STRENGTH AND POWER CONTRIBUTIONS FOR SWIM EVENTS OF 100 YARDS

A Thesis

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Abstract:
This study investigates the contributions of strength and power of the 100 yard swimming events across all four strokes. A retrospective analysis was completed on 49 Division I athletes. Swimmers performed a battery of tests involving a countermovement jump [CMJ], an isometric belt squat [IBSQT], plyometric push up, 1-RM neutral grip pull-up, and an eccentric hamstring strength assessment. A Pearson's correlation analysis was used to find relationships between the performance variables and the swim events. 50 yard splits were also examined for 3 of the 4 strokes to identify any differences between the correlations of the 3 different times per stroke. The results showed that strength and power qualities were expressed earlier in the swim and decreased as the swim progressed in freestyle and butterfly. The opposite effect was seen with the breaststroke, and no correlations were made with the 100yd backstroke. A correlation study does not provide a causal explanation, but it does offer researchers and coaches a roadmap of the qualities expressed in a 100 yard swim. This could help coaches and researchers alike identify important qualities to train for and test for success in competitive swimming.

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CHAPTER 1

INTRODUCTION

Competitive Swimming

Competitive swimming is one of the most popular sports in the world, with its popularity continuing to increase, as evidenced by nearly 35 million registered aquatic athletes (Holub et al., 2025; Keith, 2019). It is a sport that requires repetitive motion and demands varying amounts of energy due to the different distances involved in multiple events (Almeida et al., 2020; Raineteau et al., 2023). Competitive swimming is comprised of four strokes: freestyle, backstroke, breaststroke, and butterfly (Morouco et al., 2011). Races can range from 50 meters to 1,500 meters in distance (Liu & Wang, 2023). The level of competition becomes increasingly more difficult as the athletes become more advanced. The highest level of competition can be seen at the stages of the World Championships and the Olympic Games, as these are what showcase world-class talent (Ganchar et al., 2025; Konig et al., 2014; Ruiz-Navarro & Born, 2025).

There has been a steady increase in competitive swimming amongst high school and collegiate athletes across the United States, especially around the Olympic seasons (Cottle, 2017). For example, for the 2024-2025 season, the NCAA reported a total of 23,129 swim and dive athletes across Divisions I-III (NCAA, 2025). This was a 4.5% increase in participation over the past 10 years. College athletics, in particular, have opened up more opportunities for both men and women due to Title IX legislation, which has contributed to the increase in participation in many sports (Cheslock, 2008). College sports provide a clear pathway to the next step for athletes who show promise by excelling in their respective sport (McGuire, 2024). With the Olympic sports, such as water polo, tennis, track and field, and swimming, the next step may be attempting to qualify for the Olympic Games. To move forward, one must either qualify with specific times or achieve outstanding performances at the collegiate and international levels. College athletics can help bridge the gap for young athletes who require continued preparation to advance to the next level.

As swimming competitiveness increases, investments in sport performance and research have also risen to enhance knowledge about swim performance (Selvamoorthy et al., 2024; Stanula et al., 2012). Critical components of competitive swimming include start performance, swim velocity, and flip turn performance (Raineteau et al., 2023). Start performance can be broken down into the combination of reaction time, horizontal and vertical forces from the starting block, and the ability to create low resistance during underwater gliding (Beretic et al., 2013). The ability to produce force at a high rate, along with the amount of force produced, will be imperative to the success of the race (Beretic et al., 2013; Keiner et al., 2021). When it comes to swim velocity, this can be broken down into two key elements; stroke rate and stroke length (Keiner et al., 2021). Both stroke rate and length can be improved by improving maximal strength and power, as the swimmer needs to overcome drag forces and create greater propulsive forces (Barbosa et al., 2015; Keiner et al., 2015). Flip turn performance is similar to start performance in that it requires lower body strength and power to push off the wall (Keiner et al., 2021). However, flip turn success is not necessarily about producing the largest amount of force; it is a balance between limiting drag forces while generating force as you come off the wall (Lyttle et al., 1999). Swimming is a very technical sport, and effective technique is required to optimize performance. Nonetheless, developing the physical capacity of swimmers should also benefit performance. To this end, research has been conducted on the effects of strength and conditioning on swim performance (Amara et al., 2021; Amaro et al., 2017; Crowley et al., 2018; Illera-Delgado & Gea-Garcia, 2022).

Strength and Conditioning for Swimmers

Strength and conditioning refers to the physical and physiological development of athletes to enhance performance and reduce the likelihood of injury (Raineteau et al., 2023). Improving strength and power qualities has been shown to enhance the performance of athletes in various sports (Amara et al., 2021; Haruna et al., 2023; Lloyd et al., 2016; Smith et al., 2014). As stated previously, success in swimming often stems from a variety of variables, including block starts, stroke rate, stroke length, and flip turns (Illera-Delgado & Gea-Garcia, 2022; Keiner et al., 2021). Despite swimming being a highly technical skill, strength and power output play a significant role in determining an athlete's performance (Amaro et al., 2017; Beretic et al., 2013; Illera-Delgado & Gea-Garcia, 2022; Kao et al., 2018; Keiner et al., 2021; Zampagni et al., 2008). Additionally, aerobic and anaerobic capacity will play a significant role, depending on the intensity and duration of the specific event (Almeida et al., 2020).

Although there is evidence to suggest the importance of dry-land strength training, a lack of evidence exists regarding the association between dry-land strength and power performance metrics, as well as the success of swim performance for all four strokes. For example, Yang et al. (2025) investigated the effects of maximal strength training, plyometric training, and muscular endurance training on swimming-specific performance measures in college-aged swimmers and found that both maximal strength training and plyometric training were advantageous, as they improved swim performance. The swimming-specific performance measures in the study were as follows: start performance, 25m freestyle kick, 25m freestyle arm stroke without kick, 25m freestyle, and 50m freestyle. The authors found that all swimming-specific performance measures increased from pre- to post-testing, however, maximal strength and plyometric group, however, made the greatest improvements (Yang et al., 2025). The maximal strength group increased start flight distance ($p < 0.05$, $d = 0.492$ small), start 15m ($p < 0.05$, $d = -0.508$ small), 25 m freestyle kick ($p < 0.05$, $d = -0.421$ small), 25 m freestyle stroke ($p < 0.05$, $d = -0.682$ moderate), 25 m freestyle ($p < 0.05$, $d = -0.456$ small), and 50m freestyle ($p < 0.05$, $d = -0.418$ small). The plyometric group increased start flight distance ($p < 0.05$, $d = 0.278$ small), start 15 m ($p < 0.05$, $d = -0.406$ small), 25 m freestyle kick ($p < 0.05$, $d = -0.335$ small), 25m freestyle stroke ($p < 0.05$, $d = -0.265$ small), 25 m freestyle ($p < 0.05$, $d = -0.265$ small), and 50m freestyle ($p < 0.05$, $d = -0.254$ small). Similarly, Marques et al. (2020) examined the effects of a 20-week in-season strength training program on elite junior swimmers and found positive outcomes in strength and power metrics, as well as 50 m freestyle times. The authors found that the countermovement jump ($p < 0.001$, Hedges' $g = 0.57$), 1- repetition maximum squat ($p < 0.001$, Hedges'

$g = 0.46$), 1- repetition maximum bench press ($p < 0.001$, Hedges' $g = 0.34$), pull-up maximum repetition test ($p < 0.001$, Hedges' $g = 0.57$), and the 50 m freestyle swim ($p < 0.001$, Hedges' $g = 0.45$) all improved with the strength training program (Marques et al., 2020). Another study by Amara et al. (2021) examined the effects of a 9-week concurrent resistance training program (combining strength training and resistance training in water) versus a normal swim practice program on upper body strength, swim performance, and swim kinematics in competitive young swimmers. The in-water resistance program was scheduled to have the athletes use hand paddles and a water parachute on Monday and Thursday, hand paddles only on Tuesday, with water parachute only on Friday (Amara et al., 2021). Amara et al. (2021) found that concurrent training improved 1-RM bench press ($p < 0.001$, $d = 2.18$, large), 25 m freestyle ($p = 0.002$, $d = 1.62$, large), 50 m freestyle ($p = 0.009$, $d = 1.3$, large), 25 m freestyle arm stoke only ($p < 0.001$, $ES = 2.61$, large), 50 m freestyle arm stroke only ($p < 0.001$, $d = 2.59$, large), velocity to 10 m ($p = 0.001$, $d = 2.24$, large), and stroke rate to 10 m ($p < 0.001$, $d = 2.24$, large) (Amara et al., 2021). Accordingly, dry-land strength training can improve strength and power metrics and swim performance when applied appropriately.

Statement of the Problem

Although numerous studies have examined the relationships between dry-land performance metrics and swim performance (Amara et al., 2021; Beretic et al., 2013; Kao et al., 2018; Keiner et al., 2015; Morouco et al., 2011), most of the research has focused on the freestyle stroke. As a result, a clear gap exists in the literature regarding the relationships between dry-land performance tests and the other three strokes (i.e., backstroke, breaststroke, and butterfly). Knowledge of this may provide a better understanding of the qualities that are important to train when improving swim performance for all four strokes. Therefore, this study aims to examine the strength and power relationships between five dry-land performance tests (isometric belt-squat [IBSQT], 1 repetition maximum [1-RM] neutral grip pull-up, plyometric push-up, countermovement jump test [CMJ], and eccentric hamstring strength assessment) and the four strokes in the 100-yard swimming event.

Research Hypothesis

It was hypothesized that greater strength and power outcomes in the IBSQT, 1-RM neutral grip pull-up, plyometric push-up, CMJ, and eccentric hamstring strength assessment will be significantly associated with faster 100 yard swim performances across all four competitive strokes. It was further hypothesized that the magnitude of the associations will differ between the strokes due to biomechanical, technical, and neuromuscular differences of the four strokes. It was hypothesized that the IBSQT, 1-RM neutral grip pull-up, and the CMJ will have the strongest relationships with the freestyle, butterfly, and backstroke.

