, and word-of-mouth. To participate in this portion of this study, participants had been involved in consistent triathlon training for at least six months (defined as swimming, cycling, and running at least 1 day each week) and completed an Olympic distance triathlon during the 2017 triathlon season. Participants were tested as close to their race as possible, either before or after. Participants were excluded if they had any physical limitations (including injuries) that inhibited their ability to perform the tests in the manner intended or if they did not give informed consent. Participants received free BodPod, VO_2 max, and blood lactate tests, and were given a $20 gift card as compensation.

Study Protocol

Participants performed six exercise tests, either before or after their triathlon race, and were asked to maintain their training throughout the study. Participants were also asked to avoid training prior to testing on test days. Athletes completed three tests in the laboratory and the remaining three tests on their own “at home” (Table 3.1), just as they would if they were using the online calculators themselves. All laboratory tests were completed on separate days with the “at home” tests performed on the participant’s own time. The tests were performed in an order that optimized performance in each test and allowed for sufficient recovery between tests. Maximal oxygen uptake was measured using a ParvoMedics TruOne metabolic cart (ParvoMedics TrueOne, Sandy, UT) during only the maximal treadmill test. The analyzer recorded expired oxygen and carbon dioxide through a Hans Rudolph mouthpiece, on a breath-by-breath basis. However, the data were averaged to 20 second time samples. Flow and gas calibration were performed prior to each testing session according to the manufacturer's guidelines. For the cycle tests, athletes used their own cycling shoes and cycle on a home trainer (Racermate CompuTrainer).

The scientific equations of Hue and Schabort from Table 1.1 were tested:

- *Schabort (Olympic)*: **Predicted race time (s)= -129(peak TM speed km/h) + 122(lactate at 4 W/kg) + 9456.**
    - Where power (w/kg) is measured on a cycle.
- *Hue (Olympic)*: **Predicted triathlon time (s) = -1.128 (distance covered during R of C-R in meters) + 38.8 (lactate at the end of C in C-R) + 13,338.**
    - Where R= run, C-R= combined cycle-run, and C= cycle.

The performance-related variables for the online calculator are:

- A 400-yard swim
- A 20-minute cycle FTP test
- A 5km run time trial (TT)

Table 3.1 Order and location of tests participants completed in Study 1

Order of tests	Location of tests	Test details
1. Peak treadmill speed test	Laboratory	Increasing speed run test on the treadmill until volitional exhaustion
2. 20-minute cycle Functional Threshold Power (FTP) test	Off-site	Maximal sustained power output for 20 minutes on an indoor cycle trainer
3. 400-yard swim	Off-site	400-yard maximal swim time-trial
4. Cycling at 4 W/kg	Laboratory	Steady-state cycle at 4 W/kg on an indoor cycle trainer with blood drawn the last 30 seconds to measure blood lactate concentration
5. 5km run	Off-site	5km maximal run time-trial
6. Combined cycle/run test	Laboratory	30-minute maximal cycle test, 1-minute rest/change shoes, and 20-minute maximal run test with blood lactate measured at the end of the 30-minute cycle test

On the first day that participants met with the primary investigator, they completed a questionnaire and had their height, weight, and body composition measured (BodPod). Before completing the questionnaire and having anthropometric measurements taken, participants were informed of the tests they would perform throughout the study, instructed on how to perform the tests, and given a handout that guides them on how to complete each of the tests (APPENDIX G). Participants completed the peak treadmill speed test at the end of the first visit. The “at home” tests were performed on the athlete’s own time in between laboratory visits.

The questionnaire asked about the race in which participants completed (e.g., course elevation), how competent they are in triathlon (e.g., will you be swimming freestyle without stopping? How fast are your transition times?), years of triathlon experience, previous experience in a standalone event (i.e., swimming, cycling, or running), main sport competed in prior to triathlon, triathlons completed and distances of each race, personal records for each discipline and overall, personal records for standalone events in swimming, cycling, and running (e.g., marathon), purpose for competing in triathlons, and time and distance spent training during an average week (total and for each discipline). The answers to most of these questions were used as part of the input for the prediction calculator. Participants completed the questionnaire in one of the laboratory rooms at IM Circle on the campus of MSU or in the Running Science Laboratory at Eastern Michigan University (EMU). The primary investigator and trained graduate and undergraduate level exercise physiology students were on hand to answer any questions the participants had pertaining to the questionnaire.

Height was assessed to the nearest 0.1 cm using a wall-mounted, calibrated Harpenden stadiometer (Holtain Ltd., Crymych, United Kingdom). Body mass was measured to the nearest 0.01 kg using a calibrated electronic scale (COSMED USA, Inc., Concord, CA). Body volume was measured via air displacement plethysmography using the BodPod version 5.4.1 (COSMED USA, Inc., Concord, CA). Using body mass and volume measurements, each participant’s body density was calculated and converted to percent fat using the modified Siri equation. The BodPod system was calibrated with a 50.203-liter cylinder prior to testing and thoracic gas volume was estimated based on estimates developed by the manufacturer (COSMED USA, Inc., Concord, CA). Participants wore spandex clothing and a Lycra cap and will be asked not to eat or exercise for three hours prior to testing.

To assess peak treadmill speed in the equation developed by Schabort, participants performed a standard warm-up for five minutes (women at 6.2 mph, men at 7.5 mph) followed by the incremental running test to exhaustion (14). For the treadmill test, the treadmill was set to 1% to simulate the effects of outdoor running (101,102). The maximal test began at 6.8 mph for women and 8.1 mph for men. The initial speed was maintained for 60 seconds, after which it was increased by 0.6 mph every minute until volitional exhaustion. The athlete's peak treadmill speed was taken as the highest speed s/he was able to maintain for the entire 60-second stage. If s/he was unable to complete the full 60-second stage, peak treadmill speed was determined as a fraction of the final speed added to the speed of the immediately preceding stage's speed they were able to complete (see APPENDIX G for an example).

For the second laboratory visit, blood lactate levels were assessed after the athlete cycled for 5 minutes at 4W/kg. Each athlete started with a 5-minute warm-up at 2 W/kg. Then, athletes completed a 5-minute steady-state ride at 4 W/kg. Immediately upon completing the 5-minute ride at 4W/kg, athletes had blood drawn from their fingertip to determine blood lactate concentrations. If the athletes were unable to complete the entire 5 minutes at 4W/kg, they performed a modified version and cycled at 95% of the average power obtained from the 20-minute FTP test. These percentages correspond to the percentage of maximal power output that the athletes could maintain for the cycle discipline of an Olympic distance triathlon. This is similar to the power output that athletes in the study by Schabort et al. obtained while riding at 4W/kg.

At the third and final laboratory visit, the cycle and run variables in the equation developed by Hue were assessed. All procedures followed the protocol outlined in the study by Hue et al. (13). For this test, participants performed a 30-minute cycle test followed by a 20-minute run test. Athletes were instructed to perform the tests as fast as possible. For the cycle, distance was measured by the indoor cycle trainer (Racermate CompuTrainer). At the end of the 30-min cycling, athletes had 0.7µL blood drawn from their fingertip to measure lactate concentration (Nova Biomedical Lactate Plus Analyzer, Lactate Plus Meter Test Strips) and will then had one minute to change their shoes and begin the treadmill test. This time corresponds to a bike-run transition time in a triathlon. The 20-minute run began at a speed close to the athlete's speed in a classic triathlon. Triathletes were able to adjust their speed throughout the test to optimize performance. The treadmill was set to a slope of 1% to simulate the conditions of running outside (101,102) and distance was measured by the calibrated treadmill.

The performance input variables for the QT2 Systems calculator were previously listed; other input variables are also required and noted below, where the complete list of variables appears:

1. **PERFORMANCE INPUTS**
    - Body weight (lbs)
    - 400-yard pool swim time (without a wetsuit, in mm:ss)
    - 20-minute power wattage (based on a Computrainer ergometer, in watts)
    - 5km run time (in mm:ss)

2. **TRAINING VOLUME INPUTS (determined by taking the average of the athlete's two highest training weeks during the previous 6 weeks leading up to the race being predicted)**
    - Swim training yardage (minimum= 1200 yards)
    - Bike training mileage (minimum= 25 miles)
    - Run training mileage (minimum= 7 miles)
    - Years of experience (number of seasons in which the athlete has raced at the distance being estimated, not including this year)

3. **RACE DISTANCE INPUTS**
    - Swim (miles)
    - Bike (miles)
    - Run (miles)
    - Bike course ascent (ft/mile)
    - Elevation gain per mile
        - Input run course ascent (ft/mile)

For the QT2 Systems calculator, variables from the previously noted questionnaire were used. Also, the athletes completed the 400-yard swim, 20-minute cycle FTP, and 5km run time trial on their own. Instructions given to participants are located in APPENDIX G. They were asked to perform the 400-yard swim and the 20-minute cycle FTP test in between the first and second lab visit, and the 5km run time trial between the second and third lab visit. However, athletes may have performed these tests at different time points based on their schedule. Prior to the 400-yard swim test, athletes were instructed to perform a standardized warm-up and include the following:

- 200 yards of light swimming
- 9 x 50 yards descending 1-3, 4-6, 7-9 with 15 seconds of rest after each 50 yards
- 50 yards of easy swimming
- 100 yards with the first 25 at estimated TT pace and 75 yards easy

Following the warm-up, athletes were allowed a 1-2-minute rest period, and then performed the 400-yard swim time trial as fast as possible. Time was measured to the nearest tenth of a second by other members of the athlete's team or by the athletes themselves.

Athletes performed a 20-minute FTP cycle test which consists of an all-out effort for 20-minutes. Athletes performed a standardized warm-up that consisted of 15 minutes of easy cycling, three one-minute efforts at a high cadence (not high power) followed by one-minute of easy cycling after each effort, five minutes of easy cycling, five minutes of all-out cycling (this is to open up the legs and prep for the 20-minute effort), five minutes of easy cycling, and then the 20-minute FTP test. Athletes were instructed to maintain the highest possible power output for the duration of the 20-minutes and received prompts from the computer software of the indoor trainer (CompuTrainer).

The running test used in the online calculator was a 5km all-out time trial run either on the treadmill or outside. Athletes were instructed to complete the 5km as fast as possible. Each athlete was allowed to control the speed of the treadmill in order to optimize performance. If the athlete used a treadmill for the 5km time trial run, it was set to a slope of 1% to simulate the conditions of running outdoors (101,102) and distance was measured by the treadmill. If the athlete opted to perform the test outside, s/he recorded time and distance with his/her multisport watch. The protocol is outlined in APPENDIX G.

Statistical Analyses

Aim 1

Descriptive statistics were conducted and means and standard deviations (SD) are presented (Table 4.1). All performance times were obtained from the results page of the triathlon that the athlete completed. A sample size determination revealed that 46 participants were necessary for assessment by a bivariate, two-tailed correlation of $r= 0.4$ with $1-\beta$ at 0.8 and $\alpha= 0.05$, to show a statistically significant correlation.

To examine criterion validity, Pearson correlations evaluated the relationship between actual and predicted race time separately for each equation and the calculator (i.e., the QT2 Systems online prediction calculator and actual race performance, the Hue prediction equation and actual race performance, the Schabort prediction equation and actual race performance), with an α set at 0.05. Bland-Altman plots were also used to show agreement between each equation/calculator prediction and the criterion measure.

To examine convergent validity, Pearson correlations evaluated the relationship between the QT2 Systems online prediction calculator and the Schabort prediction equation, the QT2 Systems online prediction calculator and the Hue prediction equation, and the Schabort prediction equation and the Hue prediction equation. Paired sample t-tests were used to test for a difference between finish time of each the three predictions and actual finish time.

All statistical analyses were carried out using SPSS Statistics 24 and all correlations presented in the results were described based on the suggestion by Evans (1996) (103) for the absolute value of r:

- 0.00 – 0.19: “very weak”
- 0.20 – 0.39: “weak”
- 0.40 – 0.59: “moderate”
- 0.60 – 0.79: “strong”
- 0.80 – 1.0: “very strong”

STUDY 2

In order to answer questions from specific aim 2, the following methods were used:

Participants

Participants (n= 130) were non-professional, age-group triathletes who were aged 18 or older, completed an Olympic distance triathlon during the 2016 or 2017 triathlon season, and used a Garmin multisport watch that recorded his/her Olympic distance triathlon race performance. Participants were recruited through social media (e.g., Facebook, Twitter), email, and word-of-mouth, and were not required to visit the laboratory at MSU. Participants were excluded if they did not provide informed consent or were unwilling to provide a file of their Olympic distance triathlon race performance. Participants were not compensated for participating in this study.

Study Protocol

Participants completed a questionnaire (APPENDIX F) using the Qualtrics software that asked about years of triathlon experience, previous experience in a standalone event (i.e., swimming, cycling, or running), main sport competed in prior to triathlon, triathlons completed and distances of each race, personal records for each discipline and overall, personal records for standalone events in swimming, cycling, and running (e.g., marathon), purpose for competing in triathlons, and time and distance spent training during an average week (total and for each discipline). Participants were asked what level of triathlete they classified themselves as [i.e., beginner (just starting out), intermediate (not a beginner, but typically not finishing at the top of your age-group), advanced (elite age-grouper typically finishing in the top 3 in your age-group), or professional (hold an elite license)]. Participants also included a link that contains the file from the Olympic distance triathlon race using their Garmin device. This allowed the researchers to analyze which variables are associated with better performance during the Olympic distance triathlon race in each the swim, bike, and run disciplines, and overall for age-group triathletes. The variables that were extracted from the file were SWOLF, average cycling power, average cycling cadence, average running stride length, and average running cadence. However, the primary variables involved in the analyses were SWOLF, average cycling cadence, and average running stride length. Aside from time taken to complete each discipline and the overall triathlon, all performance-related variables being used are measured by the athlete’s multisport watch. For the swim portion of the triathlon, SWOLF scores were calculated by combining the number of strokes taken and the time it takes to travel 25 meters in the open water. A stroke is counted every time the arm wearing the device completes a full cycle. Cycling cadence is given in revolutions per minute and is counted each time the foot completes a full cycle. Stride length was calculated by taking the distance traveled and dividing by the number of strides a person takes.

Statistical Analyses

A sample size determination revealed that for a multiple linear regression analysis with three independent variables and two covariates, medium effect size (0.15), 1-β at 0.8 and α= 0.05, 77 participants were needed to show a statistically significant association. Effect size is the proportion of variance explained by the variables in the regression equation. According to Cohen, because a medium effect size is "large enough to be visible to the naked eye" (104), it is appropriate to use in this regression analysis. The plan was to recruit n= 84 in case of dropout.

All performance times were obtained from the results page of the Olympic distance triathlon the participant completed. Descriptive statistics were conducted and means and standard deviations (SD) are presented (Table 4.9.) Pearson correlations assessed the relationship between the multisport-watch measured variables and time in each of the three disciplines (i.e., SWOLF and swim time, cycling cadence and cycle time, and stride length and run time.) A multiple linear regression was performed to determine which of the multisport-watch measured variables (i.e., SWOLF, cycling cadence, and stride length) accounted for the highest percentage of variance in overall finish time. Covariates in the analysis were sex and age. All statistical analyses were carried out using SPSS Statistics 24 and all correlations presented in the results were described based on the suggestion by Evans (1996) (103) for the absolute value of r:

- 0.00 – 0.19: "very weak"
- 0.20 – 0.39: "weak"
- 0.40 – 0.59: "moderate"
- 0.60 – 0.79: "strong"
- 0.80 – 1.0: "very strong"

CHAPTER 4: RESULTS

STUDY 1

Participants

Approximately 100 triathletes were contacted to participate in the study. From the 100 contacted, 40 triathletes responded and were recruited for the study, and all made at least one visit to the laboratory at Michigan State University or Eastern Michigan University. Two participants were unable to complete testing due to injury. Therefore, 38 triathletes were included in the analyses (95%). Furthermore, the QT2 Systems online calculator was updated midway through this study. The calculator added the ability to input the run course elevation change (ft/mile) and the ability to input training distance, even if it was under the minimum required by the site for swim (1200 yards), bike (25 miles), and run (7 miles). Data from all 25 triathletes who had completed testing were input into the calculator prior to and after the change. The remaining 13 triathletes' data were only input into the calculator after the change. Participants were 20.5 ± 1.8 years (mean ± SD) and had been competing in triathlon for 2.6 ± 2.1 years. All 38 triathletes completed an Olympic distance triathlon during the 2017 season and completed each of the six tests as close to his/her race as possible, either before (16) or after (22). The fastest a participant was able to complete the testing was two weeks and the longest took nine weeks. Participants did not all complete the same triathlon. However, 22 of the 38 (57.9%) did. Significant differences were observed between men and women for several variables. Full participant characteristics are shown in Table 4.1.