Delimitations

The delimitations of the study are as follows:

1. Data was collected by the strength and conditioning staff working with a Division I swim team.
2. The study was open to both male and female athletes from a Division I program.
3. Swimmers who participated in at least one test were included in the analysis; analyses were conducted using all available data. For instance, if an athlete could not perform the isometric belt squat but was able to perform the rest of the dry-land assessments, they were included in the statistical analysis.

CHAPTER 2

LITERATURE REVIEW

This chapter will examine the biomechanics of the four strokes, the critical components of swimming (starts, swim velocity, and flip turns), as well as the relationship between strength and power and their influence on swim performance. The biomechanical analysis will provide a better understanding of the movements involved in each stroke. A review of the critical components of swimming will offer insight into what is needed for a successful race. The relationship between strength and power and their impact on swim performance will also be discussed to explore which performance variables can enhance swim performance. The following section will review key gaps in the literature, with particular emphasis on the role of strength and power in influencing swimming performance, while highlighting the need for further research to better define and standardize the strength and power metrics used to evaluate and predict swim performance outcomes.

Biomechanical Analysis of the Start

The block start can be broken up into five phases: preparatory position, pull, drive, flight, and entry (Formicola & Rainoldi, 2015). The block start will be the same for freestyle, butterfly, and breaststroke; therefore, this section will cover the information needed for all three strokes as it pertains to the block start. During the preparatory phase, the swimmer assumes the desired starting position and, upon receiving the start signal, pulls from the block with their arms to generate force in the horizontal direction (Formicola & Rainoldi, 2015). The desired foot position may be the grab start, track start or the kick start (Dassoff et al., 2017; Takeda et al., 2017). The grab start is described by the swimmer placing both feet and hands at the front edge of the block (Takeda et al., 2017). The track start setup involves the swimmer placing one foot near the front edge of the block and the other foot near the back edge, with both hands gripping the front edge (Takeda et al., 2017). With the introduction of a new starting block that features a back plate, this addition created a new start, known as the kick start, which is incredibly similar to the track start, except that the rear foot is now placed on the back plate (Takeda et al., 2017).

Many studies have been conducted to identify the characteristics that make a specific start more optimal (Dassoff et al., 2017; Taladriz et al., 2015). Dassoff et al. (2017) compared the performance differences between grab start and track start and found that the start phase time was greater with the grab start (*p* < 0.001), flight phase time was greater with the grab start (*p* < 0.001), flight distance was greater with the grab start (*p* = 0.013), horizontal entrance velocity was slower with the grab start (*p* < 0.001), and entered the water with a shallower angle with the track start (*p* = 0.004). Dassoff et al. (2017) suggested the grab start was inferior to the track start, as it was slower to get off the blocks, resulting in a slower velocity. Taladriz et al. (2015) produced a similar study but reviewed the differences in hands to takeoff time, block time, flight time, hands to entry time, entry distance, horizontal velocity in the flight, maximum peak acceleration, time of maximum peak acceleration, and takeoff acceleration between the grab and kick start. The authors found that the kick start outperformed the grab start in every metric (*p* < 0.05), except for flight time and entry distance (Taladriz et al., 2015). Taladriz et al. (2015) stated that the kick start was superior to the grab start, as it allowed the swimmer to achieve greater take-off speed, which is advantageous for winning a race.

The drive phase will consist of the swimmer moving their center of mass down and forward to create a forceful contraction of the gluteal muscles and quadriceps, thereby leaving the block (Formicola & Rainoldi, 2015). This phase is particularly important, as it is where force is generated to accelerate off the block. For instance, Thng et al. (2024) investigated the kinetic variables of starting block outcome measures and their relationship with the 15 m start time. All on-block outcome kinetic variables demonstrated statistically significant relationships with 15 m start performance (R^2 = 0.79-0.83, all *p* < 0.01), with average power producing the greatest practical improvement in start time. Multiple linear regression further revealed that rear resultant average force, grab resultant peak force, and front horizontal peak force were significant predictors of both average power (R^2 = .88, *p* < 0.001) and horizontal take off velocity (R^2 = 0.73, *p* < 0.001), while rear resultant peak force uniquely contributed to average power and rear horizontal peak force uniquely contributed to horizontal take-off velocity. The study's results highlight the importance of the high force application during the drive phase of the blocks. The flight phase occurs when the swimmer is airborne and ends when the swimmer enters the water, marking the beginning of the entry phase (Formicola & Rainoldi, 2015).

The block start has been associated with lower-body strength. For example, Beretic and colleagues (2013) investigated the relationships between lower-body isometric muscle characteristics and the time it took a swimmer to reach to perform a maximum effort dive and maximum underwater fly kick swim to the 10 m mark from the starting block. The authors measured isometric contraction using a tensiometric dynamometer and found that leg extensor maximum voluntary force ($p = 0.002$, $r = -.559$), leg extensor specific level of rate of force development ($p = 0.47$, $r = -.338$), leg extensor relative values of maximum muscle voluntary ($p < .001$, $r = -.727$), and leg extensor relative value of specific rate of force development ($p = 0.40$, $r = -.402$) were strongly related to start performance (Beretic et al., 2013). This demonstrates that both strength and the rate at which the force develops are important, as they contribute to the athlete's ability to start the race effectively.

Lower-body power has also been associated with block start performance. Illera-Delgado and Gea-Garcia (2022) investigated the relationships among three lower-body power tests: CMJ, squat jump, and the standing long jump, with the time it took for the swimmer to reach 15 m during the freestyle and kinematic variables such as exit knee angle, entry angle into the water, flight distance, and flight time. The authors found that the countermovement jump ($p < 0.01$, $r = -0.77$), squat jump ($p < 0.01$, $r = -0.74$), and standing long jump ($p < 0.01$, $r = -0.79$) were strongly associated with start performance and covering the first 15m (Illera-Delgado & Gea-Garcia, 2022). They also reported significant relationships between entry angle into the water and standing long jump performance ($p < 0.05$, $r = -0.34$). In addition, flight distance was significantly associated with countermovement jump ($p < 0.01$, $r = 0.56$), squat jump ($p < 0.01$, $r = 0.60$), and standing long jump performance ($p < 0.01$, $r = 0.50$). Similarly, flight time showed significant correlations with countermovement jump ($p < 0.01$, $r = 0.40$), squat jump ($p < 0.01$, $r = 0.38$), and standing long jump performance ($p < 0.01$, $r = 0.64$)

(Illera-Delgado & Gea-Garcia, 2022). This demonstrates the importance of power, as these qualities are critical for generating enough force in a timely manner to push off the block.

The start for the backstroke is unlike that of the freestyle, breaststroke, and butterfly. The start begins in the water, hands on the bar attached to the starting block, and feet either submerged or above the water, placed on the wall (de Jesus et al., 2013; Takeda et al., 2014). De Jesus et al. (2013) investigated the differences in kinematic and kinetic variables using different foot positions (immersed versus emerged) for the backstroke start to 5 m and found no significant differences in time to 5m between the two foot positions ($p = 0.28$). The backstroke start is more technical than the previously mentioned block start, as the swimmer needs to be able to arch their back and successfully create enough horizontal and vertical force to land in the water that creates the least amount of resistance, thereby minimizing deceleration (Takeda et al., 2014). This could affect any relationships involving strength and power, as measured via dry-land exercises.

Takeda et al. (2014) investigated differences in kinematic and kinetic variables and time to 5m between elite and sub-elite backstroke swimmers. The kinematic and kinetic variables examined were horizontal and vertical velocity of the center of mass, toe-off time, time to 5 m, angular momentum of the whole body, height of the toe and hip, and joint angles of the hip and knee. Takeda et al. (2014) found that hip joint angle at toe-off ($p = 0.007$, $ES = 1.60$, large), height of hip at toe-off ($p = 0.002$, $ES = 1.94$, large), angular momentum of the whole body at the signal ($p = 0.010$, $ES = 1.47$), and time to 5 m ($p = 0.009$, $ES = -1.54$) were better for elite compared to sub-elite backstroke swimmers. Elite backstroke swimmers had higher hip positions and larger hip joint angles, which prevented their hips from hitting the water too early, thereby reducing drag forces and decreasing the time to 5 m. Nara et al. (2024) investigated the timing of extension between the knee and hip and its effect on backstroke start time at 5 m. The participants completed three types of knee and hip joint sequencing: knee extension after hip extension, simultaneous hip and knee extension, and knee extension before hip extension. Nara et al. (2024) found that the knee extension after hip extension had a better time to 5 m than did the other two sequences ($p = 0.009$) and that hip joint angle was greater at toe-off compared to knee extension before hip extension ($p = 0.023$). Nara et al. (2024) reported that hip horizontal ($p = 0.031$) and vertical position ($p = 0.009$) at fingertip entry were greater when athletes completed the knee extension after hip extension (Nara et al., 2024). Knee extension after hip extension appears to be crucial, as it enables the athlete to achieve a more optimal position, where resistance entering the water is reduced, resulting in faster start times.

Although technical, the start for the backstroke does have contributions from lower-body power. Kovacova and Brodani (2019) investigated the relationship between lower-body power tests and in-water tests. The in-water tests consisted of the start speed to 4 meters and the 25 meter backstroke sprint time, while the lower body power tests consisted of the CMJ with and without arms, as well as maximum and average take-off velocity under conditions that mimic the backstroke start. The authors found the CMJ with ($p < 0.004$, $r = - 0.522$) and without arms ($p < 0.004$, $r = - 0.516$) to be strongly related to the start speed from 4 m, which demonstrates the importance of lower-body power in the backstroke start (Kovacova & Brodani, 2019).

Biomechanical Analysis of the Turn

The components of a flip turn can be divided into six phases: the approach, rotation, wall contact, glide, underwater propulsion, and stroke resumption phases (Weimar et al., 2019). Weimer et al. (2019) stated that the most critical component of the flip turn is the wall contact phase, as it is the period during which force is developed, and the speed at which it is developed is important. Lyttle et al. (1999) investigated the kinetic variables that 30 elite male swimmers produced when pushing off the wall during a flip turn and detailed peak propulsive force (1189.6 ± 246.0 N), peak drag force (-570 ± 238.0 N), and push-off time (0.218 ± 0.054 s). Lyttle et al. (1999) conducted a stepwise regression analysis, revealing that peak propulsive force ($\beta = 0.925$, $p < 0.001$), peak drag force ($\beta = 1.146$, $p < 0.001$), and push-off time ($\beta = 0.688$, $p < 0.001$) were predictive of the greater velocities during a flip turn. Research regarding flip turns has similar findings to start performance, as the athlete creates extension through the legs when pushing off the wall.

Cronin et al. (2007) investigated the relationship between lower-body power, as measured by a loaded squat jump (concentric power), CMJ akimbo (leg power without arms), and vertical jump (leg power with arms), with flip turn ability. The protocol used to assess flip turn ability was three turns of 15 m in and 15 m out at maximum velocity. The 20 kg loaded squat jump ($p = 0.01$, $r = 0.29$), 30kg loaded squat jump ($p < 0.01$, $r = 0.36$), CMJ height ($p < 0.01$, $r = 0.40$), and vertical jump height ($p < 0.01$, $r = .33$) related with velocity at 2-4 m, suggesting that the strength and power of the lower body play an important role in flip turn performance (Cronin et al., 2007). It is also worth noting that velocity at distances greater than 6 m from the wall showed a non-significant relationship ($p > 0.05$, $r = -0.14$ to -0.08) with lower body power and jump height, indicating that other factors may play a more significant role, such as technique (Cronin et al., 2007). Keiner et al. (2021) conducted a similar study that examined the squat jump, CMJ, and 1-RM barbell squat, as well as flip turn velocity from 5m from the wall, and found a moderate inverse relationship between flip turn performance and 1-RM squat ($p < 0.05$, $r = -0.54$). The results of this study further demonstrate the importance of lower-body strength in the flip turn.

The backstroke flip turn is similar to the freestyle, except that the swimmer must roll from their back to their stomach before completing the flip turn (Veiga et al., 2013). Once the swimmer makes contact with the wall, they will push off but remain on their back as they surface from the water, since the stroke is executed in the supine position (Veiga et al., 2013). As with the freestyle flip turn, it is expected that lower-body strength and power are crucial, as they significantly contribute to the athlete's ability to push off the wall quickly (Keiner et al., 2021). Veiga et al. (2013) investigated kinematic differences in the backstroke flip turn between national- and regional-level swimmers. The authors measured time to 15 m (time interval when the swimmer's head is with 7.5 m before and after the wall), distance in (the horizontal distance of the swimmer's head from the last hand entry on the back of the wall, underwater distance (the horizontal distance of the swimmer's head from the wall to the head emersion), underwater velocity (average velocity from the beginning of feet contact on the wall to the end of the turn movement), normalized underwater velocity (the underwater velocity divided by the mean stroking velocity), and the stroking velocity (the average velocity from the end of the underwater swim to the last hand entry on the back in each lap). The results indicated that national-level swimmers had shorter 15 m turn time ($p < 0.001$), greater distance in ($p < 0.05$), greater underwater velocity ($p < 0.05$), greater normalized underwater velocity ($p < 0.001$), and a greater stroke velocity ($p < 0.001$) (Veiga et al., 2013). Although strength and power measurements were not taken in the study, one could infer that national-level swimmers were able to generate more force against the wall, thereby creating higher velocities from the wall (Araujo et al., 2010).

The butterfly and breaststroke turns are unlike freestyle and backstroke, where swimmers must flip and push off the wall. The butterfly and breaststroke use an open turn, where the athlete grabs the wall with both hands, rotates their body to position it for propulsion and streamline, then makes contact with their feet to push off the wall (Chakravorti et al., 2012; Nicol et al., 2019). Much like the freestyle flip turn, the components of the open turn can be broken down into distinct phases, including approach, rotation, wall contact, glide, and stroke preparation (Slawson et al., 2010). However, in contrast to the freestyle, during the wall contact phases of the open turn, two contacts occur: first with the hands, then with the feet. Nicol et al. (2019) investigated the biomechanics of the open turn technique in men and women, comparing distances from 5 m to the wall, from the wall to 5 m, 5 m to 7.5 m, and 7.5 m to 10 m with total turn time. In men, the results from the study showed that the time from the wall to 5m was the most related to total turn time ($p < 0.05$, $r = .790$), the second strongest relationship was 5 m to 7.5 m ($p < 0.05$, $r = 0.813$), the third strongest relationship was 5m to the wall ($p < 0.05$, $r = 0.790$), and the fourth was 7.5 m to 10 m ($p < 0.05$, $r = 0.639$) (Nicol et al., 2019). In women, the strongest relationship to total turn time was 5 m to7.5 m ($p < 0.05$, $r = 0.923$), the second strongest relationship was the wall to 5 m ($p < 0.05$, $r = 0.887$), the third strongest relationship was 7.5 m to 10 m ($p < 0.05$, $r = 0.697$), and the fourth strongest relationship was 5 m to the wall ($p < 0.05$, $r = 0.581$) (Nicol et al., 2019). After conducting a regression analysis, greater distances at the point of surfacing were associated with faster turn times for men ($p < 0.01$), and greater average acceleration ($p < 0.01$) and distances at the point of surfacing were associated with faster turn times for women ($p < 0.01$) (Nicol et al., 2019). The study's results suggest that the force applied to the wall, in addition to the success of the underwater phase, is crucial for achieving a successful performance. To increase the distance before surfacing, one must generate a high push-off velocity and be able to glide with a reduced amount of drag, thereby sustaining the velocity created by the push-off from the wall. As a result, the production of force off the wall, the time it takes to produce that force, the effectiveness of underwater kicks, and the quality of underwater gliding all become important factors for reducing total turn time.

Although open turns depend on technique and timing, strength training has been shown to improve open turn performance. Kaiyang et al. (2025) investigated the effects of an 8-week training program focused on core and lower-body strength on open turn performance in the 200 m individual medley event. The time when the swimmers' heads passed 5 m before and 5 m after the wall, as well as tuck time, hip joint angle, knee joint angle, and maximal acceleration off the wall, were examined as variables in open turn performance. Four dryland assessments were used to examine core strength and lower-body strength/power; extensor and flexor endurance tests, 1-RM back squat, and the squat jump. The following are the significant improvements of the dryland assessments following the 8-week training program: extensor endurance test ($p = 0.005$), flexor endurance test ($p = 0.005$), jump height during squat jump ($p = 0.042$), relative peak force during squat jump ($p = 0.003$), relative peak power during the squat jump ($p = 0.003$). Kaiyang et al. (2025) reported significant improvements in open turns following the 8-week training program, including the butterfly-to-backstroke turn ($p = 0.004$), backstroke-to-breaststroke turn ($p = 0.018$), and breaststroke-to-freestyle turn ($p = 0.002$). In addition, Kaiyang et al. (2025) found significant improvements in other kinematic variables such as; backstroke to breaststroke tuck time ($p = 0.028$), breaststroke to freestyle tuck time ($p = 0.034$), hip joint angle of the butterfly to backstroke turn ($p = 0.005$), hip joint angle of the breaststroke to freestyle turn ($p = 0.034$), knee joint angle of the butterfly to backstroke turn ($p = 0.009$), maximal acceleration of the butterfly to backstroke turn ($p = 0.031$), maximal acceleration of the backstroke to breaststroke turn ($p < 0.001$), and the maximal acceleration of the breaststroke to freestyle turn ($p = 0.040$). The results of the study suggest that strength training can not only improve land-based power and strength values, but also improve values in the water, as the swimmers' demonstrated increases in maximum acceleration, decreases in turn and tuck times, and joint angles more favorable to swimming performance.

Biomechanical Analysis of Freestyle

Due to the swimmer competing in a body of water, there is no constant velocity, as there are continuous changes in the resistive and propulsive forces acting upon the swimmer (Gourgoulis et al., 2014). In the freestyle stroke, both legs and arms are used to create propulsive forces. However, the contributions from the arms and legs differ. For example, Deschodt et al. (1999) investigated the relative contribution of the arms and legs during the 25 m sprint freestyle swimming and found that the use of legs increased velocity by 10% ($p < 0.001$). Of that 10% increase in velocity, some may be attributed to direct propulsion; however, other factors influencing the increase in speed include changes in body position, which ultimately reduce drag. Gourgoulis et al. (2014) examined the influence that the leg kick has on the orientation of the hand, efficiency of the arm stroke, trunk inclination, the inter-arm coordination, and the intra-cyclic horizontal velocity variation of the hip in the 25 m freestyle sprint. The authors found that the use of legs has been shown to be beneficial, as it increased both stroke rate ($p = 0.04$, $d = 0.81$) and length ($p < 0.01$, $d = 1.34$), reduced trunk inclination ($p < 0.01$, $d = 1.10$), while not hindering arm action, orientation of the hand, or intra-cyclic horizontal velocity variation of the hip, thus increasing swim velocity ($p < 0.01$, $d = 2.64$) (Gourgoulis et al., 2014).