Table 4.1. Characteristics of 38 amateur triathletes who competed in an Olympic distance triathlon during the 2017 triathlon season

	All participants (n=38)	**Men (n=26)**	**Women (n=12)**	**Participants who completed the 4 W/kg cycle test (n=29)**	**Participants who could not complete the 4 W/kg cycle test (n=9)**
Age (years)	20.5 ± 1.8	20.3 ± 2.0	20.8 ± 1.5	20.4 ± 1.8	20.7 ± 1.9
Body weight (kg)	67.5 ± 8.2	70.6 ± 7.3	61.1 ± 6.2 ##	67.6 ± 8.0	67.4 ± 9.3
Percent fat	15.8 ± 7.8	11.6 ± 3.2	25.0 ± 7.0 ##	13.4 ± 5.3	23.7 ± 9.7*
VO_2 peak (mL/kg/min)	58.5 ± 8.8	63.0 ± 5.4	49.2 ± 6.9 ##	61.1 ± 6.7	50.3 ± 9.7**
400-yard swim (h:mm:ss)	0:05:36 ± 0:01:03	0:05:24 ± 0:01:04	0:06:02 ± 0:00:53	0:05:26 ± 0:01:03	0:06:09 ± 0:00:53
FTP power test (watts)	210.6 ± 55.7	230.2 ± 54.0	167.9 ± 30.2 ##	223.9 ± 54.8	167.7 ± 34.0**
5km run time (h:mm:ss)	0:20:43 ± 0:03:22	0:19:28 ± 0:02:43	0:23:25 ± 0:03:06 ##	0:19:50 ± 0:02:45	0:23:34 ± 0:03:44**
Swim training (yards)	6700 ± 2836	6830.8 ± 2947.6	6416.7 ± 2678.5	6796.6 ± 3125.4	6388.9 ± 1691.5
Cycle training (miles)	48.2 ± 25.7	53.7 ± 26.9	36.3 ± 18.8	52.0 ± 27.2	36.1 ± 16.0*
Run training (miles)	14.9 ± 7.0	16.1 ± 7.6	12.1 ± 4.8	15.7 ± 7.2	12.1 ± 5.9
Years of experience	2.6 ± 2.1	2.8 ± 2.3	2.2 ± 1.7	2.7 ± 2.1	2.1 ± 2.0
Blood lactate cycling at 4 W/kg (mmol/L)	8.6 ± 3.6	9.5 ± 3.5	6.8 ± 3.2 #	9.6 ± 3.5	5.6 ± 1.6**
Actual finish time (h:mm:ss)	2:44:34 ± 0:32:41	2:34:16 ± 0:22:22	3:06:54 ± 0:40:46 ##	2:35:45 ± 0:23:44	3:12:57 ± 0:42:12**

* different from those who could complete the 4 W/kg cycle test at p< 0.05
** different from those who could complete the 4 W/kg cycle test at p< 0.01
# different between men and women at p< 0.05
different between men and women at p< 0.01

Outliers were identified by values more than 1.5 interquartile ranges from the lower or upper quartiles (105). Extreme outliers were also identified as values more than three interquartile ranges from the lower or upper quartiles (105). Although there were outliers for several variables (i.e., percent fat, actual finish time, actual swim time, actual cycle time, actual run time, QT2 predicted swim time, QT2 predicted run time, QT2 predicted finish time, and Hue predicted finish time), these were typically the same one or two participants for each variable, and values were biologically plausible based on the individual athlete's training and capabilities. Based on this, no participants were removed from the descriptive analysis. However, nine participants (23.7%) could not complete the cycle test at 4 W/kg (3 males, 6 females), which has been identified as a submaximal, "race pace" effort for elite triathletes (14,106). In these instances, participants instead cycled at 95% of their 20-minute FTP cycle test value. This percentage is equivalent to a "race pace" effort for the Olympic distance triathlon cycle discipline for amateur triathletes (23). To assess relationships with actual and predicted finish times, analyses were run with and without these participants.

Actual and predicted finish times

Actual race finish times, along with the splits from each discipline of the race, are presented in Table 4.2. Predicted race finish times from the Schabort and Hue equations and the original and updated QT2 Systems Online calculator, along with the predicted times from each discipline from the QT2 Systems online calculator, are also presented in Table 4.2.

Table 4.2. Actual and predicted times for each discipline and overall finish time for amateur triathletes competing in an Olympic distance triathlon

	Actual time	Schabort prediction	Hue prediction	Updated QT2 Systems prediction	Original QT2 Systems prediction
Swim	0:28:35 ± 0:01:24	N/A	N/A	0:23:49 ± 0:04:42	N/A
Cycle	1:19:52 ± 0:14:30	N/A	N/A	1:18:06 ± 0:13:45	N/A
Run	0:51:46 ± 0:53:34	N/A	N/A	0:52:28 ± 0:10:45	N/A
Finish	2:44:34 ± 0:32:41	2:16:37±0:08:33**	2:25:39±0:12:28**	2:37:48±0:26:27*	2:40:55±0:24:32*

*different from actual finish time at $p < 0.05$
**different from actual finish time at $p < 0.01$

Laboratory tests

Participants completed three tests in the laboratory (i.e., peak treadmill speed, combined 30-minute cycle/20-minute run, and five-minute cycle at 4 W/kg). The only laboratory test that was associated with actual swim time was the distance covered in a run of a combined cycle-run test ($r = -0.394$, $p < 0.05$) (Table 4.3). This variable also had the highest correlation with actual cycle time ($r = -0.804$, $p < 0.01$), actual run time ($r = -0.876$, $p < 0.01$), and actual finish time ($r = -0.820$, $p < 0.01$). Peak treadmill run speed was significantly associated with actual cycle, run, and overall finish times, but not actual swim time (Table 4.3). Neither of the laboratory tests in which blood lactate was measured were significantly associated with any of the actual race times (Table 4.3). When participants who could not complete the 4 W/kg cycle test were removed from the analyses, blood lactate after cycling at 4 W/kg still did not show a significant relationship with any of the actual times (swim: $r = 0.044$, $p = 0.821$; cycle: $r = -0.029$, $p = 0.880$; run: $r = 0.116$, $p = 0.550$; finish: $r = 0.054$, $p = 0.781$).

Table 4.3. The relationship between laboratory tests and actual times in each discipline and finish time for amateur triathletes competing in an Olympic distance triathlon

	Actual swim time	Actual cycle time	Actual run time	Actual finish time
Blood lactate after 5 minutes cycling at 4 W/kg (Schabort)	-0.008	-0.226	-0.118	-0.159
Peak treadmill run speed (Schabort)	-0.079	-0.594**	-0.461**	-0.464**
Blood lactate following the cycle of a combined 30-minute cycle/20-minute run (Hue)	0.152	-0.038	-0.002	0.018
Distance covered in run of a combined 30-minute cycle/20-minute run (Hue)	-0.394*	-0.804**	-0.876**	-0.820**

*Significant at p< 0.05
**Significant at p< 0.01

“At home” tests

Participants completed three tests on their own, “at home” (i.e., 400-yard swim, 20-minute cycle FTP, and 5km run). The relationship between “at home” tests and finish time in each of the three disciplines and overall triathlon finish time can be seen in Table 4.4. Not unexpectedly, the 400-yard swim time-trial showed the greatest correlation with actual swim time (r= 0.653, p<0.01) and the 5km run showed the greatest correlation with actual run time (r= 0.839, p< 0.01). On the other hand, the 5km run was more strongly correlated with actual cycle time (r= 0.793, p< 0.01) than the FTP cycle test (r= -0.634, p< 0.01). The “at home” test that was most strongly associated with actual finish time was 5km run time (r= 0.774, p< 0.01).

Table 4.4. The relationship between “at-home” tests and actual times in each discipline and overall finish time for amateur triathletes competing in an Olympic distance triathlon

	Actual swim time	Actual cycle time	Actual run time	Actual finish time
400-yard swim	0.653**	0.222	0.328*	0.375*
FTP cycle	-0.243	-0.634**	-0.470**	-0.547**
5km run	0.368*	0.793**	0.839**	0.774**

*Significant at p< 0.05
**Significant at p< 0.01

Race times

When observing the time it took participants to complete the swim, cycle, and run portions of the actual triathlon race, the discipline that was most closely associated with overall finish time was the time it took participants to complete the cycle portion of the race (r= 0.937, p< 0.01) (Table 4.5).

Table 4.5. The relationship between actual time in each discipline and overall finish time for amateur triathletes competing in an Olympic distance triathlon

	Actual swim time	Actual cycle time	Actual run time	Actual finish time
Actual swim time	1	0.564**	0.581**	0.723**
Actual cycle time	-	1	0.830**	0.937**
Actual run time	-	-	1	0.924**
Actual finish time	-	-	-	1

**Significant at p< 0.01

Aim 1

The primary purpose of this study was to assess the criterion and convergent validity of two scientific equations (Hue, Schabort) and the online calculator (QT2 Systems) that predict overall finish time of an Olympic distance triathlon. Results from these analyses are presented in the following text.

Criterion validity

The QT2 Systems online calculator most closely predicted actual finish time (r= 0.846, p<0.01). The predicted times from the Hue equation also showed a very strong, positive correlation (103) with actual finish time (r= 0.832, p< 0.01). Finally, the predicted times from the Schabort equation showed a weak, positive correlation (103) to actual finish time (r= 0.359, p< 0.05) (Table 4.6 & Figure 4.1).

The data for all 25 participants who had completed testing prior to the QT2 Systems online calculator change were analyzed with both the original and updated calculator. The original version of the calculator had a slightly stronger correlation to actual finish time (r= 0.889, p< 0.01) than the updated calculator (r= 0.846, p< 0.01) (Table 4.6).

Table 4.6. Pearson correlations showing criterion and convergent validity of three prediction equations for an Olympic distance triathlon (n= 38)

	Schabort finish time prediction	**Hue finish time prediction**	**Updated QT2 Systems prediction**	**Original QT2 Systems prediction**	**Actual finish time**
Schabort finish time prediction	1	0.329*	0.202	0.307	0.359*
Hue finish time prediction	-	1	0.809**	0.852**	0.832**
Updated QT2 Systems prediction	-	-	1	0.949**	0.846**
Original QT2 Systems prediction	-	-	-	1	0.889**
Actual finish time	-	-	-	-	1

*Significant at p< 0.05
**Significant at p< 0.01

The mean absolute error (MAE), mean absolute percentage error (MAPE), and root mean square error (RMSE) were calculated to determine the error and accuracy between each prediction equation time and the actual finish time (Table 4.7). As seen in Table 4.7, the QT2 prediction showed the lowest error from actual finish time making it the best predictor of actual finish time for amateur triathletes in the current study.

Table 4.7. Error between each prediction equation time and actual finish time for 38 amateur triathletes who completed an Olympic distance triathlon during the 2017 triathlon season

	Schabort prediction	Hue prediction	QT2 prediction
MAE	0.488	0.357	0.218
MAPE	15.62%	15.45%	8.69%
RMSE	0.687	0.497	0.309

After performing paired-sample t-tests, it was found that all prediction equations significantly underestimated actual finish time. The Schabort prediction (2:16:37 ± 0:08:33) [t(-5.620)= p< 0.01], Hue prediction (2:25:39 ± 0:12:28) [t(-4.990)= p< 0.01], and QT2 prediction (2:37:48 ± 0:26:27) [t(-2.391)= p< 0.05] were all significantly faster than actual finish time (2:44:34 ± 0:32:41) (Table 4.2). Bland-Altman plots were constructed to calculate the bias of each prediction equation with actual finish time. As seen in figures 4.2-4.4, there was excellent agreement between each prediction equation and actual finish time. Only one participant fell outside the limits of agreement (indicated by dashed lines) for each of the prediction equations. It appears the Schabort and Hue prediction equations provide more accurate estimates of actual finish time for faster individuals (i.e., more clustering is found near the mean at the left side, or faster end of the graph) (Figures 4.2 and 4.3). The QT2 also appears to predict actual finish time more accurately for faster individuals, however, it is not as drastic as the Schabort and Hue equations (Figure 4.4).

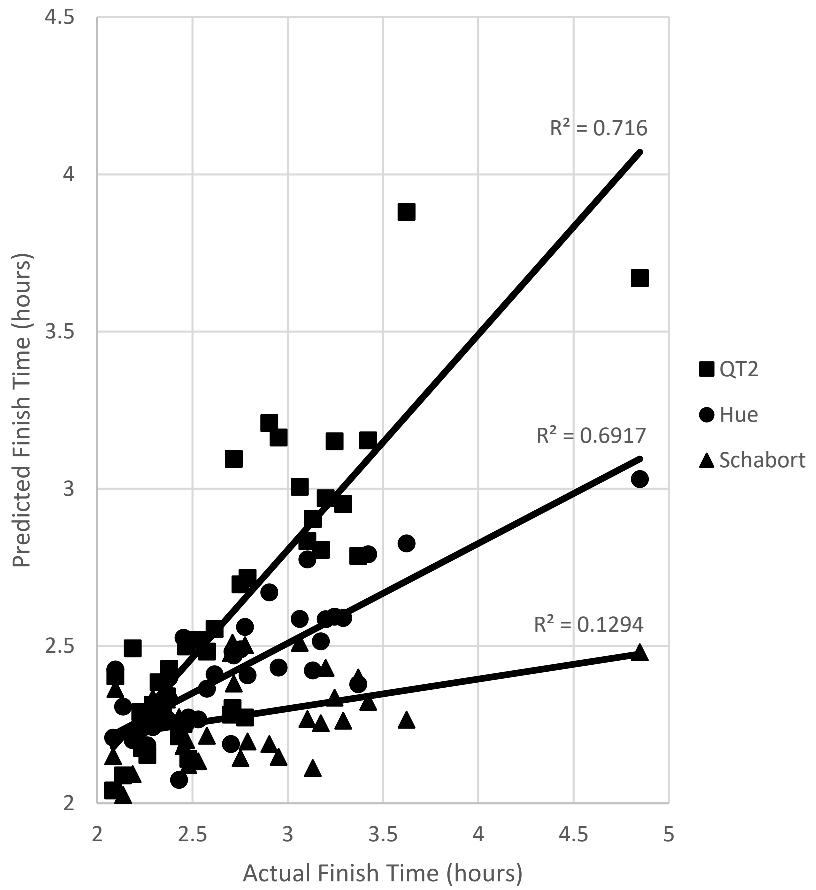

Figure 4.1. Predicted Finish Time vs. Actual Finish

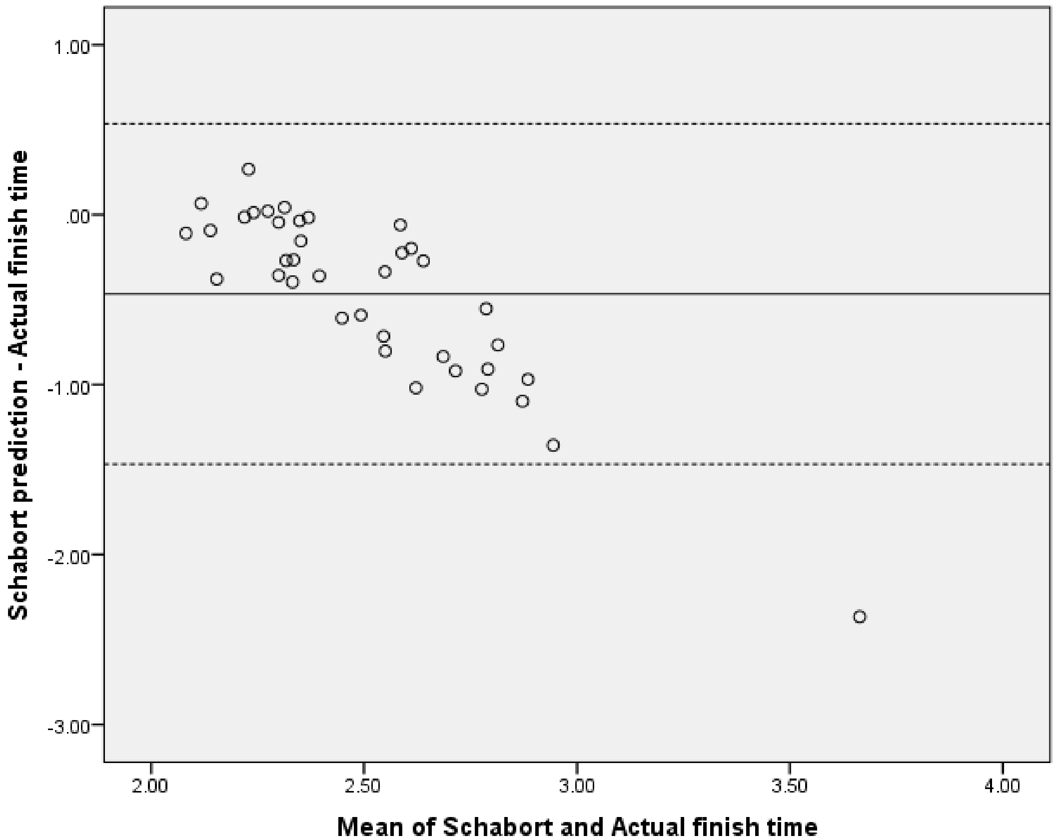

Figure 4.2. Bland-Altman plot comparing the difference of the Schabort prediction equation and actual finish time against the mean of the Schabort prediction equation and actual finish time

Figure 4.3. Bland-Altman plot comparing the difference of the Hue prediction equation and actual finish time against the mean of the Hue prediction equation and actual finish timeFigure 4.2. Bland-Altman plot comparing the difference of the Schabort prediction equation and actual finish time against the mean of the Schabort prediction equation and actual finish time

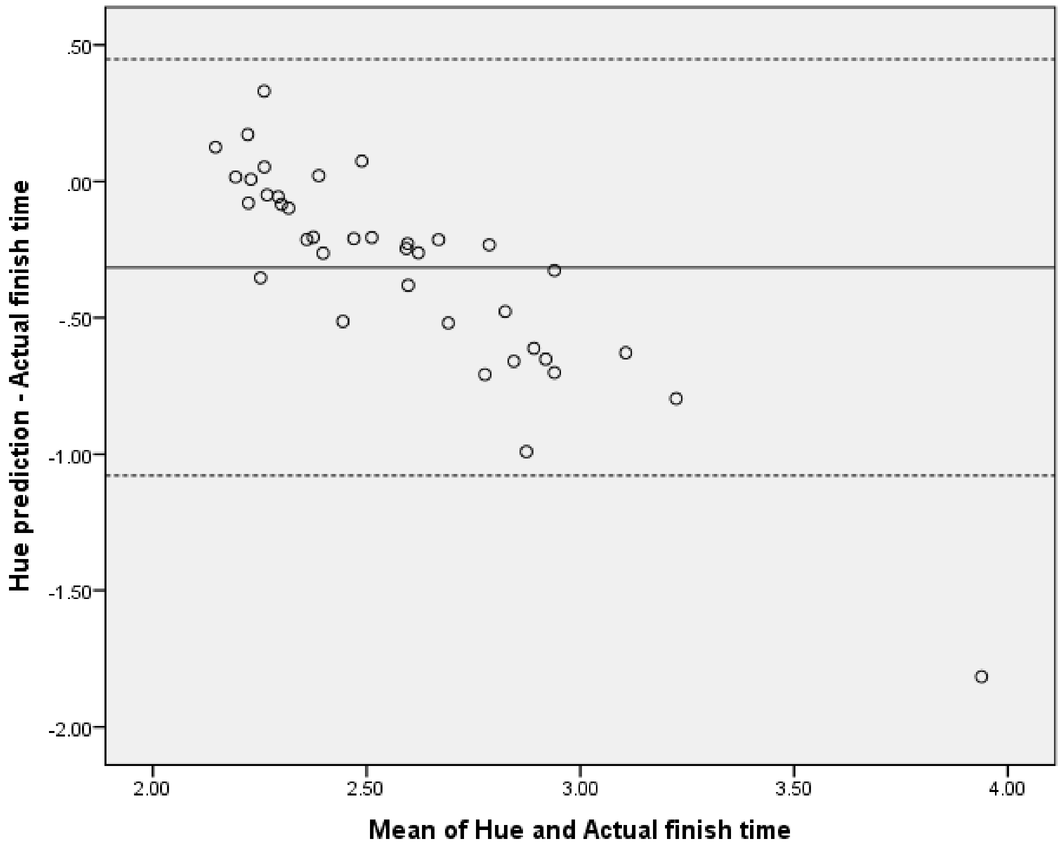

Figure 4.3. Bland-Altman plot comparing the difference of the Hue prediction equation and actual finish time against the mean of the Hue prediction equation and actual finish time