The arm action during the freestyle is measured by two factors; stroke rate (number of upper limb cycles) and stroke length (distance travelled during a complete upper limb cycle) (Alves et al., 2022). To improve swimming efficiency and performance, increasing strength and power should be beneficial, as it could help generate more propulsion forward with fewer strokes. For example, Pérez-Olea et al. (2018) investigated the relationships between lower body power (as measured by two CMJ tests) and upper body power (as measured by two pull-up tests) with the two 50 m freestyle swim tests (legs only and arms/legs). Pérez-Olea et al. (2018) found that pull-up mean velocity ($p = 0.02$, $r = -0.80$), pull-up absolute power ($p = 0.04$, $r = -0.76$), pull-up relative power ($p = 0.02$, $r = -0.80$), pull-up relative force ($p = 0.03$, $r = -0.77$), pull-up until failure mean velocity ($p = 0.0001$, $r = - 0.88$), and pull-up until failure velocity ($p = 0.03$, $r = 0.64$) strongly related to 50 m freestyle swim performance. However, no CMJ metrics were significantly related to the 50 m freestyle swim tests. In a similar study, Koa et al. (2018) investigated the relationship between the 1-RM weighted pull-up, squat jump, and back squat barbell velocity, and their impact on 45.72 m freestyle performance. Koa et al. (2018) found a correlation between the relative 1-RM weighted pull-up ($p < 0.01$, $r = -0.61$), squat jump ($p < 0.01$, $r = -0.66$), back squat barbell velocity ($p < 0.01$, $r = -0.66$) and swim performance, again, highlighting the importance of strength and power characteristics in swimming.

Biomechanical Analysis of Backstroke

The backstroke is similar to the freestyle stroke in that it is an alternating swimming technique characterized by continuous propulsion; however, it is performed with the athlete in a supine position rather than a prone position (Fernandes et al., 2022). In the backstroke, both legs and arms are used to create propulsive forces. Using the Indirect Measurement of Active Drag (IMAD) method, Shahbazi-Moghaddam (2007) measured the contributions of the arms and legs for propulsion in the backstroke swimming. Propulsive forces were measured separately in arms-only, legs-only, and full-stroke swim conditions. The study revealed correlations between swimmers’ mass and leg forces, suggesting that leg forces were used to stabilize the body. Meanwhile, arm forces and velocities were related to full stroke force and velocity, suggesting that the arms have a higher contribution to the backstroke velocity than do the legs (Shahbazi-Moghaddam, 2007).

There are five phases that can be attributed to the backstroke: entry and catch, pull, push, clearing, and recovery (Lerda & Cradelli, 2002). Lerda and Cardelli (2002) compared backstroke technique during the 25 m backstroke in expert and non-expert swimmers and found that expert swimmers exhibited greater swim velocity, greater stroke rate, longer stroke length, spent more time in the entry and catch phase, less time in the clearing phase, and performed fewer kicks per cycle ($p < 0.05$). The entry and catch variable proved to be a strong predictor ($p < 0.05$, $R^2 = 0.71$) of swim velocity, as it was observed that spending more time in the entry and catch phase helped expert swimmers maintain a streamlined body and reduce drag (Lerda & Cradelli, 2002). In relation to leg kicks, it was suggested that non-expert swimmers used an increased leg kick as a compensatory strategy to maintain a more streamlined position (Lerda & Cradelli, 2002).

Backstroke is a technical stroke but strength and power do contribute to performance. Keiner et al. (2015) investigated the relationship between the strength of the lower body, upper body, and trunk and the performance in the 50 m and 100 m backstroke swim. Keiner et al. (2015) found 1-RM squat negatively correlated to 50 m ($p < 0.05$, $r = -0.54$) and 100 m backstroke times ($p < 0.05$, $r = -0.33$), squat jump negatively correlated to 50m ($p < 0.05$, $r = -0.53$) and 100 m backstroke times ($p < 0.05$, $r = -0.36$), and CMJ negatively correlated to the 50 m ($p < 0.05$, $r = -0.53$) and 100 m backstroke swim time ($p < 0.05$, $r = -0.37$). For the upper body tests, Keiner et al. (2015) found the 1-RM bench press to be negatively correlated with the 50 m ($p < 0.05$, $r = -0.65$) and 100 m backstroke swim times ($p < 0.05$, $r = -0.37$) and the 1-RM bent-over row to be negatively correlated with the 50 m ($p < 0.05$, $r = -0.65$) and 100 m backstroke swim times ($p < 0.05$, $r = -0.39$). For the trunk tests, the deadlift ($p < 0.05$, $r = -0.50$) and ab-bench ($p < 0.05$, $r = -0.31$) were found to be negatively related to 50 m backstroke swim time. The results from Keiner et al. (2015) demonstrate the importance of strength and power in contributing to success in the water. Carvalho et al. (2023) examined the relationships between strength and power in the 25 m sprint performance of elite and non-elite swimmers across the four strokes. The strength and power tests consisted of the following: 10 maximal right and left shoulder extension/flexion contractions at 90° and 300°, measured using an isokinetic dynamometer, and three attempts of the CMJ on force plates (Carvalho et al., 2023). The authors found that faster swim times in the 25 m backstroke negatively correlated with the isokinetic test ($p < 0.05$) and the CMJ ($p < 0.01$), further highlighting the importance of strength and power in relation to swim performance.

Biomechanical Analysis of Butterfly

Butterfly is a more complex and technical stroke due to the ability to coordinate the body in a way that makes the stroke efficient (Pinto et al., 2025). The stroke uses both upper limbs simultaneously, while the trunk moves in an undulatory fashion, and the legs perform dolphin kicks (Morais et al., 2025; Yamakawa et al., 2024). The butterfly arm stroke can be broken down into four phases: entry and catch, pull phase, push phase, and recovery phase (Seifert et al., 2008). The dolphin kick can be simply broken down into two phases: the downward phase and the upward phase (Seifert et al., 2008). All these movements need to be executed in a coordinated manner for the swimmer to be efficient, allowing them to achieve faster swim times.

Seifert et al. (2008) investigated the differences in arm-leg coordination between elite and non-elite swimmers during the 25 m butterfly swim at four swimming conditions: the 50 m, 100 m, 200 m and 400 m at race pace. Elite swimmers had better coordination and synchronization of movement in the butterfly, which resulted in faster swim times ($p < 0.05$). Stroke rate was found to be greater for elite men compared to less skilled men ($p < 0.05$), while stroke lengths were found to be greater in elite women compared to less skilled women ($p < 0.05$) (Seifert et al., 2008). In a similar study, Yamakawa et al. (2024) compared butterfly swim techniques between competitive and recreational butterfly swimmers during the 25 m butterfly swim. The study's results showed that competitive swimmers had significantly greater swim velocities ($p < 0.001$, $r = 0.92$-0.94), greater stroke rate ($p < 0.001$, $r = 0.86$), greater stroke lengths ($p < 0.001$, $r = 0.95$), spent less time in the catch phase ($p = 0.031$, $r = 0.54$), more time in the recovery phase ($p < 0.001$, $r = 0.73$), more time during the second downward kick phase ($p < 0.033$, $r = 0.53$), and had less hip depth during all four phases of the stroke ($p < 0.05$, $r = 0.47\text{-}0.84$) (Yamakawa et al., 2024). Yamakawa et al. (2024) found that competitive swimmers were more proficient at timing their arm and leg actions and presented a hip depth that was sufficiently high to prevent any technical breakdown of the stroke, which helps lead to greater swim velocities (Yamakawa et al., 2024).

Although the butterfly stroke involves a great deal of technical efficiency, strength and power also play a role in performance. Holub et al. (2025) examined the relationships between lower-body and upper-body power with butterfly performance. The lower-body and upper-body power tests used were the following: squat jump, countermovement jump, akimbo countermovement jump, 15-second continuous jumps, 30-second continuous jumps, and the butterfly arm pull test. The two swim tests used to assess butterfly performance were the 25 m dolphin kick test and the 25 m butterfly arms-only test. Out of the 180 correlations, only six did not significantly correlate with the power of the 25 m dolphin kick tests, while the rest of the jumps and the metrics were moderately to strongly correlated with the metrics of the 25 m dolphin kick test ($p < 0.05$, $r = 0.58\text{-}0.90$). There was no correlation between the butterfly arms-only swim test and the butterfly arm pull test ($p > 0.05$) (Holub et al., 2025). This may be due to the fact that the butterfly is a highly technical stroke; however, this was the only test conducted to measure upper-body strength and its relationship with the butterfly performance, which raises the question of whether there are any other upper-body strength and power tests that may relate to butterfly performance. In either case, the relationship between lower-body power and the butterfly dolphin kick test demonstrates that strength and power could make a notable contribution to the success of swim performance.