Figure 4.4. Bland-Altman plot comparing the difference of the QT2 Systems online calculator prediction and actual finish time against the mean of the QT2 Systems online calculator prediction and actual finish time**Figure 4.3.** Bland-Altman plot comparing the difference of the Hue prediction equation and actual finish time against the mean of the Hue prediction equation and actual finish time

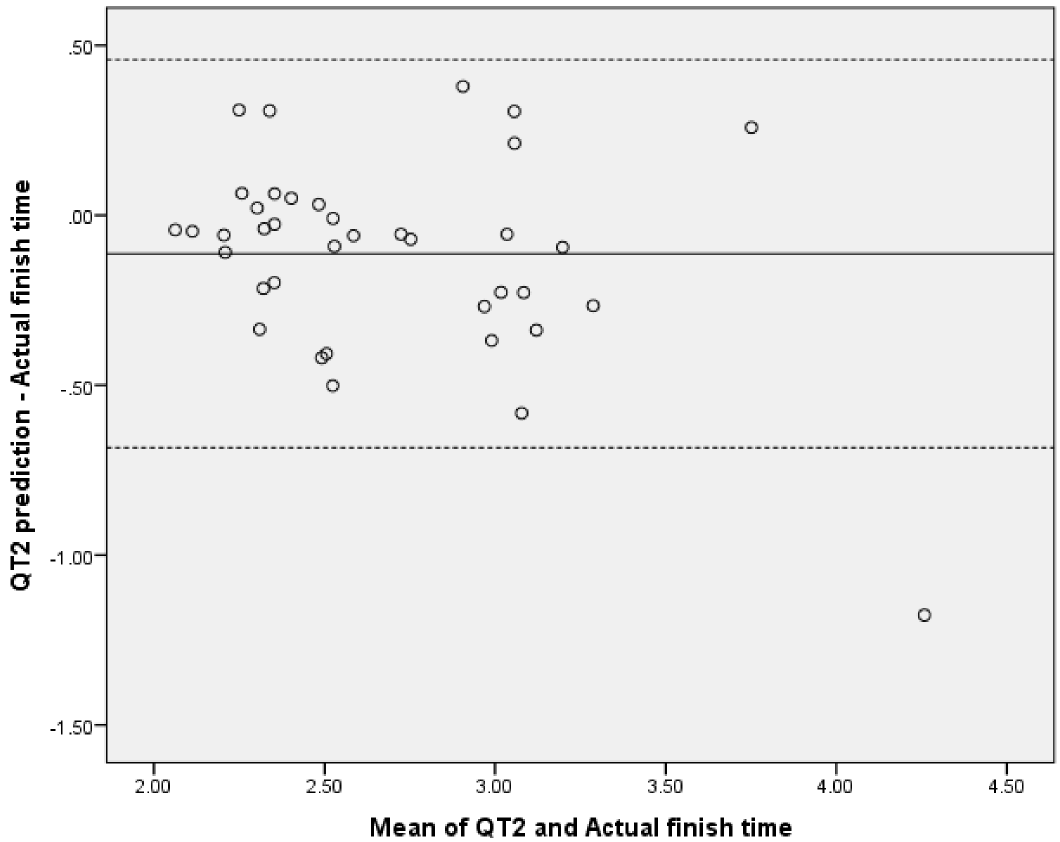

Figure 4.4. Bland-Altman plot comparing the difference of the QT2 Systems online calculator prediction and actual finish time against the mean of the QT2 Systems online calculator prediction and actual finish time

Figure 5.1. Running stride length and cadence as a function of official run time.Figure 4.4. Bland-Altman plot comparing the difference of the QT2 Systems online calculator prediction and actual finish time against the mean of the QT2 Systems online calculator prediction and actual finish time

Convergent validity

The QT2 and Hue (r= 0.809, p< 0.001) and Schabort and Hue (r= 0.329, p< 0.05), were significantly associated with each other (Table 4.8). However, the Schabort was not significantly associated with the QT2 (r= 0.202, p= 0.224). When participants who could not complete the five-minute cycle at 4 W/kg used in the Schabort equation were excluded from analyses, the significance of the relationship between the Schabort equation and the Hue equation disappeared (r= 0.360, p= 0.051) (Table 4.8). All other correlations decreased in strength except the Schabort equation and actual finish time which slightly increased.

Table 4.8. Pearson correlations showing criterion and convergent validity of three prediction equations for an Olympic distance triathlon without participants who modified the 4 W/kg cycle test used in the Schabort equation (n=29)

	Schabort finish time prediction	**Hue finish time prediction**	**QT2 Systems prediction**	**Actual finish time**
Schabort finish time prediction	1	0.351	0.389	0.365
Hue finish time prediction	-	1	0.763**	0.701**
QT2 Systems prediction	-	-	1	0.875**
Actual finish time	-	-	-	1

*Significant at p< 0.05
**Significant at p< 0.01

Post-hoc analyses

Following data collection and statistical analyses, further analyses were made to observe other relationships which the researchers did not initially set out to examine. This was done in order to explain some of the results and compare results of the current study to results of previous studies.

Faster vs. slower triathletes

A median split was performed post-hoc to separate triathletes into two groups (i.e., faster and slower) based on actual finish time. This was done because the two scientific studies in question (i.e., Schabort and Hue) used elite triathletes who are faster than amateurs. (The creator did not specify the population used to create the calculator). A repeated measures ANOVA with a Greenhouse-Geisser correction determined that predicted time was significantly different between faster and slower triathletes ($F(3,75.507) = 22.446$, $p < 0.01$). Post hoc tests using the Bonferroni correction revealed that the mean finish time predicted by the Schabort equation (2:19:34 ± 0:08:06, $p < 0.01$), Hue equation (2:34:06 ± 0:11:29, $p < 0.01$), and QT2 Systems online calculator (2:56:23 ± 0:24:56, $p < 0.05$) were significantly faster than actual finish time (3:08:43 ± 0:29:36) for the slower triathletes in this study, but not faster triathletes ($p = 1.00$ for all combinations of prediction equations and actual finish time). Therefore, we can conclude that the prediction equations more accurately predicted overall finish time for faster triathletes than for slower triathletes.

Laboratory-measured variables

Schabort et al. used a multiple regression to predict overall triathlon finishing time from peak treadmill speed and blood lactate levels after cycling at 4 W/kg for 5 minutes. Therefore, the same analysis was used in the current study. These variables accounted for 21.1% of the variance in overall finishing time when controlling for sex [$F(3,34) = 4.300$, $p < 0.05$].

Hue used a multiple regression to predict overall triathlon finishing time from lactate concentration at the end of cycling in a combined cycle-run and the distance covered in the run of a combined cycle-run. Thus, the same analysis was performed in the current study. These variables accounted for 66.7% of the variance in overall finishing time when controlling for sex [$F(3,34) = 25.697$, $p < 0.01$].

A one-sample t-test was performed to determine if there was a significant difference between the mean peak treadmill speed values in the current study and the Schabort study for both women and men. Mean peak treadmill speeds for women in the current study (15.5 ± 2.0 kph) were significantly lower (mean difference of -2.5 kph, 95% CI [-3.75 to -1.25], $t(11) = -4.413$, $p < 0.01$) than the mean peak treadmill speed values seen in the Schabort study (18.0 ± 0.9 kph). Mean peak treadmill speeds for men in the current study (19.6 ± 2.8 kph) were significantly lower (mean difference of -1.4 kph, 95% CI [-2.48 to -0.22], $t(25) = -2.461$, $p < 0.05$) than the mean peak treadmill speed values seen in the Schabort study (20.9 ± 0.9 kph).

A one-sample t-test was also performed to determine if there was a significant difference between the mean lactate values in the current study and the Schabort study. Mean lactate values in the current study (8.6 ± 3.6 mmol/L) were significantly higher (mean difference of 2.6 mmol/L, 95% CI [1.46 to 3.81], $t(37) = 4.547$, $p < 0.001$) than the mean lactate values seen in the Schabort study (6.0 ± 2.8 mmol/L). This difference was exacerbated when participants who could not complete the entire 5-minute cycle at 4 W/kg were removed from the analysis. Mean lactate values seen in the 29 participants who completed the entire 5-minute cycle test at 4 W/kg (9.6 ± 3.5 mmol/L) were significantly higher (mean difference of 3.6 mmol/L, 95% CI [2.26 to 4.91], $t(28) = 5.543$, $p < 0.001$) than the mean lactate values seen in the Schabort study (6.0 ± 2.8 mmol/L).

The amateur triathletes also covered significantly less distance during the run of the combined cycle-run test than the elite male triathletes in the Hue study. Only the men in the current study were analyzed because the Hue study did not use women. According to a one-sample t-test, the mean distance covered during the run of the combined cycle-run test in the current study (4532.8 ± 563.3m) was significantly less (mean difference of -1779.2m, 95% CI [-2000.76 to -1551.71], $t(25) = -16.105$, $p < 0.001$) than the mean distance covered during the run of the combined cycle-run test in the elite triathletes of the Hue study (6312m).

Field-based tests

The 400-yard swim was moderately correlated to actual swim time ($r = 0.653$, $p < 0.01$) (103). This analysis was also performed using only males who participated in the current study, and the correlation between 400-yard swim and 1500-meter race swim time increased to $r = 0.753$ ($p < 0.01$). When performing this analysis with women, there was no significant relationship between 400-yard swim time and 1500-meter race swim time ($r = 0.348$, $p = 0.268$).

STUDY 2

Participants

Of the 284 participants who started the online survey, 147 were removed due to incomplete surveys, and another 7 were removed because their multisport watch data could not be accessed. Therefore, 130 participants were included in the analyses (51.8%). Outliers were identified as values more than 1.5 interquartile ranges from the lower or upper quartiles (105). Extreme outliers were also identified as values more than three interquartile ranges from the lower or upper quartiles (105). Outliers existed for certain data points. One participant was removed from analyses for each cycling and swimming, and another was removed for his/her cycling and running. One participant competed in an Olympic distance triathlon where the cycle and run disciplines were not actually long enough to qualify as Olympic distance, so his/her data were removed from the cycle and run analyses. Some participants did not provide data for his/her weekly training load, and one participant's weekly training values were highly implausible (e.g., cycling 190,000 miles in a week) and identified as an extreme outlier, so that individual's data were excluded from some analyses. Finally, one participant had an extremely high weekly swim and cycle training distances (e.g., 25,000 yards of swimming). However, this individual had a very heavy training load, so the data were still included in the analyses. Participants were still included in analyses where they had the necessary data, so the total sample remained at 130.

Participants were 37.7 ± 10.4 years, 69.0 ± 3.7 inches tall, and weighed 161.1 ± 31.1 pounds. Male participants made up 65.4% of the sample. In order to obtain measurements on performance-related variables, triathletes provided data from their multisport watches. Because the cycling performance-related variables require an external unit on the triathlete's bicycle, some participants were not able to provide data for cycling cadence and power (Table 4.9). More details about participant characteristics can be found in Table 4.9.

Most participants competed in 3-4 triathlons per year (46.9%) (Table 4.10), and 67 participants (51.5%) had been competing in triathlon for less than 5 years (Table 4.11). The primary sport prior to competing in triathlon for these participants was running (32.3%) (Table 4.12). Finally, more than 50% of participants classified themselves as intermediate level triathletes (Table 4.13).

Table 4.9. Characteristics of 130 amateur triathletes who competed in an Olympic distance triathlon in 2016 or 2017					
	N	**Mean**	**SD**	**Minimum**	**Maximum**
Age	130	37.7	10.4	18.1	62.7
Gender					
Male	85 (65.4%)				
Female	45 (34.6%)				
Height (cm)	130	175.3	9.4	149.9	199.4
Weight (kg)	130	73.1	14.4	47.6	136.1
Weekly training time- swim (minutes)	126	137.0	72.8	30.0	420.0
Weekly training time- cycle (minutes)	129	298.8	123.2	40.0	780.0
Weekly training time- run (minutes)	129	204.7	78.5	45.0	450.0
Weekly training time- strength (minutes)	129	61.7	67.8	0.0	435.0
Weekly distance covered- swim (yards)	125	6441.5	3996.9	1000.0	25000.0
Weekly distance covered- cycle (miles)	126	88.8	42.5	10.0	300.0
Weekly distance covered- run (miles)	127	23.1	10.4	4.0	65.0
Official swim time (minutes)	130	29.6	6.7	16.5	57.4
Official cycle time (minutes)	129	73.7	11.3	52.5	136.4
Official run time (minutes)	130	51.9	12.5	27.8	97.8
Official finish time (minutes)	130	159.4	27.3	111.9	275.5
SWOLF	123	44.15	10.3	20	104
Cycling cadence (rpm)	83	86.4	7.0	67	98
Cycling power (W)	45	210	47.8	133	303
Running cadence (spm)	120	171.8	12.3	126	197
Running stride length (m)	120	1.2	0.2	0.71	1.61

SWOLF- number of strokes taken + time taken to travel 25 meters in open water
rpm- revolutions per minute
W- watts
spm- steps per minute
m- meters

Table 4.10. Number of triathlons completed per year		
	N	**Percent**
1-2	7	5.4
3-4	61	46.9
5-6	37	28.5
7-8	14	10.8
9+	11	8.5
Total	130	100.0

Table 4.11. Years competing in triathlon			
	N	**Percent**	**Cumulative percent**
0	1	0.8	0.8
1-2	30	23.1	23.9
3-4	36	27.7	51.6
5-10	42	32.3	83.9
10-19	8	6.15	90.05
20+	5	3.8	93.85
N/A	8	6.15	100.0
Total	130	100.0	100.0

Table 4.12. Primary sport prior to triathlon		
	N	**Percent**
Baseball/softball	10	7.7
Basketball	6	4.6
Cycling	2	1.5
Football	4	3.1
Running	42	32.3
Soccer	5	3.8
Swimming	22	16.9
Volleyball	1	0.8
Water polo	3	2.3
Other	24	18.5
None (triathlon has always been my primary sport)	11	8.5
Total	130	100.0

Table 4.13. Self-identified triathlete level		
	N	**Percent**
Beginner	11	8.5
Intermediate	67	51.5
Advanced	42	32.3
Total	130	100.0

Race times

When observing actual finish times from each discipline (swim, cycle, and run), actual run time was most closely related to overall finish time (r= 0.912, p< 0.01), followed by actual cycle time (r= 0.901, p< 0.01), and actual swim time (r= 0.660, p< 0.01) (Table 4.14).

Multisport watch-measured variables

SWOLF score had a strong, positive correlation to actual swim time (r= 0.788, p< 0.01); the lower the SWOLF score, the faster (lower) the swim time. Cycling cadence had a moderate, negative correlation to actual cycle time (r= -0.401, p< 0.01); the faster (higher) an individual pedaled, the faster (lower) the cycle time. Running stride length showed a very strong, negative correlation to actual run time (r= -0.884, p< 0.01); the longer (higher) an individual's stride length, the faster (lower) the run time. When compared to overall finish time, running stride length was most closely related among the performance-related variables (r= -0.837, p<0.01), followed by SWOLF (r= 0.595, p<0.01), and cycling cadence (r= -0.477, p<0.01) (Table 4.14).

SWOLF and running stride length were very closely associated with actual swim and run times, respectively. However, the performance-related variable that was most closely related to actual cycle time was running stride length (r= -0.708, p<0.01), not cycling cadence (r= -0.401, p<0.01) (Table 4.14).

A multiple linear regression was performed to determine how much variance the multisport-watch measured variables (i.e., SWOLF, cycling cadence, and stride length) accounted for in overall finish time. The performance-related variables of SWOLF, cycling cadence, and stride length significantly predicted official finish time, $F(5, 67) = 32.807$, $p < 0.001$, $R^2 = 0.710$ (adjusted $R^2 = 0.688$) (Table 4.15).

Table 4.14. Pearson correlations between multisport watch-measured variables and time in an Olympic distance triathlon for amateur triathletes

	SWOLF	Cycling cadence	Cycling power	Running cadence	Running stride length	Official swim time	Official transition 1 time	Official cycle time	Official transition 2 time	Official run time	Official finish time
SWOLF	1	-0.430**	-0.489**	-0.225*	-0.445**	0.788**	0.339**	0.387**	0.399**	0.449**	0.595**
Cycling cadence	-	1	0.278	0.251*	0.504**	-0.281*	-0.123	-0.401**	-0.210	-0.493**	-0.477**
Cycling power	-	-	1	0.414**	0.712**	-0.532**	-0.368*	-0.624**	-0.308*	-0.628**	-0.671**
Running cadence	-	-	-	1	0.398**	-0.253**	-0.079	-0.479**	-0.255*	-0.690**	-0.587**
Running stride length	-	-	-	-	1	-0.424**	-0.457**	-0.708**	-0.504**	-0.884**	-0.837**
Official swim time	-	-	-	-	-	1	0.289**	0.432**	0.426**	0.438**	0.656**
Official transition 1 time	-	-	-	-	-	-	1	0.467**	0.529**	0.349**	0.501**
Official cycle time	-	-	-	-	-	-	-	1	0.515**	0.764**	0.900**
Official transition 2 time	-	-	-	-	-	-	-	-	1	0.486**	0.601**
Official run time	-	-	-	-	-	-	-	-		1	0.911**
Official finish time	-	-	-	-	-	-	-	-		-	1

*p<0.05
**p<0.01

Table 4.15. Multiple linear regression coefficients								
		Unstandardized coefficients		Standardized coefficients			95.0% confidence interval for B	
Model		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
1	(Constant)	263.100	31.669		8.308	0.000	199.888	326.313
	Sex	2.189	4.380	0.038	0.500	0.619	-6.553	10.932
	Age	0.080	0.189	0.030	0.425	0.672	-0.297	0.458
	SWOLF	0.585	0.246	0.191	2.381	0.020	0.095	1.075
	Cycling cadence	-0.207	0.313	-0.051	-0.660	0.511	-0.832	0.418
	Running stride length	-101.469	12.907	-0.710	-7.862	0.000	-127.231	-75.707
Dependent variable: Official finish time *significant at p< 0.05 **significant at p< 0.01								

Post-hoc analyses

Following data collection and statistical analyses, further analyses were made to observe other relationships which the researchers did not initially set out to examine. This was done in order to explain some of the results and compare results of the current study to results of previous studies.

Swim

For women in the current study, a moderate, positive relationship (103) existed between swim time and overall finish time ($r= 0.562$, $p< 0.01$). For men, the time taken to complete the swim showed a strong, positive correlation to overall finish time ($r= 0.709$, $p< 0.01$). A Fisher's r-to-z transformation was performed to determine if there was a difference between women and men for the relationship between the time taken to complete the swim and overall finish time. It was determined that there was no significant difference between women and men ($p= 0.190$).

SWOLF and height

After performing a correlation between SWOLF and height for both men and women in the current study, the relationship between the two variables was not significant (men: $r= -0.117$, $p= 0.304$;

women: r= -0.235, p= 0.125). The same non-significant result was found in both sexes when observing the relationship between swim time and height (men: r= -0.062, p= 0.574; women: r= -0.223, p= 0.141).

Swim time and triathlete skill level

There was a significant difference in swim finish time between Advanced, Intermediate, and Beginner triathletes as determined by a one-way ANOVA [F(2, 116)= 9.621, p< 0.001]. A Tukey post-hoc test revealed that Advanced triathletes (0:26:26 ± 0:05:00) had significantly lower swim times than Beginner (0:33:41 ± 0:10:02, p< 0.01) and Intermediate triathletes (0:30:35 ± 0:05:31, p< 0.01). There was no significant difference in swim finish time between the Intermediate and Beginner triathletes (p= 0.243).

Cycle

For women in the current study, a very strong, positive correlation (103) existed between cycle time and overall finish time (r= 0.926, p< 0.01). For men, a very strong, positive correlation (103) existed between cycle time and overall finish time (r= 0.845, p< 0.01). As determined by a Fisher's r-to-z transformation, the time taken to complete the cycle was more closely related to overall finish time for women than men (p< 0.05).

Cycling cadence and height

No significant associations were found between cycling cadence and height (men: r= 0.013, p= 0.921; women: r= 0.046, p= 0.827) and cycle time and height (men: r= -0.026, p= 0.816; women: r= -0.083, p= 0.591).

Cycling cadence and triathlete level

There was a significant difference in cycling cadence among Advanced, Intermediate, and Beginner triathletes as determined by a one-way ANOVA [F(2, 73)= 7.123, p< 0.01]. A Tukey post-hoc test revealed that Advanced triathletes (89.28 ± 5.0 rpm) had significantly higher cycling cadences than

Beginner triathletes (81.20 ± 12.6 rpm, $p < 0.05$) and Intermediate triathletes (84.05 ± 6.7 rpm, $p < 0.01$). There was no significant difference in cycling cadence between the Intermediate and Beginner triathletes ($p = 0.630$).

A one-sample t-test was performed to determine if there was a significant difference between the mean cycling cadence for Advanced triathletes in the current study and the "optimal" cadence (60-80 rpm) reported by Ettema & Loras (107). Mean cycling cadence for Advanced triathletes in the current study (89.3 ± 5.0 rpm) were significantly higher (mean difference of 6.4 rpm, 95% CI [4.85 to 7.92], $t(82) = 8.293$, $p < 0.001$) than the high end of "optimal" cadence (i.e., 80 rpm) reported by Ettema & Loras. The high end of the range (80 rpm) was tested because the mean cycling cadence for Advanced triathletes in the current study was 89.3 ± 5.0 rpm. If there was a significant difference between cycling cadence in the current study and 80 rpm, then there would also be a significant difference between cycling cadence in the current study and 60 rpm.

Cycle finish time and triathlete level

There was a significant difference in cycle finish time among Advanced, Intermediate, and Beginner triathletes as determined by a one-way ANOVA [$F(2, 116) = 13.184$, $p < 0.001$]. A Tukey post-hoc test revealed that Advanced triathletes (1:07:10 ± 0:07:28) had significantly lower cycle times than Beginner (1:20:31 ± 0:08:55, $p < 0.01$) and Intermediate triathletes (1:16:57 ± 0:12:20, $p < 0.01$). There was no significant difference between cycle finish time for the Intermediate and Beginner triathletes ($p = 0.559$).

Cycling power and triathlete level

There was a moderate, positive correlation between cycling power and cycle time ($r = 0.624$, $p < 0.01$) and cycling power and overall finish time ($r = 0.671$, $p < 0.01$). When grouping triathletes based on skill level, there was a significant difference in cycling power among Advanced, Intermediate, and

Beginner triathletes as determined by a one-way ANOVA [$F(2, 38)= 8.595$, $p< 0.01$]. A Tukey post-hoc test was not able to be performed because only one Beginner triathlete provided data for cycling power. However, the mean power output of the Advanced triathletes (236.64 ± 46.1 W) was higher than the Intermediate triathletes (188.28 ± 35.1 W) and was higher than the Beginner triathlete (133.0 W).

Run

For women and men in the current study, there was a very strong, positive correlation (103) between run time and overall finish time ($r= 0.926$, $p< 0.01$; $r= 0.887$, $p< 0.01$, respectively). A Fisher's r-to-z transformation was performed to determine if there was a difference between women and men for the relationship between the time taken to complete the run and overall finish time. It was determined that there was no significant difference between women and men ($p= 0.246$).

Running stride length and height

There was no significant relationship between height and running stride length for men ($r= 0.169$, $p= 0.142$) or women ($r= 0.243$, $p= 0.117$). Additionally, there was no significant relationship between height and time taken to complete the running portion of the triathlon for women ($r= -0.145$, $p= 0.347$) or men ($r= -0.018$, $p= 0.873$).

Running cadence

Running cadence was significantly related to run time ($r= -0.618$, $p< 0.01$) and overall finish time ($r= -0.532$, $p< 0.01$). These relationships were significantly lower than the correlation between running stride length and run time ($r= -0.871$, $p< 0.01$) and running stride length and overall finish time ($r= -0.822$, $p< 0.01$) as determined by a Fisher's r-to-z transformation ($p< 0.01$).

Running stride length and triathlete level

There was a significant difference in running stride length among Advanced, Intermediate, and Beginner triathletes as determined by a one-way ANOVA [$F(2, 109) = 23.720$, $p< 0.001$]. A Tukey post-hoc test revealed that the running stride length was significantly longer for the Advanced (1.31 ± 0.18m) than the Intermediate (1.10 ± 0.16m, $p < 0.01$) and Beginner (1.02 ± 0.18m, $p < 0.01$) triathletes. There was no significant difference in running stride length between the Intermediate and Beginner triathletes ($p = 0.333$).

Running time and triathlete level

There was a significant difference in running finish time among Advanced, Intermediate, and Beginner triathletes as determined by a one-way ANOVA [$F(2, 116) = 19.399$, $p < 0.001$]. A Tukey post-hoc test revealed that Advanced triathletes (0:43:18 ± 0:06:57) had significantly lower run times than Beginner (1:01:11 ± 0:15:14, $p < 0.01$) and Intermediate triathletes (0:55:23 ± 0:12:21, $p < 0.01$). There was no significant difference in run finish time for the Intermediate and Beginner triathletes ($p = 0.248$).

Run and cycle

A Fisher's r-to-z transformation showed no significant difference between run and cycle time and their respective relationship to overall finish time ($p = 0.624$). A Fisher's r-to-z transformation also showed there was no significant difference between running stride length and cycling power for their respective relationships between the time taken to complete the cycle discipline ($p = 0.497$).

CHAPTER 5: DISCUSSION

The purpose of Study 1 was to assess the criterion and convergent validity of two scientific equations (13,14) and an online calculator (17) that predict overall finish time of an Olympic distance triathlon in a population of amateur triathletes. The QT2 Systems online calculator most closely estimated actual finish time ($r = 0.846$, $p < 0.01$) of the three predictions in the current study. The calculator involves easily accessible tests and is available to anyone with an internet connection making it the best of the three options amateur triathletes have of predicting overall finish time of an Olympic distance triathlon.

The primary purpose of Study 2 was to determine if certain multisport watch-measured variables are associated with time in each the swim, bike, and run disciplines, and overall, during an Olympic distance, non-drafting triathlon for amateur triathletes. The results revealed that SWOLF ($r = 0.788$, $p < 0.01$), cycling cadence ($r = -0.401$, $p < 0.01$), and running stride length ($r = -0.871$, $p < 0.01$) were all moderate-to-strongly related to the time taken to complete their respective disciplines. Of the multisport watch-measured variables, running stride length showed the strongest relationship to actual cycle time ($r = -0.694$, $p < 0.01$) and overall finish time ($r = -0.822$, $p < 0.01$). This indicates that triathletes should focus on improving their running stride length in order to be faster across multiple disciplines as well as the entire Olympic distance triathlon race.

STUDY 1

QT2 Systems online calculator

The QT2 Systems online calculator showed the strongest relationship with actual finish time ($r = 0.846$, $p < 0.01$) among the three predictions in the current study. This was stronger than the hypothesized value of $0.40 \leq r < 0.80$. The QT2 Systems online calculator takes eight different variables about the participant into account when predicting triathlon finish time: body weight, 400-yard swim time, 20-minute FTP power output, 5km run time, swim training yardage, cycle training mileage, run training mileage, and years of experience. Additionally, it takes cycle and run course elevation change into account as well. In total, 10 different variables are entered into the calculator to give a prediction of overall triathlon finishing time. Because the variables entered in the calculator are so specific to each individual, it is not surprising that it showed the strongest relationship with actual finish time among the three predictions in the current study.

Many of the variables selected for the QT2 Systems online calculator have been shown to be strongly correlated with time in swimming, cycling, and/or running. Using a 400-yard swim (108), 20-minute FTP power output (109), and 5km run (110) have all been used to predict races of longer distances. Furthermore, the addition of training distance and years of experience to the calculator increases its effectiveness even more. Training time, distance, and years of experience have all been shown to be strongly correlated with time in swimming, cycling, and running (76,111–113).

Another piece to the calculator is that it requires triathletes to enter the time it took to complete certain events (i.e., a 400-yard swim and a 5km run). In the current study, there were two participants who swam the 400-yard test in the same amount of time. This resulted in the same race swim prediction for their respective races. However, their swim training distance was vastly different (6000 yards/week vs. 15,000 yards/week) and these triathletes were also members of opposite sexes (which cannot be entered in the calculator). After further analyses of the QT2 Systems online calculator, it was discovered that the only factor which influences swim time is the 400-yard swim test. In fact, unless training distance is below a certain threshold (i.e., 3800 yards for swimming, 48 miles for cycling, and 10 miles for running), it does not appear that training distance influences the prediction for the swim, cycle, or run disciplines. Based on the previously mentioned studies that found training distance to be strongly correlated with finishing time, this may be one area where the calculator could be improved.

Even with the room for improvement based on training distances, the QT2 Systems online calculator still performed the best of the three prediction methods test in this study. It is easy to use and accessible for amateur triathletes making it a great option for those looking to predict their triathlon finishing time.

Hue equation

Like the QT2 Systems online calculator, the Hue equation showed a strong relationship with actual finish time ($r = 0.832$, $p < 0.01$). This was also a stronger relationship than hypothesized ($0.40 \leq r < 0.60$). In the study by Hue, the two best predictors of overall finish time in an Olympic distance triathlon were 1. Distance covered in the run of a combined cycle-run ($r = -0.92$, $p < 0.01$ and 2. Lactate concentration at the end of cycling in a combined cycle-run ($r = 0.83$, $p < 0.05$), resulting in the following prediction equation:

Predicted triathlon time (s) = -1.128 (distance covered during R of C-R in meters) + 38.8 (lactate at the end of C in C-R) + 13,338 (where R= run, C-R= combined cycle-run, and C= cycle)

In the current study, the first variable (distance covered in the run of a combined cycle-run) showed a strong relationship with overall finish time ($r = -0.820$, $p < 0.01$), but the second variable (lactate concentration at the end of cycling in a combined cycle-run) did not show a relationship to overall finish time ($r = -0.018$, $p = 0.912$). In the study by Hue, these two variables accounted for 93% of the variance in overall finishing time while in the current study, they only accounted for 69.4% of the variance in overall finishing time. According to Hue, these results indicate that triathletes need to have high maximal and threshold values of lactate during the cycle portion of the triathlon in order to run as fast as possible after cycling (13).

While Hue observed triathletes competing in a draft legal triathlon where it is possible to have a lower rate of ATP production while on the cycle (ensuring a greater percentage energy production is coming from aerobic sources), the current study involved triathletes competing in a non-drafting triathlon. During the cycle portion of the race, athletes cannot draft behind another cyclist and must ride at or close to his/her threshold in order to maximize performance. This means that energy production must occur at a higher rate and therefore, the production of blood lactate will also increase. Riding at higher intensities during a non-draft triathlon means that blood lactate levels will be elevated above those seen in a draft legal triathlon. Previous research showed that blood lactate levels during the cycle portion a draft legal triathlon were 4.0 ± 0.3 mmol/L compared to 8.4 ± 0.4 mmol/L in a non-drafting triathlon. (52) A further study showed blood lactate levels to be significantly higher (6.3 ± 0.4 mmol/L vs. 3.5 ± 0.2 mmol/L, $p < 0.01$) during an alternating draft triathlon (where the triathlete alternatively rode in front or at the back of another cyclist, rotating every 500 meters, while keeping speed constant) than a continuous draft triathlon (where the triathlete cycled behind a professional cyclist with comparable body size at the same speed as the alternating draft triathlon) (51). Keeping blood lactate levels low during the cycling portion of the race enables triathletes competing in draft legal triathlons to reach higher blood lactate levels during the subsequent run compared to non-drafting triathlons (51,52). This results in a significantly faster time during the run portion of the draft legal triathlon. This could be why the current study found a lower percentage of variance accounted for by lactate levels at the end of the cycle and distance covered in the run, of a combined cycle-run, than seen in the Hue study. However, because of the strong correlation to overall finish time, the regression equation could be updated for amateur triathletes to still include distance covered in the run of a combined cycle-run to predict finish time for a non-drafting, Olympic distance triathlon.

Hue also found that time in the 400-meter swim was related to the 1500-meter race swim time ($r = 0.84$, $p < 0.04$). In the current study, it was found that the 400-yard swim was also correlated to actual swim time ($r = 0.653$, $p < 0.01$), just not as strongly. The Hue equation was developed using professional triathletes, who are not allowed to wear a wetsuit during the swim portion of the race.

Therefore, when they performed the 400-meter swim test, it closely matched the 1500-meter race swim. However, amateur triathletes are permitted to wear wetsuits during a race but did not wear them during the 400-yard swim test. Wetsuits have been shown to reduce drag in the water by up to 16%, with slower swimming velocities obtaining greater benefit from the wetsuit (114). Toussaint estimated that triathletes would swim 5% faster with a wetsuit while swimming at 1.25 m/s (114). Amateur triathletes in the current study swam at an average of 0.88 m/s during their 1500-meter race swim, meaning the benefit seen in race swim time (with a wetsuit) vs. pool swim time (without a wetsuit) would be at least 5% faster because of the reduction of drag. Therefore, the 400-yard swim time may have underestimated 1500-meter race swim time for amateur triathletes. A more accurate estimation of 1500-meter race swim time may be obtained by amateur triathletes if a wetsuit is worn for the 400-yard swim test in order to more closely simulate race conditions.

Hue found that times for actual cycling and running were strongly correlated with overall triathlon time ($r= 0.87$, $p< 0.03$; $r= 0.83$, $p< 0.04$, respectively) while swim time was not (13). The current study found that actual cycle and run times were also strongly correlated with overall finishing time ($r= 0.937$, $p< 0.01$; $r= 0.924$, $p< 0.01$, respectively). However, unlike Hue, the current study found that swim time was also strongly correlated with overall finishing time ($r= 0.660$, $p< 0.01$). This is likely due to the draft legal triathlon observed in the study by Hue and the non-draft legal triathlon observed in the current study. In a draft legal triathlon, finishing time is not as important as finishing position (90,115). This means that athletes can conserve energy in the first two disciplines (swim and bike) as long as they stay in the lead group (52). Then, the fastest runner is most often the winner of the race (14,39,90,115). In a non-draft legal triathlon, groups cannot be formed because drafting would result in a penalty. Therefore, each discipline of the triathlon becomes important. Research has shown that finish time each discipline is significantly correlated to overall finishing time of a non-draft legal triathlon (14,39,46,116). Some (39,116) have shown finishing time in the swim portion of the race to be less strongly correlated to overall finishing time than others (14,46). It appears that the swim is more important in shorter distance triathlons (i.e., sprint and Olympic) where the swim makes up a greater proportion of the race than the longer distance triathlons (2.9% vs. 1.7% of total distance). This could explain why the current study found a strong correlation between finishing time in the swim and overall finishing time than reported by Hue who examined a draft legal triathlon. Therefore, the non-drafting triathletes may be able to more evenly pace themselves so each discipline in the triathlon becomes more important than in a draft legal triathlon. This further highlights the different physiological and strategical differences required for a draft legal triathlon versus a non-drafting triathlon.