Biomechanical Analysis of Breaststroke

The breaststroke is the slowest stroke due to its body positioning, which creates more drag than other strokes (Gourgoulis & Nikodelis, 2022). The arm stroke is divided into four phases: recovery, glide, out-sweep, and in-sweep, and the leg kick is divided into three phases: the sweep, lift, and glide, and the recovery (Takagi et al., 2004). The breaststroke is also described as being more complicated due to the high coordination required between the arms and legs (Takagi et al., 2004). Takagi et al. (2004) investigated the differences in stroke phases, arm-leg coordination, and intra-cyclic hip velocity fluctuations among the 50 m, 100 m, and 200 m breaststroke events from the 2001 FINA World Championship. The researchers included the out-sweep and in-sweep of the arm stroke and sweep phase of the leg stroke as propulsive phases. The arm and leg motions were categorized into one of three groups: percentage of simultaneous recovery time, percentage of arm lag time, and percentage of simultaneous propulsion time. This categorization was used to help identify key factors that distinguished between qualified and eliminated swimmers in the breaststroke. The minimum velocity of the hip was expressed as a percentage of mean swimming velocity to evaluate the fluctuation of intra-cycle hip velocity (Takagi et al., 2004). Qualified swimmers were faster than eliminated swimmers ($p < 0.001$) and stroke length was greater in qualified swimmers compared to eliminated swimmers ($p < 0.001$) (Takagi et al., 2004). The percentage of mean swimming velocity was significantly lower in the eliminated group than in the qualified group ($p < 0.01$). The qualified swimmers exhibited a greater percentage of arm lag time than the eliminated swimmers ($p < 0.05$) and spent a significantly smaller percentage of time in propulsive phases ($p < 0.01$). This is important, as one might intuitively think that creating more propulsive forces will make a swimmer faster. However, based on the study's findings, faster swimmers spent more time in the glide phase, regardless of race distance, as indicated by the increased time spent in the arm lag phase. The differences in the percentage of mean swimming velocity demonstrate that the qualified swimmers were better at maintaining a steady speed and avoiding velocity fluctuations throughout the swim. In addition, as the distance of the races got longer, stroke rate was decreased ($p < 0.001$), and stroke length was increased ($p < 0.001$). Therefore, as a high stroke rate may be a good strategy for short distances, it is also appropriate to increase stroke length for longer distances to conserve energy.

The breaststroke, although technically challenging, incorporates elements of strength and power that may help reduce swim times. Invernizzi et al. (2014) investigated the relationship between strength tests and velocity, stroke rate, and stroke length in the 100 m breaststroke swim of male and female swimmers. The two dry-land tests used were the chin-up to exhaustion and the CMJ. Neither of the dryland tests was related to swim velocity ($p > 0.05$). Stroke length was inversely correlated to chin-up performance in men ($p < 0.01$, $r = -0.57$) and women ($p < 0.01$, $r = -0.64$), but positively related to CMJ in men ($p < 0.001$, $r = 0.85$) and women ($p < 0.05$, $r = 0.45$). Stroke rate was positively correlated with chin-ups in men ($p < 0.01$, $r = 0.60$) and women ($p < 0.01$, $r = 0.66$), and with CMJ in men ($p < 0.001$, $r = 0.87$) and women ($p < 0.01$, $r = 0.61$), despite the study text describing this as an “inverse” relationship. The results of the study indicate that swimmers employ different strategies for the breaststroke due to the expression of strength. For example, swimmers in the high-stroke rate group appeared to be stronger in the chin-up test, while those in the low-stroke group performed significantly better during the jump and reach tests. Strength appears to contribute, as it plays a role in breaststroke, even though it does not directly correlate with swim velocity.

Summary

The literature demonstrates that strength, power, coordination, and technical ability are all important qualities that impact swim performance. Lower body strength and power have been shown to be important qualities for start and turn performance, as they could aid in decreasing time off the block and wall. Upper body strength and power have been shown to be important as they can increase swimming velocity. Core strength has been shown to decrease time to transition with open turns and time to tuck, thereby improving swim times. All these qualities have been shown to be important when it comes to improving swim performance; however, gaps remain in how these qualities can be assessed across all four strokes.

CHAPTER 3

METHODS

Participants

Retrospective analysis was completed on a sample of 49 swimmers from a Division I collegiate program. Swimmers who participated in at least one test were included in the analysis; analyses were conducted using all available data. All participants were active competitive swimmers and had satisfied the university's requirements for collegiate athletic participation, including completion of a pre-participation physical examination and all required consent and medical forms. The data was gathered to view pre- and post-training adaptations as regular practice by the sports performance coaching staff. The standard procedures for data collection were provided by the sports performance staff, who ensured that the data was collected as accurately as possible.

Procedures

All testing was conducted on-site at the university. The testing battery took place in the weight room over a 3-day span. All athletes were familiar with all testing protocols, as this had been part of standard monitoring practices from the sports performance staff. The session began with the team's dynamic warm-up protocol, which included a mobility series that targeted the hamstrings, quadriceps, obliques, thoracic spine, hip flexors, shoulders, chest, and adductors. Exercises included in the dynamic warm-up include world's greatest stretch, inch worms, 90/90s, adductor rock back, scapular push-up, and thoracic rotations. After this, the athletes performed 25 jumping jacks along with a banded series that targeted the shoulder joint. On the first day, athletes completed the CMJ and eccentric hamstring strength assessment. Day two included the 1-RM neutral grip pull-up and the isometric belt squat test. Day three included the plyometric push-up. Swim times were taken from a dual meet in the Fall of 2025, in which the athletes competed. Each swimmer completed the swim stroke under investigation only once during the swim meet. The time between the performance tests and the swim meet was about 5 weeks. The procedures for each test will be detailed below.

Assessments

Countermovement Jump (CMJ)

The CMJ was used to measure peak power, and the equipment used was force plates (ForceDecks, Vald Performance, Albion, Australia). The athletes were instructed to place one foot on each force platform and stand still to measure their weight. Afterwards, they were instructed to place their hands on their hips and jump as high as they could without their hands leaving their hips. Subjects then lowered themselves to a self-selected depth and followed with a maximal effort jump. If their hands left their hips or they did not land on the force plates properly, they were instructed to provide another repetition. They were to complete a total of 2 jumps, and the highest jump was used for analysis. Peak concentric force (N), peak relative power (W/kg), rate of force development n/s [RFD], peak power (N), peak velocity (m/s), eccentric peak force (N), and reactive strength index- modified m/s [RSI-mod] were extracted for the analyses.

Isometric Belt Squat (IBSQT)

The equipment used to measure peak force from the IBSQT was force plates (ForceDecks, Vald Performance, Albion, Australia). Athletes were instructed to place one foot on each force platform and stand still while it measured their weight and then wore a hip belt that had a numbered chain attached. The hip belt was anchored to a metal frame that held the force plates. The frame and force plates were placed inside a rack. The number of links in the chains was adjusted based on their height and desired squat depth. The desired squat depth was when the knees were flexed approximately at 135°. They were instructed to contract as hard and as fast as possible and to hold for a minimum of 2 seconds. All athletes received verbal encouragement and were instructed on when to start and stop. They were allowed 2 attempts with a 2-minute rest in between each attempt. Peak vertical force (N), relative peak force (N), start time to peak force (N), RFD 200ms (n/s), and RFD 250ms (n/s) were extracted for the analyses, with the best attempt used for the analyses.

Plyometric Push-Up

The equipment that was used to measure takeoff peak force from the plyometric push-up was force plates (ForceDecks, Vald Performance, Albion, Australia). Athletes were instructed to place one foot on each force platform and stand still while it measured their weight. After their weight measurement, they placed one hand on each force plate in a push up position. They were instructed to flex their arms, allowing their chest to come closer to the floor, and once their arms reached 90°, to propel themselves upwards as forcefully as possible. They were instructed to land softly as they returned to the force plates. After the first repetition, they were given 30 to 60 seconds of rest before they completed their second attempt. Concentric RFD (n/s), height (cm), concentric peak force (N), and eccentric peak force (N) were extracted from the analysis.

1-RM Neutral Grip Pull-Up

The pull-up specific warm-up protocol followed was 1 set of 5 scapular pull-ups, followed by 1 set of 3 neutral-grip pull-ups. After this was completed, athletes put on a weight belt (if required) and were set to start the test. The starting position of the pull-up was arms fully extended and hands in a neutral grip position. For the repetition to count, there had to be no leg or body swinging present, and the chin had to be fully over the bar. After each completed attempt, more weight was added to the weight belt. If the athlete's goal was 45 lb or above, they would start with a 25 lb plate and add 10lb after every successful attempt. If their goal was to get 4.5-11.4 kg, then they started with a 4.5 kg plate and would add 2.27 kg after every successful attempt. If their goal was to achieve one pull-up with just body weight, then they would start with one set of five scapular pull-ups and then test.

Eccentric Hamstring Strength Assessment

The eccentric hamstring strength assessment test was conducted using the NordBord (Vald Performance, Albion, Australia), which measured the peak force (N) generated by the hamstrings. Athletes were instructed to complete two repetitions of eccentric Nordics on a glute-hamstring bench. After two Nordic repetitions, the athletes were instructed to place their knees on the NordBord in a comfortable position, allowing their ankles to fit the cuffs securely. Once set, they were instructed to slowly lower the upper body, trying to resist the movement down by contracting their hamstrings. A neutral position between the trunk and hips was encouraged as they completed each repetition. They were also instructed to catch themselves with their hands when they could no longer resist. Athletes were instructed to have their arms crossed over their chest, but catch themselves when they reached failure. Peak forces (N) from each leg were averaged to obtain a single value. Two repetitions were completed for this test, and the best attempt was used for the analyses.

Statistical Analysis

Statistical analyses were performed using SPSS (Version 31.0.0.0, Armonk, NY). Descriptive statistics with means and standard deviations (means ± SD: 95% confidence intervals) were calculated for each variable. Variables of interest included;

- CMJ concentric peak force (N)
- CMJ relative peak power (W/kg)
- CMJ RFD (n/s)
- CMJ peak power (N)
- CMJ peak velocity (m/s)
- CMJ eccentric peak force
- CMJ RSI-modified, (m/s)
- IBSQT vertical force (N)
- IBSQT relative peak vertical force (N)
- IBSQT start time to peak force (s)
- IBSQT RFD 200ms (n/s)
- IBSQT RFD 250ms (n/s)
- eccentric hamstring strength assessment maximum force (N)
- plyometric push-up concentric RFD (n/s)

- plyometric push-up height (cm)
- plyometric push-up peak concentric peak force (N)
- plyometric push-up eccentric peak force (N)
- and 1-RM pull-up (kg).