Schabort equation

The Schabort equation showed a weak, positive (103) relationship with actual finish time ($r = 0.359$, $p < 0.05$) which is weaker than hypothesized ($0.40 \leq r < 0.60$). In the Schabort study, a very strong, positive relationship was observed between blood lactate concentration during submaximal cycling at 4 W/kg and both cycle ($r = 0.90$) and overall ($r = 0.92$) finishing time. However, the current study did not show a significant relationship between blood lactate and cycle time ($r = -0.226$, $p = 0.173$) or overall finish time ($r = -0.159$, $p = 0.340$). This could be due to the fact that cycling at 4 W/kg is a submaximal effort for elite triathletes (117). However, when amateur triathletes performed the cycle test at 4 W/kg, many (23.7%) were unable to complete the entire 5-minutes. For these cases, the test was modified for an amateur's submaximal power by calculating 95% of the participant's 20-minute FTP cycle test (23,117). Additionally, the average blood lactate level while cycling at 4 W/kg in the Schabort study was 6.0 ± 2.8 mmol/L. In the current study, the average lactate levels were 8.6 ± 3.6 mmol/L. This value was significantly higher ($p < 0.05$) than seen in the Schabort study, meaning triathletes in the current study were not as aerobically fit and had to work harder in order to maintain the same relative intensity. This is not entirely surprising because this power output is meant to be submaximal. For elite, national level triathletes, 4 W/kg is a submaximal effort. However, it was clear during the testing sessions that for amateur triathletes, this was not the case. Even some of the participants who completed the five minutes at the prescribed 4 W/kg struggled with the test. The participants in the current study who completed the test reached steady-state (i.e., heart rate did not increase by more than 5 bpm within the final 30 seconds of the test). However, had the testing progressed longer than five minutes, many of the participants would have been unable to continue. Therefore, the use of the 4 W/kg cycle test used in the Schabort equation may not be appropriate for all amateur triathletes.

Analyses were performed without triathletes who could not complete the cycle test at 4 W/kg in the current study. When these cases were excluded from analyses, the convergent relationship between the Schabort equation and Hue equation became non-significant. Furthermore, the relationship with the Schabort equation and actual finish time was only low-to-moderately correlated with actual finish time ($r = 0.359$, $p < 0.05$). This suggests that the equation developed by Schabort et al. may not be valid for use in amateur triathletes.

Criterion and convergent validity

The QT2 Systems online calculator ($r = 0.846$, $p < 0.01$) and Hue equation ($r = 0.832$, $p < 0.01$) both showed a very strong, positive relationship (103) with actual finish time and showed the best convergent validity ($r = 0.809$, $p<0.01$). This could be due to the fact that the QT2 Systems online calculator and Hue equation each involved similarly timed cycle (20 vs. 30 minutes) and run [21 (average time of 5km run) vs. 20 minutes] tests. Because of the similarity in the tests used (and the time taken to complete those tests), and especially because the 5km run time and the combined 30-minute cycle/20-minute run tests were most related to all finish times, this could have led to the comparable correlations between actual finish time and the respective equations as well as the very strong (103) convergent validity between the two.

The Schabort and Hue equations showed a weak, positive (103) convergent validity ($r = 0.329$, $p < 0.05$). This is somewhat surprising because both equations were developed using elite triathletes. Therefore, any performance decrements seen in one study protocol should be seen in the other because amateur triathletes were completing both protocols. For the Hue study, participants were simply instructed to go as fast as possible while cycling and running. However, the Schabort study involved a specified power output (based on body weight) for the cycle test and had a set starting speed on the running test. This meant that the amateur triathletes were not able to self-select their speed or pace. This was evident in the cycle test where participants were required to cycle at 4 W/kg for five minutes; many (23.7%) were unable to complete the test. Although the elite triathletes in the Schabort study and the amateur triathletes in the current study weighed the same, elite triathletes in the Schabort study had a significantly lower body fat percentage for males ($p < 0.01$) and females ($p < 0.05$) than the amateur triathletes in the current study. Therefore, when performing the cycle test based on the athlete's body weight, the amateurs had less lean mass to perform the same amount of work. This would result in a greater relative ATP production being met by the active skeletal muscle in amateurs. Therefore, the activity will be increasingly more difficult for the amateurs compared to the elites. Perhaps if the test was performed in relation to lean mass instead of total body weight, amateur triathletes would have performed better.

As noted previously, many triathletes could not complete the entire five-minute test and even those who could struggled to complete it. Additionally, the amateur triathletes in the current study performed the running tests much slower than those in the Hue and Schabort studies. The amateur triathletes reached significantly slower peak treadmill speeds (women: $p < 0.01$, men: $p < 0.05$) and covered significantly less distance in the combined cycle-run test ($p < 0.01$) than the elite triathletes in the Schabort and Hue studies, respectively. If treadmill running speed in the test is supposed to predict running speed in a race, then a stronger relationship would have been expected. And since the Schabort equation showed a weak relationship with overall finish time while the Hue equation showed a strong relationship with overall finish time, it may be that the Schabort equation is not valid for amateur triathletes. This could be a potential reason the two equations showed low convergent validity.

Finally, the QT2 Systems online calculator and the Schabort equation did not show a significant convergent relationship ($r= 0.202$, $p= 0.224$). Although they did not have any variables in common to formulate prediction times, the QT2 Systems online calculator used a 5km run and the Schabort equation used a peak treadmill speed run test. In multiple studies, it has been shown that peak treadmill running speed is highly related ($r > 0.90$) to running performance for distances ranging from 5km to the marathon (26,110). Therefore, it would be expected that the QT2 Systems online calculator and the Schabort equation would be more closely associated. For the Schabort equation, peak running speed on the treadmill predicts overall finishing time in the triathlon race. Likewise, in the QT2 Systems online calculator, a 5km time trial run predicts overall finishing time in a triathlon. The difference is that in the Schabort equation, peak treadmill running speed is only one of two variables to predict overall finishing time. In the QT2 Systems online calculator, 5km running time is one of eight variables used to predict overall finishing time (along with body weight, 400-yard swim time, FTP power output, years of experience, swim training yardage, cycle training mileage, and run training mileage). Perhaps the 5km running time is not as heavily weighted in the QT2 Systems online calculator as the peak treadmill speed is in the Schabort equation. However, when manipulating both equations to reflect a 1 kph change in peak treadmill running speed or a 1 kph change in average 5km time, the results tell otherwise. A 1 kph change in peak treadmill running speed creates a difference of 0:02:15 in predicted finishing time for the Schabort equation. However, using the QT2 Systems online calculator, a 1 kph change in average 5km running speed yields more than a 3-minute difference in predicted running time in an Olympic-distance triathlon. Additionally, when considering that a 1 kph change in mean peak treadmill running speed is a 5.5% difference from the mean (18.27 kph), performing the same 5.5% manipulation to mean 5km running time (0:20:43) in the QT2 equation still yields a difference of approximately 3 minutes. Therefore, one would view the blood lactate levels after cycling at 4 W/kg as more important than the peak treadmill running speed for the Schabort equation. However, when viewing the Schabort equation (seen below), peak treadmill speed has a greater effect on the predicted race time than lactate concentration.

Predicted race time (s) = -129(peak treadmill speed [kph]) + 122([lactate]at 4 W/kg) + 9456

Therefore, it can be concluded that the Schabort equation is simply unsuitable for use in a population of amateur triathletes.

The scientific equations developed by Schabort and Hue were developed with 10 and 8 triathletes, respectively. Having a sample size this low could lead to several problems. First, both equations were developed using a limited number of homogeneous participants. There was little variability in predicted finishing times in each of those studies. Only 8 minutes separated participants in the Hue study and participants in the Schabort study all finished within 30 minutes of each other. Participants in the current study showed a much wider range of actual finishing times (02:45:49). Having such a small number of participants and little variability in the outcome variable (predicted finishing time) could mean that both studies were underpowered. Neither study reported the power achieved, so this is a likely explanation. Simply put, the regression models developed by Schabort and Hue are tailored to fit the random noise of their specific samples – elite triathletes. Therefore, the generalizability of the studies is also limited. While both were able to develop strong regression equations, the validity and generalizability of these equations for amateur triathletes (who make up the majority of triathletes) does come into question.

STUDY 2

SWOLF

Pearson correlations showed a strong, positive correlation between SWOLF and actual swim time ($r= 0.788$, $p< 0.01$) and this value was not significantly different from the hypothesized value of $r > 0.80$ ($p> 0.05$). SWOLF was also positively correlated with overall finish time ($r= 0.600$, $p< 0.01$). due to this being the first known study to compare SWOLF with actual race times in a triathlon, comparison to previous research involving these correlations is not possible. Therefore, SWOLF should be analyzed based on the variables that comprise it: 1. Number of strokes taken to swim 25 meters and 2. Time taken to swim 25 meters.

The number of strokes taken to swim a given distance has been shown to be the best predictor of performance in a swimming event, regardless of distance (93,118–121). The ability to generate greater propulsive forces per stroke can be linked to certain anthropometric variables of the athlete. Stature ($r= 0.40$-0.55), the axilla cross-sectional ($r= 0.74$), arm length ($r= 0.68$), hand cross-sectional area ($r= 0.57$) foot cross-sectional area ($r= 0.68$), and leg frontal area ($r= 0.61$) all had a positive correlation with stroke length (29,121,122). Of these five anthropometric variables, axilla cross-sectional area was shown to have the largest influence on distance per stroke, accounting for 57% of the variance in stroke length (29). It is also the only variable that is not primarily determined by genetic factors (29) which means that athletes could train to improve the muscles surrounding the axilla in order to increase his/her distance per stroke.

The current study did not measure any of these variables, although each participant was asked to provide his/her height. However, after performing a correlation between SWOLF and height for both men and women in the current study, the relationship between the two variables was not significant. Conversely, another study found that height was strongly related to swim speed and stroke length, for men and women swimmers competing in the 50-, 100-, and 200-meter freestyle event at the 1992 Olympics (118). The study also found that the distance a swimmer covered in each stroke was significantly related to the swimmer's average speed for men and women across all distances, but the frequency of strokes was not related to speed for any distance among either sex (118). Furthermore, in a review of the biomechanics of swimming, it was determined that increasing stroke length could improve swimming performance more than increasing stroke frequency (123). This could mean that triathletes should simply focus on improving stroke length instead of SWOLF. However, the GPS devices used in the current study do not directly measure stroke length. Instead, they measure stroke frequency and distance swam to give an estimation of stroke length. Furthermore, the devices are only accurate within 15 meters, 95% of the time (124) and one study found that the GPS device does not provide accurate stroke count detection during freestyle swimming, which is used in triathlon competitions (125). Because typical stroke lengths average between 1 and 3 meters (118,121,123,126), having an accuracy of 15 meters does not allow the specificity to detect small changes in stroke length in the open water using the wearable GPS devices. Coupled with the inaccuracy of the watch detecting the correct number of strokes during freestyle swimming, it may be difficult to trust these variables in a triathlon setting.

The other component of SWOLF that should be made note of is the time taken to swim 25 meters. This variable is likely the reason for such a strong correlation between SWOLF and swim and overall finish times. It should be evident that a lower time taken to swim 25 meters will strongly correlate with lower swim and overall finish times. Perhaps the SWOLF variable should not be used because it could give triathletes misguided information. Instead, the focus should be placed on improving distance per stroke because that has been shown across a variety of distances to be one of the few controllable factors that will increase swim velocity (93,118–121). While the watch may not be able to reliably measure length during a race, triathletes can use this in training where the device is much more accurate across shorter distances (125). Because triathletes do not look at their watch during the race, it would not be necessary for them to view this number while racing. During training sessions, triathletes could use the multisport watch as a tool to observe changes in distance per stroke. The strong, negative relationship between stroke length and time (93,118–121) indicates that triathletes should focus on improving this variable in order to improve swim time.

Cycling cadence

When comparing cycling cadence to actual cycle time, a moderate, negative correlation was observed ($r = -0.401$, $p < 0.01$). This did not follow the hypothesized value of $r < -0.60$. Cycling cadence was also negatively correlated with overall finish time ($r = -0.477$, $p < 0.01$). This is similar to results that found cycling cadence to be significantly correlated to cycling speed ($r = 0.66$) (31), but not to the same extent. A possible reason for this could be that the study conducted by Lucia et al. observed professional cyclists who competed in a time-trial at one of three major cycling events (Giro d'Italia, Tour de France, or Vuelta a Espana). These professional cyclists exceeded 30 mph and 400W for the duration of the time-trial. This is significantly different ($p < 0.01$) from the ~20 mph and 210W exhibited from the participants in the current study. This could mean that cycling cadence is more closely related to cycling speed if the cyclist has more experience cycling. In fact, when analyzing the current dataset, there was no significant relationship between cycling cadence and cycle time or overall finish time in triathletes who classified themselves as Beginner or Intermediate. However, a significant relationship between cycling cadence and cycle time ($r = -0.507$, $p < 0.01$) and overall finish time ($r = -0.466$, $p < 0.01$) was observed for triathletes who classified themselves as Advanced.

These Advanced triathletes also completed the cycle portion of the triathlon faster than the Beginner or Intermediate triathletes. The higher cycling cadence and faster finish time for the cycle portion of the triathlon seen in the Advanced triathletes are somewhat contradictory to previous research that shows a negative effect of cadence on efficiency. According to a review of efficiency in cycling, the optimal cadence falls between 60 and 80 rpm in laboratory-based studies (107), which is significantly lower than the mean cycling cadence observed in Advanced triathletes in the current study (89.3 ± 5.0 rpm). However, it has been found that the longer the exercise duration (34) and the higher the cycling intensity (53,127) the more energetically optimal a higher cadence becomes. This nonlinear increase in the optimal pedaling frequency with increasing power output could allow the cyclist to maximize efficiency and minimize energy expenditure for a given power output (73). Perhaps this is the reason the Advanced triathletes, who cycled at a higher power output than the Intermediate or Beginner triathletes, adopted a higher cycling cadence. Because of the prolonged duration of the cycling portion of an Olympic distance triathlon (i.e., >60 minutes in amateur triathletes), a higher cadence may be beneficial to optimizing performance and reducing time.

Running stride length

A strong, negative correlation existed between running stride length and actual run time ($r = -0.871$, $p < 0.01$) which confirms the hypothesized value of $r < -0.85$. This is similar to the only other study that has observed this relationship during an actual triathlon race ($r = -0.841$) (38). Studies observing runners have shown a similar trend (99,128–131). Running stride length was also the multisport watch-measured variable that was most closely associated with overall finish time ($r = -0.822$, $p < 0.01$). This was also similar to the study by Landers who found that the final finishing position of triathletes was strongly determined by their stride length ($r = -0.704$) (38). Therefore, it appears that having a longer running stride length is very important in producing faster running times and overall finishing time during a triathlon.

Stride length is one of the two components that establish running velocity (along with stride cadence). Although stride length and cadence were weakly correlated with each other ($r = 0.398$, $p <$

0.01), both showed moderate to strong relationships with actual run time (length: r= -0.871, p< 0.01; cadence: r= -0.618, p< 0.01) and overall finish time (length: r= -0.822, p< 0.01; cadence: r= -0.532, p< 0.01). However, after performing a Fisher's r to z transformation, these values were significantly different from one another. While both stride length and stride cadence are significantly related to running and overall finish times, it appears that longer stride lengths are more important in producing faster running (Figure 5.1) and overall finish times (Figure 5.2) than higher stride cadences.

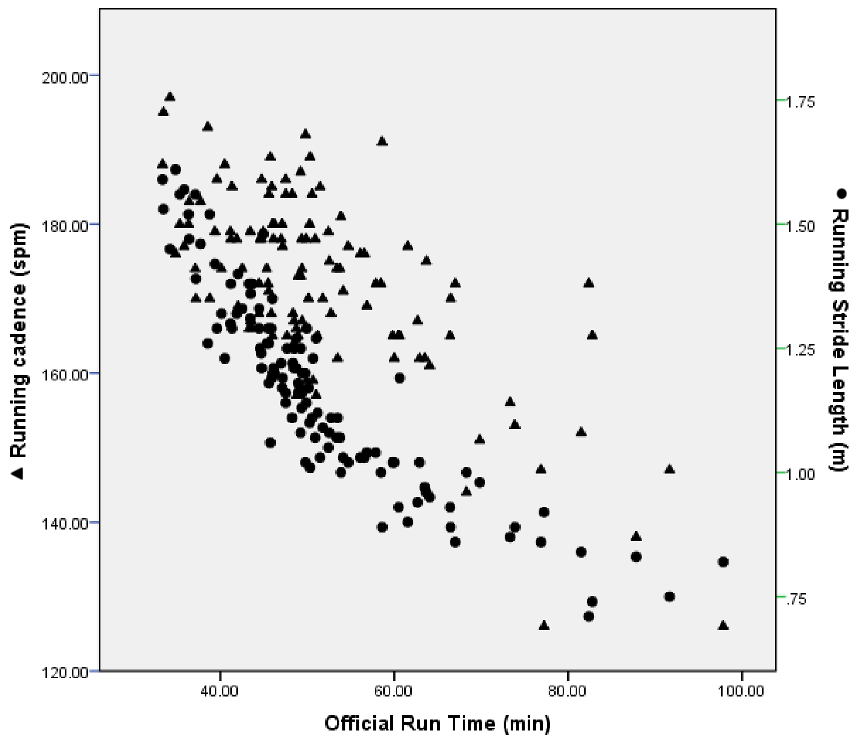

Figure 5.1. Running stride length and cadence as a function of official run time.

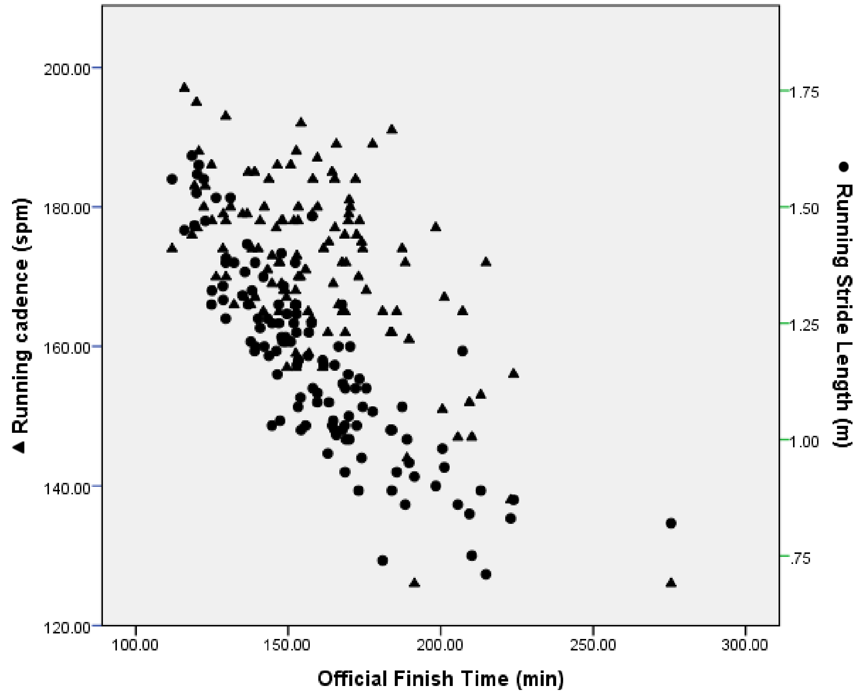

Figure 5.2. Running stride length and cadence as a function of official finish time.

However, this finding is somewhat in disagreement with previous research regarding stride length and running economy. In one of the first studies to investigate the effect of running stride length and cadence on exercise economy, Hogberg found that the most economical stride length was that chosen by the runner. When the runner's stride length was shortened (by 14 cm) or lengthened (by 20 cm), the oxygen consumption increased by 4.13% and 19.4%, respectively. The authors concluded that "The most economical stride always lies in the range of the freely chosen one when the subject is well-trained. An increase in stride length above the freely chosen one gives a larger increase in oxygen consumption than a shortening of the stride." (132). Because increasing a runner's chosen stride length increases oxygen consumption for a given velocity, this could simply mean that the taller runners in this study have longer stride lengths and are running faster.

However, in the current study, there was no significant relationship between height and running stride length for women (p= 0.117) or men (p= 0.142). Additionally, there was no significant relationship between height and time taken to complete the running portion of the triathlon (women: p= 0.347;

men: $p = 0.873$). The lack of clear relationship between height and stride length is surprising because one would expect taller runners to take longer strides. While it may seem counter-intuitive, this is similar to results from a previous study that found no consistent relationship between leg length and optimal stride length in runners (128).

It has also been found that inexperienced runners are just as capable as experienced runners at optimizing stride length for optimal oxygen consumption (129). Participants in that study used self-selected paces, so while the more experienced runners were running faster, the inexperienced runners were still able to optimize their stride length to consume the lowest amount of oxygen at their given running speed.

As runners become more highly trained, they may incur changes in aerobic capacity, running economy, body weight, and body composition (133–135). Therefore, the runner's stride length may change over time. However, across any level of the athlete spectrum, it appears that the chosen stride length is ideal for running economy. Indeed, the Advanced triathletes in the current study had significantly higher stride lengths than the Intermediate or Beginner triathletes ($p < 0.001$).

This could be due in part to the ability of the Advanced triathletes to utilize the elastic energy stored in the Achilles tendon and other tendons of the foot. It has been estimated that these tendons can store over 50% of the kinetic and potential energy in a step while running (136). Training seems to allow an athlete to improve the ability to utilize this elastic energy (137) by taking advantage of the stretch shortening cycle and the stretch reflex phenomenon. These allow the lower leg to act like a spring that stores energy and releases it once the runner's foot leaves the ground. Untrained runners may not fully engage these processes in the lower leg because of poor biomechanics (138). This could lead to higher oxygen consumption rates during running which has been estimated to be 30-40% higher without contributions from elastic energy storage and return (139).

Therefore, stride length may increase the more experienced a triathlete becomes, and the more running is involved in his/her training by allowing the body to take advantage of the anatomical and physiological adaptations that occur. Still, it is quite clear that stride length is a very important factor in running time during a triathlon and overall finishing time of a triathlon and every effort should be made to improve upon it.

When controlling for age and sex, the multisport-watch measured variables (i.e., SWOLF, cycling cadence, and running stride length) significantly predicted overall finish time and accounted for 71.0% of the variance in overall finish time, with the majority coming from stride length. Similar relationships have been seen with running stride length and running velocity in male and female sprinters. It was found that 85% and 80%, respectively, of the variance in running speed was explained by stride length (140). The reason for a lower percentage in the current study could be due to the nature of a triathlon where athletes must swim and cycle prior to running. It has been shown that there is an increase in the energy cost of running immediately following a bout of cycling (141–144). This is likely the reason for a lower relationship with running stride length and triathlon finish time seen in the current study compared to previous work that has been conducted only with running.

Race finish times

Actual times for all three disciplines (i.e., swim, bike, run) were related to overall finish time (swim, $r = 0.660$, $p < 0.01$; bike, $r = 0.901$, $p < 0.01$; run, $r = 0.912$, $p < 0.01$). This is in line with previous research (46,61,90) and not surprising because the time taken to complete each of the three disciplines constitutes the overall finish time, so a strong relationship is expected. For women in the current study, a moderate, positive relationship (103) existed between swim time and overall finish time ($r = 0.562$, $p < 0.01$). Additionally, a very strong, positive correlation (103) existed between cycle time and overall finish time and run time and overall finish time ($r = 0.926$, $p < 0.01$ for both cycle and run). This could highlight the importance of the cycle and run disciplines for women competing in an Olympic distance, non-draft legal triathlon, and that the training should focus on these two disciplines and not as heavily on the swim discipline. For men, a similar theme presented itself. The time taken to complete the swim was not as closely related to overall finish time ($r= 0.719$, $p< 0.01$) as the time taken to complete the cycle ($r= 0.845$, $p< 0.01$), or run ($r= 0.887$, $p< 0.01$) disciplines.

For both men and women, the time taken to complete the run was the most strongly correlated with overall finish time. The reason for such strong correlations between run time and overall finish time in both men and women could be because the sport triathletes reported engaging in most prior to beginning triathlon was running (32.3% - Table 4.12). Therefore, triathletes might save more of their energy for the run, a practice that is common among triathletes, which may help to optimize overall race performance (137). Or, it could be that because triathletes are saving energy for the run and completing the run the fastest, there will be a stronger correlation between running time and overall finish time than seen in swimming or cycling. Further research is needed to determine if triathletes are performing each discipline as fast as they can or if they are holding themselves back in the swim and cycle disciplines in order to be fresh for the final run portion of the triathlon.

The training takeaway from these data could be that men and women should emphasize the cycle and run disciplines of a triathlon and spend place less importance on the swim. For both men and women, primary emphasis during training should be placed on the run discipline as that has been shown to be most closely related with overall finish time.

Variables not studied

There are a host of performance-related variables that were not analyzed in the current study. The following is a list of all performance-related variables that are measured with the Garmin multisport watch:

Swim-

- Total strokes
- Average stroke rate (strokes/min)
- Maximum stroke rate (strokes/min)
- SWOLF

Cycle-

- Average cadence (revolutions/minute)
- Maximum cadence (revolutions/minute)
- Average power (watts)
- Maximum power (watts)
- Maximum average power (20-minute watts)
- Normalized power (watts)
- Left/right balance (%)
- Left/right torque effectiveness (%)
- Left/right pedal smoothness (%)
- Left power phase (˚)
- Right power phase (˚)
- Left power phase arc length (˚)
- Right power phase arc length (˚)
- Left peak power phase (˚)
- Right peak power phase (˚)
- Left peak power phase arc length (˚)
- Right peak power phase arc length (˚)

Run-

- Average cadence (steps/minute)
- Maximum cadence (steps/minute)
- Average stride length (meters)
- Average vertical ratio (%)
- Average vertical oscillation (cm)
- Average ground contact time balance (%)
- Average ground contact time (ms)

After determining which performance-related variables have been studied in previous research for the standalone sports of swimming, cycling, and running, it was decided that for the current study, only one performance-related variable would be analyzed from each discipline.

SWOLF was chosen for the swim because it is a unique measurement that does not have any research that exists on its influence of triathlon swim time or overall finish time of a triathlon.

Cycling cadence was chosen because it has been shown to be influential in standalone cycling events (31,34). Cycling power was analyzed post-hoc because it is typically considered a necessity for triathletes wishing to get the most out of their training and racing (146,147).

Running stride length was chosen over stride cadence because one study (38) has observed both stride length and cadence during an actual triathlon competition and found that stride length was more important than cadence in determining the final finishing position of triathletes.

Practical implications

The findings of the current study have several practical implications for triathletes wishing to maximize their training and racing performance. First, the time taken to complete the cycle and run disciplines are more important than the swim in determining overall finish time in an Olympic distance triathlon for both men and women. This suggests that triathletes competing at the Olympic distance should focus their training around the cycle and run disciplines. Furthermore, the importance of cycle time was significantly greater in determining overall finish time for women than men ($p < 0.05$). This suggests that a woman may want to emphasize the cycle discipline more than men in her training in order to optimize finish time in an Olympic distance triathlon.

Second, running stride length was the multisport watch-measured variable that was most closely associated with actual cycle time ($r = -0.694$, $p < 0.01$), actual run time ($r = -0.871$, $p < 0.01$), and overall finish time ($r = -0.822$, $p < 0.01$). This finding suggests that triathletes should train to increase their running stride length in order to optimize performance across multiple disciplines as well as the Olympic distance triathlon in its entirety. This can be improved by strength training (148) as well as spending more time running (128).

Although, running stride length was most closely associated with actual cycle time among the three multisport watch-measured variables initially studied, post-hoc analyses revealed that cycling power also showed a moderate, positive relationship with actual cycle time. This indicates that triathletes could also work to increase their cycling power in order to produce a faster cycling time during an Olympic distance triathlon.

A final important finding from the current study showed that Advanced triathletes tended to have lower SWOLF scores, higher cycling cadences, and longer stride lengths (as well as faster swim, cycle, run, and overall finish times) than Intermediate and Beginner triathletes. This could encourage less skilled triathletes to adopt the strategies that more advanced and faster triathletes employ.

CHAPTER 6: Conclusions and Future Research

Conclusions

Choosing a time goal based on the athlete's current training and fitness levels is important in order to increase motivation, improve performance, and decrease the risk of injury (19,20,56,57,149). Therefore, it is important that prediction equations and calculators give accurate predictions. Setting appropriate goals based on the athlete's current fitness levels can prevent injury and optimize race performance (56,57,149). However, if amateur triathletes are trying to set a goal time based on a prediction equation developed for professional triathletes, it may not yield an accurate result (as seen with the Schabort equation). Additionally, while the Hue equation provides a very accurate prediction, it involves blood lactate testing which may not be accessible for amateur triathletes.

After splitting the participants into two groups based on overall finishing time (faster and slower), analyses were performed to determine if the prediction methods were better at predicting overall finishing time for faster or slower triathletes. The analyses showed that each of the predictions were significantly different from overall finishing time for the slower triathletes in this study (i.e., those who took longer than 2:36:54 to complete the triathlon). Therefore, it can be concluded that each of the prediction methods is more effective at predicting overall triathlon finish time for triathletes who completed their triathlon faster than 2:36:55. Further analyses were performed after removing one participant who was 1.5 IQRs from the upper quartile. All predictions were still significantly different from overall finishing time for the slower triathletes in this study. However, the QT2 Systems online calculator was borderline not significantly different ($p = 0.046$) while the Schabort and Hue equations were still significantly different at $p < 0.01$. This shows that the QT2 Systems online calculator could be useful for faster and slower triathletes alike.

Unlike both scientific equations (13,14), which require blood lactate testing, the QT2 Systems online calculator involves easily accessible tests the triathlete can do on their own. The QT2 Systems online calculator showed strong correlations to overall finish time and time in each of the three disciplines as well. Therefore, while the scientific equations (Hue, in particular) showed moderate-to-strong correlations, they may not be needed by amateur triathletes to predict actual finishing time of an Olympic distance triathlon.

It was also discovered that of the three disciplines of a triathlon (swim, cycle, and run), the time taken to complete the swim is not as important as the time taken to complete the cycle or run in determining overall finish time. Furthermore, the multisport watch-measured variable that was most closely related to both cycle and run (and overall finish) times is running stride length. Therefore, when triathletes are analyzing their data and trying to determine which multisport watch-measured variables to focus on in their training, they should emphasize training that will improve their running stride length. This will maximize training time and yield the greatest benefit when training to improve one of the numerous multisport watch-measured variables. It will also lead to a greater likelihood that the triathlete finishes the Olympic distance triathlon as fast as possible.

Strengths and limitations

To the author's knowledge, this is the first study to investigate whether the equations developed by Schabort et al. and Hue to predict triathlon finishing time are appropriate for use in amateur triathletes. It is also the first study known to validate the QT2 Systems online calculator for predicting finish time in each discipline of a triathlon as well as the overall finish time. Additionally, this study is the first of its kind to observe relationships among the variables measured by a triathlete's multisport watch and the time it takes to complete a triathlon and its collective disciplines. Triathletes are data driven, but it can be difficult for them to sort through the copious amounts of data that are measured by a multisport watch. Additionally, without the aid of a coach, determining a specific area of training to focus on improving can be overwhelming. Hopefully this study sheds light on the areas of training that triathletes should focus on.

Another strength of the current study was the sample size of 38 participants in Study 1 and 130 participants in Study 2. The scientific equations developed by Schabort and Hue used 10 and eight participants, respectively. Having a larger sample size compared to the studies by Schabort and Hue increases the statistical power of the analyses conducted in the current study and makes the results more generalizable. This study also obtained multisport watch data from 130 amateur triathletes in the United States, Canada, Europe, Australia, and New Zealand, who competed in an Olympic distance triathlon. To the author's knowledge, no other study has used data from a triathlete's multisport watch to analyze the factors associated with faster finish times during a triathlon race. One study observed triathletes during a race and used video analysis to obtain cycling cadence, stride length, and stride cadence (38). However, they used only 51 triathletes and they were all elite males. Study 2 had a population of amateur triathletes that equally reflects the gender distribution of triathletes worldwide (1), making the results of the study extremely generalizable.

A potential limitation of Study 1 is that a narrow age range of participants was used. All participants were college-aged, but the largest age-group of triathletes in the United States is 40-49 years (1). Therefore, the findings may not be generalizable to all triathletes. However, the current study is a vast improvement over the previously developed equations which used elite, national level triathletes making the use of amateur triathletes a strength.

Another limitation of Study 1 could be that participants were tasked with performing three tests on their own. The investigators were reliant on the participants to report accurate data. However, some participants may have mis-reported some information which could have resulted in inaccurate predictions by the QT2 Systems online calculator.

An additional limitation could be that the studies by Schabort et al. and Hue observed triathletes competing in a draft legal triathlon while the current study observed triathletes competing in a non-draft legal triathlon. Because the physiological requirements are slightly different for each of the race formats, the results of the current study may not accurately reflect the physiological requirements of a draft legal triathlon. However, the majority of triathletes compete in the non-draft legal format of racing, so the use of this race format could also be seen as a strength due to increased generalizability.

A final limitation of Study 1 could be that the QT2 Systems online calculator changed halfway through data collection. This might cause an issue for triathletes looking for consistent information. Because it is in the public domain, any online calculator is subject to change without warning. While the change in predicted overall finish time will likely not be drastic (mean change of 0:03:21 in the current study), it could be quite a large difference for some (max change of 0:23:13 in the current study). This would be enough to alter the training zones of athletes and change the way they approach the race itself.

One limitation of Study 2 is that the triathletes competed on a variety of courses across the United States, Canada, Europe, Australia, and New Zealand meaning that very few athletes raced on the same course on the same day. Therefore, it could be a limitation to compare triathletes who competed on different courses with different elevation changes, different race day weather, and potentially different length courses. While all races were Olympic distance, they could still vary slightly in distance for each discipline resulting in time correlations that are not as accurate as they would be if all participants had completed the same race.

Another limitation of Study 2 is that different models of the multisport GPS watch were used by participants. All were the same make (Garmin), but some participants had newer models of the watch (e.g., Forerunner 935) which use updated software that improves GPS accuracy (150). Different software programs use different algorithms to determine distance swam, cycled, or ran (151). So although each watch was made by Garmin, the newer models could have been more accurate due to newer software. This may have caused sub-optimal inter-device reliability in Study 2.

Future Research

Future research should observe a greater number and wider age-range of triathletes to ensure accurate predictions are being made by the equations, particularly the QT2 Systems online calculator. Furthermore, the five-minute cycle test at 4 W/kg used in the Schabort study should be modified to suit amateur triathletes. Instead of the submaximal intensity of 4 W/kg for elite triathletes (53,117,127), the test should be conducted at 95% of FTP for the use in amateur triathletes. This could improve the prediction of the Schabort equation with amateur triathletes.

It may also be in the interest of researchers to perform time trials instead of laboratory-based measurements. In the current study, only two of the four laboratory-based tests had a significant relationship with actual time in the swim, cycle, run, or overall finish (i.e., distance covered in the run of a combined 30-minute cycle/20-minute run and peak treadmill speed run). On the other hand, each of the time trial tests (i.e., 400-yard swim, FTP cycle, and 5km run) showed a significant relationship with their respective actual times, and all showed a significant relationship with overall finish time. However, only one of the time trials (the run) had a strong relationship with its respective finish time (i.e., actual triathlon run time) and overall finish time. The 400-yard swim and FTP cycle test had moderate relationships with actual triathlon swim time and actual triathlon cycle time, respectively. Finally, the FTP cycle showed a moderate relationship, and the 400-yard swim showed a low correlation, with overall triathlon finish time, respectively. It may behoove researchers to determine if a certain distance time trial is more effective at predicting actual triathlon race times for the swim, cycle, and run disciplines, and overall triathlon finish time.