The swim variables included freestyle 100 yd (s), breaststroke 100 yd (s), butterfly 100 yd (s), backstroke 100 yd (s). Split times for 50 yds were also recorded and used for the freestyle, butterfly, and breaststroke, but this data was not available for the backstroke, so only 100 yd time was analyzed for this stroke. A Pearson's correlation analysis was used to assess relationships between swim times of the four strokes and the five dry-land assessments. An alpha level of 0.05 was used to determine significance. The strength of the correlation coefficient (*r*) was defined as follows: strong correlation ± 0.9-0.7, moderate correlation ± 0.4-0.6, and weak correlation < ± 0.3 (Akoglu, 2018).

CHAPTER 4

RESULTS

Table 1 displays the descriptive physiological and performance data gathered by the performance staff. The number of participants in the table varied due to injuries that prevented participation during testing and scheduling conflicts. Scheduling conflicts related to class conflicts, athletic scheduling interferences, and medical interferences if the athlete was injured.

Relationships of Performance Variables and Freestyle

Table 2 highlights the significant correlations between the 100 yd freestyle swim and the performance variables. Almost all CMJ variables, except for CMJ RFD and eccentric peak force, were found to have a strong significant relationship to the first 50 yards of the 100 yd freestyle. In addition, IBSQT RFD 200ms, plyo push-up peak concentric peak force, and the 1RM neutral grip pull up were found to be strongly related to the first 50 yds of the 100 yd swim. CMJ peak concentric force, CMJ peak power, CMJ RSI-modified, IBSQT RFD 200ms, and the plyometric push-up concentric peak force variables were found to be strongly correlated with the second 50 yd of the 100 yd freestyle. Total swim time was found to be strongly correlated with CMJ concentric peak force, CMJ relative peak power, CMJ peak power, CMJ peak velocity, CMJ RSI-modified, ISBQT RFD 200ms, and plyometric push-up concentric peak force.

Table 1. Descriptive Statistics

Measure	*N*	Mean ± *SD*
Age (years)	49	19.98 ± 1.67
Height (cm)	47	180.40 ± 9.99
Weight (kg)	48	75.05 ± 10.24
CMJ Concentric Peak Force (N)	48	1765.10 ± 372.69
CMJ Relative Peak Power/ BM (W/kg)	48	49.32 ± 7.64
CMJ RFD (n/s)	48	709.27 ± 813.80
CMJ Peak Power (N)	48	3756.25 ± 910.26
CMJ Peak Velocity (m/s)	48	2.72 ± .28
CMJ Eccentric Peak Force	48	1702.27 ± 495.06
CMJ RSI-mod (m/s)	48	.4688 ± .119
IBSQT Peak Vertical Force (N)	45	3544.31 ± 1082.35
IBSQT Relative Peak Vertical Force (N)	45	46.92 ± 12.80
IBSQT Start Time to Peak Force (s)	45	4.85 ± 3.19
IBSQT RFD 200ms (n/s)	45	2460.32 ± 3134.649
IBSQT RFD 250ms (n/s)	45	2000.16 ± 923.194
Eccentric Hamstring Strength Assessment Average Max Force (N)	43	322.18 ± 71.26
Plyometric Push-Up Concentric RFD (n/s)	43	.2142 ± .147
Plyometric Push-Up Height (cm)	43	11.11 ± 6.95
Plyometric Push-Up Concentric Peak Force (N)	43	963.95 ± 304.73
Plyometric Push-Up Eccentric Peak Force (N)	43	860.65 ± 333.60
Neutral Grip Pull-Up 1-RM (kg)	48	21.73 ± 14.36
Freestyle 100yd	10	47.20 ± 2.54
Backstroke 100yd	10	51.28 ± 3.26
Butterfly 100yd	11	51.54 ± 3.52
Breaststroke 100yd	8	59.39 ± 4.15

Table 2. Correlations Between the Performance Variables and the 100yd Freestyle. Significant relationships are bolded.

Variables	1st 50 yd Split	2nd 50 yd Split	Total Swim Time
CMJ Concentric Peak Force (N)	***r* = -.779** ***p* = .013**	***r* = -.859** ***p* = .003**	***r* = -.885** ***p* = .003**
CMJ Relative Peak Power/ BM (W/kg)	***r* = -.772** ***p* = .015**	*r* = -.632 *p* = .068	***r* = -.718** ***p* = .029**
CMJ RFD (N/s)	*r* = .257 *p* = .504	*r* = -.013 *p* = .973	*r* = .107 *p* = .785
CMJ Peak Power (N)	***r* = -.865** ***p* = .003**	***r* = -.827** ***p* = .006**	***r* = -.875** ***p* = .002**
CMJ Peak Velocity (m/s)	***r* = -.860** ***P* = .003**	*r* = -646 *p* = .060	***r* = -.765** ***p* = .002**
CMJ Eccentric Peak Force (N)	*r* = -.159 *p* = .683	*r* = -.335 *p* = .378	*r* = -.269 *p* = .484
CMJ RSI-modified	***r* = -.761** ***p* = .017**	***r* = -.760** ***p* = .018**	***r* = -.789** ***p* = .012**
IBSQT Peak Vertical Force (N)	*r* = -.538 *p* = .169	*r* = -.193 *p* = .646	*r* = -.361 *p* = .380
IBSQT Start Time to Peak Force (s)	*r* = -.188 *p* = .656	*r* = -.044 *p* = .918	*r* = -.060 *p* = .888
IBSQT RFD 200ms (N/s)	***r* = .960** ***p* < .001**	***r* = .740** ***p* = .036**	***r* = .870** ***p* = .005**
IBSQT RFD 250ms (N/s)	*r* = .068 *p* = .873	*r* = -.113 *p* = .668	*r* = -.035 *p* = .934
Eccentric Hamstring Strength Assessment Average Max Force (N)	*r* = -.287 *p* = .454	*r* = -.167 *p* = .668	*r* = -.226 *p* = .558
Plyometric Push-Up Flight: Contraction Time	*r* = -.222 *p* = .598	*r* = -.002 *p* = .995	*r* = -.106 *p* = .803
Plyometric Push-Up Concentric RFD (n/s)	*r* = -.203 *p* = .630	*r* = .098 *p* = .817	*r* = -.048 *p* = .909
Plyometric Push-Up Height (cm)	*r* = -.380 *p* = .353	*r* = -.120 *p* = .776	*r* = -.252 *p* = .547
Plyometric Push-Up Concentric Peak Force (N)	***r* = -.847** ***p* = .008**	***r* = -.813** ***p* = .014**	***r* = -.871** ***p* = .005**
Plyometric Push-Up Eccentric Peak Force (N)	*r* = -.310 *p* = .455	*r* = -.221 *p* = .598	*r* = -.271 *p* = .516
Neutral Grip Pull Up 1-RM (kg)	***r* = -.755** ***p* = .019**	*r* = -.441 *p* = .235	*r* = -.579 *p* = .090

Relationships of Performance Variables and Butterfly

Table 3 outlines the significant relationships between the butterfly swim times and the performance variables. The first 50 yards of the 100 yd butterfly were found to be strongly related to CMJ relative peak power, CMJ RSI-modified, IBSQT RFD 200 ms, plyometric push-up flight: contraction time and moderately related to CMJ peak power, CMJ peak velocity, IBSQT peak vertical force and the plyometric push-up height. The second 50 yards of the swim showed a strong significant correlation with IBSQT RFD 200 ms and moderate relationships to the IBSQT peak vertical and the plyometric push-up flight: contraction time variable. The total butterfly time was strongly related to IBSQT 200 ms and plyometric push-up flight: contraction time. Total swim time was moderately related to CMJ relative peak power, CMJ peak velocity, CMJ RSI-modified, and IBSQT peak vertical force.

Relationships of Performance Variables and Breaststroke

Table 4 shows the significant relationships between breaststroke swim times and the performance variables. The first 50 yards of the 100yd breaststroke had no significant relationships with any of the performance variables. The second 50 yards of the 100yd breaststroke had strong, significant relationships with the following performance variables: CMJ concentric peak force, CMJ eccentric peak force, IBSQT peak vertical force, plyometric push-up concentric RFD, plyometric push-up concentric peak force, and plyometric push-up eccentric peak force. The total breaststroke time was found to be strongly significantly related to the plyometric push-up concentric peak force and plyometric push-up eccentric peak force.

Relationships of Performance Variables and Backstroke

No significant relationships were found between the 100yd backstroke swim and the performance tests (Table 5).

Table 3. Correlations Between Performance Variables and the 100yd Butterfly. Significant relationships are bolded.