Future research should assess more of these performance-related variables to determine if any are more important than those analyzed in the current study. Additionally, these performance-related variables should be assessed during different triathlon race distances (e.g., Ironman). Perhaps there are variables that are more important during the long-course triathlons than the short-course triathlons.

An impactful variable for the swim discipline could be average stroke rate. While stroke rate has not been shown to be impactful in previous studies (93,118,123), these were all performed in a pool whereas triathlons are performed in open water. Having shorter, faster strokes could be more important in triathlon swimming because of the rough open water compared to the smooth water of the pool. The rough water of a triathlon swim could make a longer stroke less efficient because the swimmer will not glide as far as they would in a calm pool. Conversely, having a faster, but less propulsive turnover, may allow the swimmer to maintain velocity during the rough open water swim. This hypothesis has not been examined and could be a key aspect of future research.

A meaningful variable for the cycle discipline could be average power output. In the current study, post-hoc analyses showed that faster, more advanced triathletes produced greater power outputs during the cycle discipline of the triathlon. However, only 41 of the 130 participants in the current study used a power meter. The majority of those (53.7%) were Advanced and just one Beginner reported power output data. Obtaining more power output data from a wider range of triathletes could be useful in determining the contribution of power output to cycle and overall triathlon finish time.

Ground contact time and vertical oscillation (the vertical motion of an individual while running) could be important variables for future research of the run discipline during a triathlon. According to previous research, average ground contact time was significantly shorter in more advanced, faster runners than novice runners (152). Strength training is one avenue through which runners could decrease ground contact time (148). Additionally, a greater vertical oscillation has been seen during a triathlon run and a marathon run when compared to an isolated run of 45 minutes (143). According to the authors, the greater vertical oscillation is indicative of increased levels of fatigue. This could imply that runners should focus on strength training to decrease ground contact time and delay fatigue through improved rate of force development and improved maximal strength (148).

APPENDICES

APPENDIX A: Study 1 Consent Form

You are being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

Study Title: Physiological and performance-related variables that predict success in the sport of triathlon

Researcher: Todd Buckingham, MA
Department and Institution: Michigan State University Department of Kinesiology

Contact Information: 308 West Circle Drive, Rm 40, East Lansing MI 48824; cell phone: 231.349.7801; email: buckin21@msu.edu

Responsible Project Investigator: Karin Pfeiffer, Ph.D., FACSM

1. PURPOSE OF RESEARCH

- You are being asked to participate in a research study that aims to examine factors related to triathlon performance.
- You have been selected as a possible participant in this study because you are 24 years of age or younger, have been participating in triathlon training for at least six months, and plan to compete, or have already competed, in an Olympic-distance triathlon during the 2017 triathlon season.
- From this study, we hope to determine which scientific equations or online calculator will best predict your performance in the Olympic-distance triathlon race.
- Your participation in this study will involve six different exercise tests. Three will be performed in a laboratory setting with the researchers and the other three will be completed on your own. We will also ask you to complete a short questionnaire that asks about your participation in triathlon and other sports.
- The study will span approximately 4-6 weeks and involve 50 collegiate triathletes.

2. WHAT YOU WILL DO

- There will be 3 study visits that will take place either in the Human Energy Research Lab (HERL) at IM Circle on the campus of Michigan State University or in the Running Science Lab at Rackham Hall on the campus of Eastern Michigan University.
- Each visit will take ~30-60 minutes and entail a different test each visit. You will be asked to do the following:
    - Complete a questionnaire on your participation in triathlon and other sports
    - Have your height and weight assessed, and have your body composition measured in a BodPod
    - Perform a peak treadmill speed test, a cycle test, and a combined cycle-run test
        - For each of these tests you will have your blood lactate measured by an experienced technician at the end of each test, which involves poking your fingertip with a small needle
        - For the peak treadmill speed test, you will have your oxygen consumption measured by a mouth piece while you are running

- For the remaining three tests, you will be required to complete these on your own over the course of 4-6 weeks, prior to or just following your Olympic-distance triathlon race, and report your results to the researchers.

3. POTENTIAL BENEFITS

- After completing the tests, you will find out which equation or calculator gave the best estimated performance time for the Olympic-distance triathlon race. You will also receive a measurement of your maximal aerobic capacity (VO_2max) and your body fat percent. Additionally, you will gain the normal training benefits that accompany high-intensity exercise.

4. POTENTIAL RISKS

- The study involves high intensity exercise and therefore carries the normal risks typically associated with exercise (e.g., fatigue, delayed onset muscle soreness).
- The survey should not cause distress as there are no right or wrong answers. Questions can be left unanswered if you choose.
- You will have a small amount of blood drawn from your fingertip at the end of the peak treadmill speed test and the laboratory cycle tests, but it should not cause any distress (may have slight discomfort).

5. PRIVACY AND CONFIDENTIALITY

- Information about you will be kept confidential to the maximum extent allowable by law. You will be assigned a study ID number that will be used on all study documents where data are recorded. Your collected data will be stored separately from your name or any identifying information.
- Your name and identifying information will be stored for 3 years in a locked drawer in IM Circle at Michigan State University. After that, your identifying information will be destroyed.
- The results of this study may be published or presented at professional meetings, but the identities of all research participants will remain anonymous.
- The following people will have access to the Study ID number with associated data: Researchers and research staff and individuals from the Human Research Protection Program at Michigan State University.

6. YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW

- Participation is voluntary. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.
- You have the right to say no.
- You may change your mind at any time and withdraw.
- You may choose not to answer specific questions or to stop participating at any time.

7. COSTS AND COMPENSATION FOR BEING IN THE STUDY

- You will be responsible for your transportation costs to and from the study.
- Upon completion of all the tests, you will be given a $20 gift card. Additionally, you will be able to complete multiple laboratory tests (VO_2max and body fat percent) that normally cost between $100 and $300 each. The tests will also allow you to gain knowledge that can help you in your future triathlon races.

8. THE RIGHT TO GET HELP IF INJURED

- *No costs will be paid.*
- If you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining emergency care, if necessary, for your research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or in excess of what are paid by your insurance, including deductibles, will be your responsibility. The University's policy is not to provide financial compensation for lost wages, disability, pain or discomfort, unless required by law to do so. This does not mean that you are giving up any legal rights you may have. You may contact Todd Buckingham (231.349.7801) or Karin Pfeiffer (517.353.5222) with any questions or to report an injury.

9. CONTACT INFORMATION

- If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher, Todd Buckingham at 231.349.7801, email buckin21@msu.edu, or regular mail at 308 W. Circle Dr. Rm 40, East Lansing MI 48824. You may also contact the responsible project investigator, Dr. Karin Pfeiffer, at 517.353.5222 or kap@msu.edu.
- If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at Olds Hall, 408 West Circle Drive #207, MSU, East Lansing, MI 48824.

10. DOCUMENTATION OF INFORMED CONSENT

Your signature below means that you voluntarily agree to participate in this research study. You will be given a copy of this form to keep. By signing you also verify that you:

- Are 24 years of age or younger
- Have been involved in consistent triathlon training for the past 6 months
- Plan to complete, or have already completed, an Olympic-distance triathlon during the 2017 triathlon season

APPENDIX B: Study 1 Parental Consent Form

Your child is being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

Study Title: Physiological and performance-related variables that predict success in the sport of triathlon

Researcher: Todd Buckingham, MA
Department and Institution: Michigan State University Department of Kinesiology

Contact Information: 308 West Circle Drive, Rm 40, East Lansing MI 48824; cell phone: 231.349.7801; email: buckin21@msu.edu

Responsible Project Investigator: Karin Pfeiffer, Ph.D., FACSM

1. PURPOSE OF RESEARCH

- Your child is being asked to participate in a research study that aims to examine factors related to triathlon performance.
- Your child has been selected as a possible participant in this study because he/she is younger than 18 years of age, has been participating in triathlon training for at least six months, and plans to compete, or has already competed, in an Olympic-distance triathlon during the 2017 triathlon season.
- From this study, we hope to determine which scientific equations or online calculator will best predict your child's performance in the Olympic-distance triathlon race.
- Your child's participation in this study will involve six different exercise tests. Three will be performed in a laboratory setting with the researchers and the other three will be completed on your child's own. We will also ask your child to complete a short questionnaire that asks about his/her participation in triathlon and other sports.
- The study will span approximately 4-6 weeks and involve 50 collegiate triathletes.

2. WHAT YOU WILL DO

- There will be 3 study visits that will take place either in the Human Energy Research Lab (HERL) at IM Circle on the campus of Michigan State University or in the Running Science Lab at Rackham Hall on the campus of Eastern Michigan University.
- Each visit will take ~30-60 minutes and entail a different test each visit. Your child will be asked to do the following:
    - Complete a questionnaire on your participation in triathlon and other sports
    - Have height and weight assessed, and have body composition measured in a BodPod
    - Perform a peak treadmill speed test, a cycle test, and a combined cycle-run test
        - For each of these tests your child will have your blood lactate measured by an experienced technician at the end of each test, which involves poking your child's fingertip with a small needle
        - For the peak treadmill speed test, your child will have your oxygen consumption measured by a mouth piece while s/he is running

- For the remaining three tests, your child will be required to complete these on your own over the course of 4-6 weeks, prior to, or just after, the Olympic-distance triathlon race, and report his/her results to the researchers.

3. POTENTIAL BENEFITS

- After completing the tests, your child will find out which equation or calculator gave the best estimated performance time for the Olympic-distance triathlon race. Your child will also receive a measurement of his/her maximal aerobic capacity (VO_2max) and body fat percent. Additionally, your child will gain the normal training benefits that accompany high-intensity exercise.

4. POTENTIAL RISKS

- The study involves high intensity exercise and therefore carries the normal risks typically associated with exercise (e.g., fatigue, delayed onset muscle soreness).
- The survey should not cause distress as there are no right or wrong answers. Questions can be left unanswered if your child chooses.
- Your child will have a small amount of blood drawn from his/her fingertip (similar to a blood glucose measurement for diabetics) at the end of the peak treadmill speed test and the laboratory cycle tests, but it should not cause any distress (may have slight discomfort).

5. PRIVACY AND CONFIDENTIALITY

- Information about your child will be kept confidential to the maximum extent allowable by law. Your child will be assigned a study ID number that will be used on all study documents where data are recorded. Your child's collected data will be stored separately from his/her name or any identifying information.
- Your child's name and identifying information will be stored for 3 years in a locked drawer in IM Circle at Michigan State University. After that, any identifying information will be destroyed.
- The results of this study may be published or presented at professional meetings, but the identities of all research participants will remain anonymous.
- The following people will have access to the Study ID number with associated data: Researchers and research staff and individuals from the Human Research Protection Program at Michigan State University.

6. YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW

- Participation is voluntary. Refusal to participate will involve no penalty or loss of benefits to which your child is otherwise entitled. Your child may discontinue participation at any time without penalty or loss of benefits to which your child is otherwise entitled.
- Your child has the right to say no.
- Your child may change his/her mind at any time and withdraw.
- Your child may choose not to answer specific questions or to stop participating at any time.

7. COSTS AND COMPENSATION FOR BEING IN THE STUDY

- Your child will be responsible for your transportation costs to and from the study.
- Upon completion of all the tests, your child will be given a $20 gift card. Additionally, s/he will be able to complete multiple laboratory tests (VO_2max and body fat percent) that normally cost between $100 and $300 each. The tests will also allow your child to gain knowledge that can help him/her in future triathlon races.

8. THE RIGHT TO GET HELP IF INJURED

- *No costs will be paid.*
- If your child is injured as a result of your participation in this research project, Michigan State University will assist him/her in obtaining emergency care, if necessary, for research related injuries. If your child has insurance for medical care, your child's insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or in excess of what are paid by your child's insurance, including deductibles, will be your responsibility. The University's policy is not to provide financial compensation for lost wages, disability, pain or discomfort, unless required by law to do so. This does not mean that you are giving up any legal rights you may have. You may contact Todd Buckingham (231.349.7801) or Karin Pfeiffer (517.353.5222) with any questions or to report an injury.

9. CONTACT INFORMATION

- If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher, Todd Buckingham at 231.349.7801, email buckin21@msu.edu, or regular mail at 308 W. Circle Dr. Rm 40, East Lansing MI 48824. You may also contact the responsible project investigator, Dr. Karin Pfeiffer, at 517.353.5222 or kap@msu.edu.
- If you have questions or concerns about your child's role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at Olds Hall, 408 West Circle Drive #207, MSU, East Lansing, MI 48824.

10. DOCUMENTATION OF INFORMED CONSENT

Your signature below means that you voluntarily agree to allow your child to participate in this research study. You will be given a copy of this form to keep. By signing you also verify that your child:

- Is younger than 18 years of age
- Has been involved in consistent triathlon training for the past 6 months
- Plans to complete, or has already completed, an Olympic-distance triathlon during the 2017 triathlon season

APPENDIX C: Study 1 Assent Form

You are being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

Study Title: Physiological and performance-related variables that predict success in the sport of triathlon

Researcher: Todd Buckingham, MA
Department and Institution: Michigan State University Department of Kinesiology

Contact Information: 308 West Circle Drive, Rm 40, East Lansing MI 48824; cell phone: 231.349.7801; email: buckin21@msu.edu

Responsible Project Investigator: Karin Pfeiffer, Ph.D., FACSM

1. PURPOSE OF RESEARCH

- You are being asked to participate in a research study that aims to examine factors related to triathlon performance.
- You have been selected as a possible participant in this study because you are currently younger than 18 years of age, have been participating in triathlon training for at least six months, and plan to compete, or have already competed, in an Olympic-distance triathlon during the 2017 triathlon season.
- From this study, we hope to determine which scientific equations or online calculator will best predict your performance in the Olympic-distance triathlon race.
- Your participation in this study will involve six different exercise tests. Three will be performed in a laboratory setting with the researchers and the other three will be completed on your own. We will also ask you to complete a short questionnaire that asks about your participation in triathlon and other sports.
- The study will span approximately 4-6 weeks and involve 50 collegiate triathletes.

2. WHAT YOU WILL DO

- There will be 3 study visits that will take place either in the Human Energy Research Lab (HERL) at IM Circle on the campus of Michigan State University or in the Running Science Lab at Rackham Hall on the campus of Eastern Michigan University.
- Each visit will take ~30-60 minutes and entail a different test each visit. You will be asked to do the following:
    - Complete a questionnaire on your participation in triathlon and other sports
    - Have your height and weight assessed, and have your body composition measured in a BodPod
    - Perform a peak treadmill speed test, a cycle test, and a combined cycle-run test
        - For each of these tests you will have your blood lactate measured by an experienced technician at the end of each test, which involves poking your fingertip with a small needle
        - For the peak treadmill speed test, you will have your oxygen consumption measured by a mouth piece while you are running

- For the remaining three tests, you will be required to complete these on your own over the course of 4-6 weeks, prior to, or just after, your Olympic-distance triathlon race, and report your results to the researchers.

3. POTENTIAL BENEFITS

- After completing the tests, you will find out which equation or calculator gave the best estimated performance time for the Olympic-distance triathlon race. You will also receive a measurement of your maximal aerobic capacity (VO_2max) and your body fat percent. Additionally, you will gain the normal training benefits that accompany high-intensity exercise.

4. POTENTIAL RISKS

- The study involves high intensity exercise and therefore carries the normal risks typically associated with exercise (e.g., fatigue, delayed onset muscle soreness).
- The survey should not cause distress as there are no right or wrong answers. Questions can be left unanswered if you choose.
- You will have a small amount of blood drawn from your fingertip at the end of the peak treadmill speed test and the laboratory cycle tests, but it should not cause any distress (may have slight discomfort).

5. PRIVACY AND CONFIDENTIALITY

- Information about you will be kept confidential to the maximum extent allowable by law. You will be assigned a study ID number that will be used on all study documents where data are recorded. Your collected data will be stored separately from your name or any identifying information.
- Your name and identifying information will be stored for 3 years in a locked drawer in IM Circle at Michigan State University. After that, your identifying information will be destroyed.
- The results of this study may be published or presented at professional meetings, but the identities of all research participants will remain anonymous.
- The following people will have access to the Study ID number with associated data: Researchers and research staff and individuals from the Human Research Protection Program at Michigan State University.

6. YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW

- Participation is voluntary. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.
- You have the right to say no.
- You may change your mind at any time and withdraw.
- You may choose not to answer specific questions or to stop participating at any time.

7. COSTS AND COMPENSATION FOR BEING IN THE STUDY

- You will be responsible for your transportation costs to and from the study.
- Upon completion of all the tests, you will be given a $20 gift card. Additionally, you will be able to complete multiple laboratory tests (VO_2max and body fat percent) that normally cost between $100 and $300 each. The tests will also allow you to gain knowledge that can help you in your future triathlon races.

8. THE RIGHT TO GET HELP IF INJURED

- *No costs will be paid.*
- If you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining emergency care, if necessary, for your research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or in excess of what are paid by your insurance, including deductibles, will be your responsibility. The University's policy is not to provide financial compensation for lost wages, disability, pain or discomfort, unless required by law to do so. This does not mean that you are giving up any legal rights you may have. You may contact Todd Buckingham (231.349.7801) or Karin Pfeiffer (517.353.5222) with any questions or to report an injury.

9. CONTACT INFORMATION

- If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher, Todd Buckingham at 231.349.7801, email buckin21@msu.edu, or regular mail at 308 W. Circle Dr. Rm 40, East Lansing MI 48824. You may also contact the responsible project investigator, Dr. Karin Pfeiffer, at 517.353.5222 or kap@msu.edu.
- If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at Olds Hall, 408 West Circle Drive #207, MSU, East Lansing, MI 48824.

10. DOCUMENTATION OF INFORMED CONSENT

Your signature below means that you voluntarily agree to participate in this research study. You will be given a copy of this form to keep. By signing you also verify that you:

- Are younger than 18 years of age
- Have been involved in consistent triathlon training for the past 6 months
- Plan to complete, or have already completed, an Olympic-distance triathlon during the 2017 triathlon season

APPENDIX D: Study 1 Questionnaire

1. Name: ____________________________
2. Team: ____________________________
3. Did you complete or do you plan to complete an Olympic-distance triathlon during the 2017 triathlon season?
    a. Yes
    b. No
4. What is the name of the nearest Olympic-distance triathlon you completed or plan to complete?
    a. _________________________________
5. What is your gender?
    a. Male
    b. Female
6. What is your date of birth?

    a. _______ /_______ /________
7. How long have you been competing in triathlon?

    a. ______________ years
8. How many triathlons do you complete in each year?
    a. 1-2 races
    b. 3-4 races
    c. 5-6 races
    d. 7-8 races
    e. 9+ races
9. What distance triathlon do you primarily compete in?
    a. Sprint
    b. Olympic
    c. 70.3 (Half-Ironman)
    d. Ironman

10. What was your primary competitive sport prior to triathlon? Primary means the sport you competed in during high school and/or college or you began to participate in competitions in that sport after school.
    a. Swimming
    b. Cycling
    c. Running
    d. Baseball/softball
    e. Basketball
    f. Football
    g. Soccer
    h. Water polo
    i. Volleyball
    j. Other
        i. Please list
    k. None

11. What are your personal records for each of the following? (Circle N/A if you have not done one of them) (hh:mm:ss)
    a. Olympic-distance triathlon swim time: _______ : _______ : _______ (N/A)
    b. Olympic-distance triathlon bike time: _______ : _______ : _______ (N/A)
    c. Olympic-distance triathlon run time: _______ : _______ : _______ (N/A)
    d. Olympic-distance triathlon overall time: _______ : _______ : _______ (N/A)
    e. Standalone 100m swim time: _______ : _______ : _______ (N/A)
    f. Standalone 400m swim time: _______ : _______ : _______ (N/A)
    g. Standalone 1500m swim time: _______ : _______ : _______ (N/A)
    h. Standalone 20k cycle time: _______ : _______ : _______ (N/A)
    i. Standalone 40k cycle time: _______ : _______ : _______ (N/A)
    j. Standalone 5k run time: _______ : _______ : _______ (N/A)
    k. Standalone 10k run time: _______ : _______ : _______ (N/A)
    l. Standalone marathon run time: _______ : _______ : _______ (N/A)

12. Why do you compete in triathlon?
    a. To stay in shape
    b. Personal challenge
    c. Competition
    d. Other
        i. ________________________________

13. What is the average time you spend training each week? (hh:mm:ss)

    a. Swimming: ____ : ____ : ____

    b. Cycling: ____ : ____ : ____

    c. Running: ____ : ____ : ____

    d. Strength/other: ____ : ____ : ____

14. What is the average distance you cover during training each week?

    a. Swimming: _____________________ yards

    b. Cycling: ___________________ miles

    c. Running: _________________miles

APPENDIX E: Study 2 Consent Form

You are being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

Study Title: Physiological and performance-related variables that predict success in the sport of triathlon

Researcher: Todd Buckingham, MA
Department and Institution: Michigan State University Department of Kinesiology

Contact Information: 308 West Circle Drive, Rm 40, East Lansing MI 48824; cell phone: 231.349.7801; email: buckin21@msu.edu

Responsible Project Investigator: Karin Pfeiffer, Ph.D., FACSM

1. PURPOSE OF RESEARCH

- You are being asked to participate in a research study to look at what multisport watch-measured factors affect triathlon performance.
- You have been selected as a possible participant in this study because you are 18 years or older, competed or will compete in an Olympic distance triathlon, and have a multisport triathlon watch that recorded or will record your performance in this race.
- From this study, we hope to learn what factors affect triathlon performance. Specifically, we want to see which variables measured by your multisport watch play the largest role in your finish time in each of the three disciplines and in the overall triathlon.
  Your participation in this study will take about 10 minutes. We will ask you to complete a short questionnaire that asks about your participation in triathlon and other sports. We will also ask you to copy and paste a link from Garmin Connect of your Olympic distance triathlon race as measured by your multisport watch.

2. WHAT YOU WILL DO

- Complete a questionnaire that asks about your participation in triathlon and other sports.
- Copy and paste a link from Garmin Connect of your Olympic distance triathlon race information as measured by your multisport watch to the end of the survey.
  - Information gathered from this link will include:
    - SWOLF swim score, cycling cadence, and running stride length
  - Time to complete each discipline and the overall race will be attained from the race website
    - In the questionnaire, we ask that you provide us with your bib number from the race in order to look these times up
  - If you do not have, or do not provide, multisport watch data, we will not be able to use your information. Please wait until you have multisport watch data for each of the three disciplines from a recent Olympic distance triathlon and complete the survey then.
    - To see a detailed list of instructions on what you need to do prior to competing in the race, please visit www.toddbuckingham.com/blog/todds-triathlon-study

3. POTENTIAL BENEFITS

- You will not directly benefit from participation in this study. However, you will obtain information that could potentially improve your training and racing performance.

4. POTENTIAL RISKS

- There are no foreseeable risks associated with participation in this study. Online communication is not perfectly secure, but every step will be taken to protect your anonymity.
- The survey should not cause distress as there are no right or wrong answers to the questionnaire. Questions can be left unanswered if you choose.

5. PRIVACY AND CONFIDENTIALITY

- Information about you will be kept confidential to the maximum extent allowable by law. You will be assigned a study ID number that will be used on all study documents where data are recorded. Your collected data will be stored separately from your name or any identifying information.
- Your name and identifying information will be stored for 3 years in a locked drawer in IM Circle at Michigan State University. After that, your identifying information will be destroyed.
- The results of this study may be published or presented at professional meetings, but the identities of all research participants will remain anonymous.
- The following people will have access to the Study ID number with associated data: Researchers and research staff and individuals from the Human Research Protection Program.

6. YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW

- Participation is voluntary. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.
- You have the right to say no.
- You may change your mind at any time and withdraw.
- You may choose not to answer specific questions or to stop participating at any time.

7. COSTS AND COMPENSATION FOR BEING IN THE STUDY

- Participation will not cost you anything
  You will not be paid for participating in the study. However, you will gain knowledge that can help you in your future triathlon races.

8. CONTACT INFORMATION

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher, Todd Buckingham at 231.349.7801, email buckin21@msu.edu, or regular mail at 308 W. Circle Dr. Rm 39, East Lansing MI 48824. You may also contact the responsible project investigator, Dr. Karin Pfeiffer, at 517.353.5222 or kap@msu.edu.

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at Olds Hall, 408 West Circle Drive #207, MSU, East Lansing, MI 48824.

9. DOCUMENTATION OF INFORMED CONSENT.

Checking the box below means that you voluntarily agree to participate in this research study. By agreeing, you also verify that you:

- Are older than 18 years of age
- Completed an Olympic distance triathlon race
- Have a multisport triathlon watch that recorded your race performance

Do you give consent to participate in this study?

- I agree and wish to continue with the study
- I do not agree and do not wish to continue with the study

APPENDIX F: Study 2 Questionnaire

1. Which Olympic distance race have you most recently competed in that you have multisport watch data for?
    a. Fill in the blank
2. What was your bib number for that race?
    a. Fill in the blank
3. What is your gender?
    a. Male
    b. Female
4. What is your date of birth?
    a. (mm/dd/yyyy)
5. What was your race height, in inches?
    a. Fill in the blank
6. What was your race weight, in pounds?
    a. Fill in the blank
7. What age group did you compete in at the race?
    a. 18-19
    b. 20-24
    c. 25-29
    d. 30-34
    e. 35-39
    f. 45-49
    g. 50-54
    h. 55-59
    i. 60-64
    j. 65-69
    k. 70-74
    l. 75-79
    m. 80-84
    n. 85+
8. How long have you been competing in triathlon?
    a. Fill in the blank
9. How many triathlons do you compete in each year?
    a. 1-2 races
    b. 3-4 races
    c. 5-6 races
    d. 7-8 races
    e. 9+ races
10. What distance triathlon do you primarily compete in?
    a. Sprint
    b. Olympic
    c. 70.3 (Half-Ironman)
    d. Ironman
11. What level triathlete do you consider yourself?
    a. Beginner (just starting out)
    b. Intermediate (not a beginner, but typically not finishing at the top of your age-group)

    c. Advanced (elite age-grouper typically finishing in the top 3 in your age-group)
    d. Professional (hold an elite license)

12. What was your <u>primary</u> competitive sport prior to triathlon? Primary meaning the sport you competed in during high school and/or college or you began to participate in competitions in that sport after school.
    a. Baseball/softball
    b. Basketball
    c. Cycling
    d. Football
    e. Running
    f. Soccer
    g. Swimming
    h. Volleyball
    i. Other
        i. Please list
    j. None, triathlon has always been my primary sport
13. Why do you compete in triathlon?
    a. To stay in shape
    b. For fun
    c. Personal challenge
    d. Competition
    e. Other
        i. Please list
14. What are your personal records for each of the following? (Leave the box blank if you do not have a personal record for an option).
    a. Olympic-distance triathlon swim time:
    b. Olympic-distance triathlon bike time:
    c. Olympic-distance triathlon run time:
    d. Olympic-distance triathlon overall time:
    e. Standalone 100m swim time:
    f. Standalone 400m swim time:
    g. Standalone 1500m swim time:
    h. Standalone 20km cycle time:
    i. Standalone 40km cycle time:
    j. Standalone 5km run time:
    k. Standalone 10km run time:
    l. Standalone half-marathon run time
    m. Standalone marathon run time:
15. What is the average time you spend training each week?
    a. Swimming:
    b. Cycling:
    c. Running:
    d. Strength/other:
16. What is the average distance you cover during training each week?
    a. Swimming:

b. Cycling:
c. Running:

17. Please copy the link from your triathlon multisport watch from the most recent race you competed in. This is the important part! If you do not have multisport watch data for each of the three disciplines from your most recent Olympic-distance triathlon, please end the survey now and complete it once you have this data.
    a. To copy the link, go to the Garmin Connect website (www.garminconnect.com) and sign in with your username and password
    b. Click on the menu button (three lines in the top left corner) and then click 'Calendar'
    c. Go to the date when you completed your most recent triathlon, click the activity for the race (a separate window will open on the page), and click 'View Details'
    d. Click the 'Privacy' button (the lock shaped icon in the top right corner) and click 'Everyone'
    e. Copy the link url (e.g, https://connect.garmin.com/modern/activity/8675309) and paste it here
        i. Upload spot for file here
18. Is there anything else you would like us to know?
    a. Fill in the blank

APPENDIX G: Study 1 Testing Directions

Peak treadmill speed

1. Instructions
    a. A researcher will set the slope of the treadmill to 1%
    b. A stopwatch will be used to record time
    c. Participants will be fitted with a Hans Rudolph mouthpiece to measure expired air in order to estimate the athlete's VO_2 peak
2. Warm-up
    a. 5-minute run at 6.2 mph for women and 7.5 mph for men
3. Rest for 5 minutes before beginning the incremental running test to exhaustion
4. Maximal test
    a. Start running at 6.8 mph for women and 8.1 mph for men
    b. Maintain this speed for 60 seconds
    c. Speed will be increased by 0.6 mph every minute until exhaustion
5. The athlete's peak treadmill speed will be taken as the highest speed s/he is able to maintain for the entire 60-second stage.
    a. If s/he is unable to complete the full 60-second stage, peak treadmill speed will be determined as a fraction of the final speed added to the speed of the immediately preceding stage's speed they were able to complete
        - E.g., if the athlete makes it to 11.0 mph and completes 20 seconds at 11.6 mph, the peak treadmill speed will be 11.2 mph
            - 20s/60s = 1/3
            - 11.6 – 11.0 = 0.6 mph
            - 1/3 x 0.6 mph = 0.2 mph
            - 0.2 + 11 = 11.2 mph

FTP cycle test

1. Instructions
    a. Using your own bicycle (or the Phantom 3 cycle trainer), set up the CompuTrainer indoor cycle trainer (or Phantom 3 cycle trainer) to ride on a flat course
    b. Use a stopwatch or your triathlon/running watch to record time
    c. Warm up with 15 minutes of easy cycling
    d. Calibrate the Computrainer (or Phantom 3 cycle trainer)
2. Warm-up
    a. Perform three one-minute efforts at a high cadence (not high power) followed by one-minute of easy cycling after each effort
        i. 3 x (1' HC/1' easy)
    b. 5 minutes of easy cycling
    c. 5 minutes of all-out cycling
        i. Go hard, but not so hard that you die before the end. This is to open up the legs and prepare for the 20-minute effort
    d. 5-10 minutes of easy cycling
3. 20-minute FTP test
    a. This should be the fastest possible speed you can sustain for the entire 20 minutes
4. 10 minutes very easy cool-down

5. Upon completion of the test, record your average power for the 20-minute FTP test and send it via email to the PI (Todd Buckingham, buckin21@msu.edu)

400-yard swim TT

1. Warm-up
    a. 200 yards of light swimming
    b. 9 x 50 yards descending 1-3, 4-6, 7-9 with 15 seconds of rest after each 50 yards
        i. Descending means that your times get faster as you go
        ii. So #1 is slower than #2 is slower than #3, #4 is slower than #5 is slower than #6, and #7 is slower than #8 is slower than #9
    c. 50 yards of easy swimming
    d. 100 yards with the first 25 at estimated time trial (TT) pace and 75 yards easy
2. 1-2 minutes of rest before starting the 400-yard TT
3. 400-yard TT
    e. Swim 400 yards as fast as possible

Cycle lactate test

1. Participants will use his/her own cycle or the Phantom 3 cycle trainer
2. A researcher will set up the CompuTrainer indoor cycle trainer (or Phantom 3 cycle trainer) to ride on a flat course
3. A stopwatch will be used to record time
4. Warm-up
    a. 5 minutes of pedaling at 2 W/kg.
5. 4 W/kg testing
    b. Immediately following the 5-minute warm-up ride at 2 W/kg, participants will have his/her workload increased to 4 W/kg
    c. Ride for 3-4 minutes until steady-state has been reached (HR does not change by more than 5bpm within a 30-second time-period)
        i. During the final 30 seconds of the workload, blood will be drawn from the participant's fingertip to determine blood lactate concentration
6. *NOTE: If the athletes are unable to complete the 4W/kg tests, s/he will perform a modified version and cycle at 74% or 82% (men or women, respectively) of the average power obtained from the 20-minute FTP test, instead of the 4W/kg test

5km run

1. Instructions
    a. Set the slope of the treadmill to 1%
    b. Use a multisport/running watch or stopwatch to record time
2. Warm-up
    c. 5 minutes of easy running
    d. 2 x 20 seconds building to 1-mile pace with 40 seconds of easy running after each
    e. 1 minute of easy running
    f. 1 minute of running at the pace the athlete will try to maintain for the duration of the 5km TT
    g. 30 seconds of easy running followed by 30 seconds of walking
3. Press 'Stop' on the treadmill to reset the distance

4. 1-2 minutes stepping off the treadmill to prepare for the 5km TT
5. 5km Test
    h. This should be the fastest Press 'Start' on the treadmill and increase the speed to desired 5km pace
6. Once the treadmill gets up to speed, note the distance on the display and add this number to 3.10 miles (5km)
    i. E.g., you started the treadmill and it takes 30 seconds to increase the speed to 8 mph (7:30/mile). During this time, the treadmill belt has traveled 0.04 mile which is reflected on the treadmill display. Once you step on the treadmill and start running, you will need to run until the treadmill reads 3.14 miles (because of the 0.04 mile that the treadmill belt traveled before you started running).
7. *NOTE: If you are able to run outside instead of on the treadmill, please do so. Keep in mind the following criteria:
    a. You should be able to run the full 3.10 miles without having to stop. Pick a course or route that allows you to do so
    b. 12.5 laps on a 400m track (25 laps on a 200m track)
    c. Your course should be relatively flat. If you have to repeat the same loop multiple times to accomplish this, that is okay
    d. Poor weather conditions can adversely affect your time. Snow, rain, ice, and wind are all prevalent this time of year and could cause you to run slower than normal. Choose a day with moderate temperatures, clear roads, and no precipitation
    e. If you are not able to find a course that fits these requirements and if the weather is not ideal, please perform the test on the treadmill
8. After you complete the 5km run, record the time it took to complete and send it via email to the PI (Todd Buckingham, buckin21@msu.edu)

30-minute cycle/20-minute run test

1. Instructions
    a. Participants will perform a 30-minute cycle test followed by a 20-minute run test
        ii. Participants will perform these tests as fast as possible
    b. Cycle
        iii. Participants will perform the test using his/her own bicycle with the RacerMate CompuTrainer or on the stationary CycleOps Phantom 3 indoor cycle trainer
        iv. At the end of the 30-minute cycling, athletes will have blood drawn from their fingertip to measure lactate concentration
        v. S/he will have one minute to change from his/her cycling shoes to running shoes and begin the treadmill test
            - This time corresponds to a bike-run transition time in a triathlon
    c. Run
        vi. Use a multisport/running watch to record time
        vii. Set the treadmill to 1%
        viii. Set the treadmill speed close to that which you would run in a triathlon race
            - You will be able to adjust the speed throughout the test to optimize performance

ix. Once the treadmill gets up to speed, note the distance on the display and subtract this number from your total distance at the end of the 20 minutes
    - E.g., you started the treadmill and it takes 30 seconds to increase the speed to 8 mph (7:30/mile). During this time, the treadmill belt has traveled 0.04 mile which is reflected on the treadmill display. After the 20 minutes are over, the treadmill reads 2.71 miles. Subtract 0.04 mile (because of the 0.04 mile that the treadmill traveled before you started running) to get your final distance of 2.67 miles.

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