Variables	1st 50 yd Split	2nd 50 yd Split	Total Swim Time
CMJ Concentric Peak Force (N)	*r* = -.569 *p* = .086	*r* = -.423 *p* = .223	*r* = -.508 *p* = .134
CMJ Relative Peak Power/ BM (W/kg)	***r* = -.709** ***p* = .022**	*r* = -.623 *p* = .054	***r* = -.618** ***p* = .030**
CMJ RFD (N/s)	*r* = .186 *p* = .607	*r* = .138 *p* = .704	*r* = .116 *p* = .647
CMJ Peak Power (N)	***r* = -.667** ***p* = .035**	*r* = -.504 *p* = .137	*r* = -.600 *p* = .067
CMJ Peak Velocity (m/s)	***r* = -.697** ***p* = .035**	*r* = -.627 *p* = .052	***r* = -.677** ***p* = .032**
CMJ Eccentric Peak Force (N)	*r* = -.614 *p* = .059	*r* = -.519 *p* = .081	*r* = -.579 *p* = .079
CMJ RSI-modified	***r* = -.702** ***p* = .024**	*r* = -.576 *p* = .081	***r* = -.654** ***p* = .040**
IBSQT Peak Vertical Force (N)	***r* = -.619** ***p* = .027**	***r* = -.674** ***p* = .032**	***r* = -.697** ***p* = .025**
IBSQT Start Time to Peak Force (s)	*r* = -.240 *p* = .503	*r* = -.034 *p* = .925	*r* = -.142 *p* = .695
IBSQT RFD 200ms (N/s)	***r* = .869** ***p* < .001**	***r* = .773** ***p* = .009**	***r* = .853** ***p* = .002**
IBSQT RFD 250ms (N/s)	*r* = -.351 *p* = .319	*r* = -.505 *p* = .136	*r* = -.436 *p* = .208
Eccentric Hamstring Strength Assessment Average Max Force (N)	*r* = .109 *p* = .780	*r* = .090 *p* = .817	*r* = .103 *p* = .793
Plyometric Push-Up Flight: Contraction Time	***r* = -.825** ***p* = .006**	***r* = -.695** ***p* = .038**	***r* = -.779** ***p* = .013**
Plyometric Push-Up Concentric RFD (n/s)	*r* = -.540 *p* = .134	*r* = .460 *p* = .212	*r* = -.513 *p* = .158
Plyometric Push-Up Height (cm)	***r* = -.671** ***p* = .048**	*r* = -.564 *p* = .113	*r* = -.633 *p* = .067
Plyometric Push-Up Concentric Peak Force (N)	*r* = -.574 *p* = .106	*r* = -.453 *p* = .221	*r* = -.527 *p* = .145
Plyometric Push-Up Eccentric Peak Force (N)	*r* = -.615 *p* = .078	*r* = -.522 *p* = .149	*r* = -.583 *p* = .099
Neutral Grip Pull Up 1-RM (kg)	r = -.544 *p* = .130	*r* = -.384 *p* = .308	*r* = -.476 *p* = .195

Table 4. Correlations Between Performance Variables and the 100yd Breaststroke. Significant relationships are bolded.

Variables	1st 50 yd split	2nd 50 yd Split	Total Swim Time
CMJ Concentric Peak Force (N)	*r* = -.511 *p* = .241	***r* = -.879** ***p* = .009**	*r* = -.744 *p* = .055
CMJ Relative Peak Power/ BM (W/kg)	*r* = .482 *p* = .274	*r* = .177 *p* = .704	*r* = .350 *p* = .441
CMJ RFD (N/s)	*r* = .079 *p* = .866	*r* = .153 *p* = .744	*r* = .124 *p* = .791
CMJ Peak Power (N)	*r* = -.105 *p* = .823	*r* = -.468 *p* = .290	*r* = -.307 *p* = .502
CMJ Peak Velocity (m/s)	*r* = .085 *p* = .856	*r* = -.240 *p* = .640	*r* = -.084 *p* = .858
CMJ Eccentric Peak Force (N)	*r* = -.459 *p* = .300	***r* = -.850** ***p* = .015**	*r* = -.701 *p* = .079
CMJ RSI-modified	*r* = .571 *p* = .180	*r* = .209 *p* = .653	*r* = -.415 *p* = .355
IBSQT Peak Vertical Force (N)	*r* = -.587 *p* = .220	***r* = -.873** ***p* = .023**	*r* = -.778 *p* = .069
IBSQT Start Time to Peak Force (s)	*r* = -.109 *p* = .837	*r* = -.285 *p* = .584	*r* = -.209 *p* = .691
IBSQT RFD 200ms (N/s)	*r* = -.569 *p* = .316	*r* = -.644 *p* = .241	*r* = -.641 *p* = .224
IBSQT RFD 250ms (N/s)	*r* = -.662 *p* = .152	*r* = -.744 *p* = .090	*r* = -.778 *p* = .089
Eccentric Hamstring Strength Assessment Average Max Force (N)	*r* = -.429 *p* = .337	*r* = -.229 *p* = .621	*r* = -.351 *p* = .441
Plyometric Push-Up Flight: Contraction Time	*r* = -.063 *p* = .906	*r* = -.509 *p* = .303	*r* = -.303 *p* = .560
Plyometric Push-Up Concentric RFD (n/s)	*r* = -.585 *p* = .223	***r* = -.838** ***p* = .037**	*r* = -.757 *p* = .081
Plyometric Push-Up Height (cm)	*r* = .600 *p* = .208	*r* = .605 *p* = .203	*r* = .646 *p* = .166
Plyometric Push-Up Concentric Peak Force (N)	*r* = -.710 *p* = .114	***r* = -.939** ***p* = .005**	***r* = -.877** ***p* = .022**
Plyometric Push-Up Eccentric Peak Force (N)	*r* = -.670 *p* = .145	***r* = -.923** ***p* = .009**	***r* = -.849** ***p* = .033**
Neutral Grip Pull Up 1-RM (kg)	*r* = -.654 *p* = .111	*r* = -.607 *p* = .149	*r* = -.673 *p* = .098

Table 5. Correlations Between Performance Variables and the 100yd Backstroke

Variables	Total Swim Time
CMJ Concentric Peak Force (N)	r = .525 p = .147
CMJ Relative Peak Power/ BM (W/kg)	r = .281 p = .463
CMJ RFD (N/s)	r = -.595 p = .091
CMJ Peak Power (N)	r = .509 p = .162
CMJ Peak Velocity (m/s)	r = .374 p = .321
CMJ Eccentric Peak Force (N)	r = .337 p = .375
CMJ RSI-modified	r = .389 p = .300
IBSQT Peak Vertical Force (N)	r = .064 p = .881
IBSQT Start Time to Peak Force (s)	r = -.043 p = .920
IBSQT RFD 200ms (N/s)	r = -.384 p = .347
IBSQT RFD 250ms (N/s)	r = -.443 p = .272
Eccentric Hamstring Strength Assessment Average Max Force (N)	r = -.199 p = .669
Plyometric Push-Up Flight: Contraction Time	r = -.267 p = .522
Plyometric Push-Up Concentric RFD (n/s)	r = .153 p = .717
Plyometric Push-Up Height (cm)	r = -.544 p = .163
Plyometric Push-Up Concentric Peak Force (N)	r = .180 p = .669
Plyometric Push-Up Eccentric Peak Force (N)	r = .190 p = .653
Neutral Grip Pull Up 1-RM (kg)	r = .083 p = .833

CHAPTER 5

DISCUSSION

This study investigated the relationships between five performance variables and the 100 yd swim events of all four strokes. It was hypothesized that greater strength and power outcomes in the IBSQT, 1-RM neutral grip pull-up, plyometric push-up, CMJ, and eccentric hamstring strength assessment would be significantly associated with faster 100 yard swim performances across all four competitive strokes. It was further hypothesized that the IBSQT, 1-RM neutral grip pull-up, and the CMJ would have the strongest relationships with the freestyle, butterfly, and backstroke. The hypothesis was partially supported. Strength and power showed the greatest number of correlations with freestyle, followed by butterfly, breaststroke, and backstroke, respectively. The freestyle stroke correlated with all performance variables except the eccentric hamstring strength assessment. The butterfly stroke showed strong correlations with the IBSQT, CMJ, and plyometric push-up strength and power variables, but none with the 1-RM neutral grip pull-up or the eccentric hamstring strength assessment. The breaststroke was correlated to the CMJ, IBSQT, and plyometric push-up. The backstroke resulted in no correlations with the performance variables. The nature of these findings may highlight the further necessity of research on understanding swim and dry-land performance variables in collegiate athletes.

Freestyle

The first 50 yards of the 100 yd freestyle had eight significant correlations with the performance variables. Lower body strength and power seemed to have the greatest impact, while the upper body still contributed, as evidenced by the correlations with the plyometric push-up and neutral grip pull-up. CMJ concentric peak force, relative peak power, peak power, peak velocity, and RSI-modified showed a strong inverse relationship; greater CMJ force, power, or velocity was associated with faster swim times. The IBSQT RFD 200 ms also had a strong relationship, indicating that faster rates of force development were associated with faster swim times. This may come as no surprise, as the first 50 yards may be partially explained by the performance of the block start. Born et al. (2024) investigated the contribution of start and turn performances in short-course races across all strokes at the European swimming championships and found that start performance, measured at the 15 m mark, had a large effect on the 50 m time across all four strokes. A swimmer who is more powerful, stronger, and can generate force more quickly will have an advantage over one who does not possess the same qualities (Carvalho et al., 2023; Kao et al., 2018). Plyometric push-up concentric peak force and the 1-RM neutral grip pull-up were also associated with the first 50 yds of the 100 yd freestyle, indicating that strength and power of the upper body will be important, especially in the first half of the race, which aligns with previous research (Kao et al., 2018; Perez-Olea et al., 2018).

The second 50 yards of the 100 yard freestyle had fewer significant correlations (five) with the performance variables. However, the significant relationships were still strong. CMJ concentric peak force, peak power, and RSI-modified had a strong inverse relationship with the second 50 yd swim time. IBSQT 200ms RFD and plyometric push-up concentric peak force were also found to be strongly related to swim times as well. Similar to the first 50 yd, the strength and power of the upper and lower body remained important for the second 50 yd, but this time, the emphasis on the lower body may be attributed in part to the flip turn performance. Flip turn performance will be dictated by technical (stroke technique, underwater gliding, and underwater kicking) and physical performance variables (lower-body strength and power) (Born et al., 2024; Cronin et al., 2007; Keiner et al., 2021; Lyttle et al., 1999). Nonetheless, based on the current findings, the upper and lower body may still play a significant role in the second half of the race.

However, we did observe a reduction in the number of significant relationships from the first 50 yd to the second 50 yd. The reductions of significant relationships were quantified as three. This may be attributed to metabolites accumulating in the body, reducing the swimmer's ability to maintain similar levels of strength and power in the second half of the race. Almeida-Coelho et al. (2016) investigated stroke index and blood lactate measures during the 25 m, 50 m, and 75 m test simulations, as well as during an all-out 100 m swim. The authors found that velocity decreased from the first 25 m and that blood lactate concentrations increased every lap during the swim. Almeida-Coelho et al. (2016) also reported that stroke length decreased while stroke rate increased as a compensatory strategy to maintain speed. Although the stroke length, stroke rate, and lactate concentrations were not measured in the current study, the average reduction in speed (1.76s) and alterations in swimming kinematics may be attributed to fatigue, which could reduce strength and power output during the swim stroke.

The total freestyle swim time had moderate to strong correlations with CMJ peak force, relative peak power, peak power, peak velocity, and RSI-modified. IBSQT RFD 200 ms and plyometric push-up concentric peak force were also strongly related to the total swim time. Even with the change in relationships with the second 50 yd of the swim, strength and power still appear to relate to the entire swim. This may be a culmination of the importance of strength and power during a variety of factors, such as the starting blocks, flip turns, and the ability to exhibit the strength and power characteristics at the beginning of the swim, where there is minimal fatigue to hinder the expression of those qualities (Almeida-Coelho et al., 2016). These data may suggest that strength and power could be more influential at the beginning of the 100 yd freestyle, while resistance to fatigue may be important in the back half, although this was not measured in the current study.

Butterfly

The first 50 yards of the 100 yard butterfly had eight significant relationships with the performance variables. CMJ relative peak power, CMJ peak power, CMJ peak velocity, CMJ RSI-modified, IBSQT peak vertical force, IBSQT RFD 200 ms, plyometric push-up flight: contraction time, and plyometric push-up height were moderately to strongly correlated with the first 50 yards of the 100 yd butterfly. IBSQT peak vertical force is one variable to note, as it measures the ability to produce as much force as possible. This performance variable, being moderately correlated with the first 50 yd, may be related to the fact that the swimmer must apply force to the starting block to propel themselves into the water. In addition, the ability to apply that force quickly will be important, which was reflected by the IBSQT RFD 200 ms significant relationship. These results are in agreement with Bertec et al.

(2013), who found that isometric lower-body maximum strength and rate of force development were strongly related to a swimmer's start performance. Although we did not measure start performance in isolation, it could be assumed that these variables are linked to start performance. In addition, the swimmer's start off the blocks accounts for approximately 30% of the first 50 yards. Plyometric push-up height and flight: contraction time were the two upper body tests that correlated with the first 50 yards of the 100 yd butterfly. Matjiur et al. (2025) examined key variables influencing the sprint of the 50 m butterfly and found that total peak force during the plyometric push-up was the strongest predictor, highlighting the importance of upper-body muscular power during the short sprint of the butterfly. Consequently, there is agreement that upper-body power is important.

The second 50 yards of the 100 yd butterfly, much like the freestyle, had less significant correlations. The second 50 yd had three significant relationships compared to the eight from the first 50 yd butterfly. ISBQT peak vertical force, RFD 200 ms, and plyometric push-up flight: contraction time were moderately to strongly correlated to the second half of the swim. This may be in part due to the flip turn that is performed in the last half, in addition to force generation needed when swimming. This possible explanation is supported by previous research of the importance of the lower body when it comes to flip turn performance. (Cronin et al., 2007; Keiner et al., 2021). In addition, the plyometric push-up flight: contraction ratio remained significant, demonstrating that upper-body power may still contribute to swim performance. Even with the three performance variables being significant, the total number of significant correlations decreased by five, which may be due to the influence of fatigue. de Jesus et al. (2012) investigated kinematic changes in the butterfly stroke during a submaximal and a maximal 100 m bout and found that the maximal swim showed greater technique changes and lower velocity, especially towards the end of the swim. Not only does fatigue result in lower-quality movement, but it may also reduce power output, as seen in previous research on the 100m freestyle (Almeida-Coelho et al., 2016).

The total swim time had moderate to strong correlations between a variety of performance variables. CMJ relative peak power, peak velocity, RSI-modified, IBSQT peak vertical force, RFD 200 ms, and plyometric push-up flight: contraction time were all significantly associated with the entire butterfly swim. As in freestyle swimming, the upper and lower body strength and power remained important throughout the swim. These findings agree with Holub et al. (2025), who found that jump tests correlated with butterfly kicking. Although the authors did not find a significant relationship between the upper body strength test and the arms-only swim in their study, our findings showed that upper body power was associated with the 100 yd swim. This may be due to the powerful arm strokes the swimmer must execute to generate propulsive force in the butterfly stroke. Lower body strength and power may have been significantly correlated to the butterfly swim as in addition to the force needed within the stroke, the 100 yd swim involves three flip turns and a block start, both of which have been associated with lower body strength and power (Beretic et al., 2013; Cronin et al., 2007; Illera-Delgado & Gea-Garcia, 2022; Keiner et al., 2021). Much like the freestyle swim, the 100yd butterfly had two fewer significant correlations than did the first 50 yards of the swim. Again, this may be due to fatigue accumulation, which may hurt technique and inhibit sustained power output. Either way, the lower and upper body strength and power may have important contributions pertaining to the success of the butterfly swim.

Breaststroke

The first 50 yd of the 100 yd breaststroke showed no significant correlations with any of the performance variables. This could be surprising, as the block start comprises approximately 30% of the first 50yd, and previous research cited here shows that lower body strength and power are associated with better starts (Beretic et al., 2013; Illera-Delgado & Gea-Garcia, 2022). However, the lack of significant relationships may have been influenced by the nature of the breaststroke, as compared to the other strokes, given its complex, highly technical mechanics (Takagi et al., 2004). The breaststroke is composed of four phases: recovery, glide, out-sweep, and in-sweep, and the leg kick is divided into four phases: the sweep, lift, glide, and recovery (Takeda et al., 2014). Takagi et al. (2004) found that better swimmers delay arm motion during leg sweeps, thereby increasing the time spent in the non-propulsive phases. If swimmers are increasing the time spent in non-propulsive phases, they are not actively generating propulsive forces, which may help explain the current findings. Now, we did not measure any kinematic variables of the breaststroke, so this reasoning is not definitive. In addition, greater propulsive forces may be attributed to greater strength and power outputs, but the lack of significant findings raises the question of whether the breaststroke is too technical for strength and power qualities to be easily expressed. Invernizzi et al. (2014) found that upper and lower body strength tests showed no significant correlations with swim velocity for the breaststroke, which is in line with our findings.

The second 50 yards of the 100 yd breaststroke, however, detailed six significant correlations. CMJ concentric peak power, eccentric peak force, IBSQT peak vertical force, plyometric push-up concentric rate of force development, concentric peak force, and eccentric peak force were all found to be strongly correlated with the second half of the breaststroke. CMJ concentric peak power and IBSQT peak vertical force may be in part important as they will play a significant role in the open turn (Kaiyang et al., 2025). For CMJ and plyometric push-up, the eccentric peak forces were significant relative to the second half of the swim, even though there are little to no eccentric actions in swimming (Gomez-Bruton et al., 2019). The only eccentric muscle actions that may be at play occur when swimmers accept force on the wall with their arms and legs as they prepare for the open turn. Following this point, the breaststroke does not follow the same pattern as the freestyle and butterfly. In the two previous strokes, performance variables were not correlated due to the possibility of fatigue and metabolic accumulation, which inhibited power and strength expression as the swim progressed. Conversely, as the breaststroke progressed, strength and power qualities appeared to have a greater impact, as indicated by the correlations. Oxford et al. (2016) investigated changes in kinematic and arm-leg coordination during the 100-m breaststroke swim and found that swim velocity and stroke index decreased, suggesting that fatigue, via metabolic acidosis, may have contributed to a less efficient stroke. As stroke efficiency decreases, the effort required of the swimmer will increase as an attempt to maintain swim velocity (Thompson et al., 2000). This is seen when stroke rate increases and stroke length decreases as the swim goes on (Thompson et al., 2000). The results suggest that the swimmer may muscle through the end of the race as their technique decreases to maintain swim velocity, highlighting the importance of strength and power towards the end of the race. Although research and findings from other freestyle and butterfly strokes may indicate the opposite, this explanation may point to an area warranting further investigation for the breaststroke.

The total swim time for the breaststroke had two correlations with the performance variables. Plyometric push-up concentric and eccentric peak force were strongly related to the entire swim time. Much like the second 50yd of the total swim, the upper body strength played a role in the entirety of the swim. Once again, an eccentric force is playing a role that was not predicted, since the swim is nearly concentric (Gomez-Bruton et al., 2019). As this was consistent with our findings in breaststroke, this area needs further research. The lack of correlations with other performance variables raises questions about our sample size. In addition, it raises another question: how does fatigue affect swim technique, along with strength and power expression throughout the 100 yard swim? This will also serve as another research question that will need further investigation.

Backstroke

The backstroke did not have any times for the 50 yd splits because the University's time sheet did not list all swimmers' data. Thus, only the total time of the 100 yard backstroke was analyzed. On that note, no performance variables were found to be significantly correlated with the total swim time. As lower body strength and power have been correlated to flip turns, it may be surprising that no significant correlations were observed, as the same number of flip turns were performed in this swim compared to the others. This may have been different if we had evaluated the 50 yard splits, given the current results for the other strokes, as well as previous research detailing strength and power relationships with the earlier stages of the backstroke swimming race. Kovacova and Brodani (2019) found that the CMJ with and without arms was significantly related to the backstroke up to 4 meters. However, this is speculative, as we had no access to the backstroke splits. Although the performance variables we chose did not correlate with the 100 yd backstroke, lower and upper body strength and power have been previously documented as important for the backstroke in short-distance races (Carvalho et al., 2023; Keiner et al., 2015).

Limitations

There are several limitations to the study. The participants are from the same university, making them a homogenous group, which may decrease variability. In addition, the sample sizes in each group are small, which may limit the study's statistical power. However, the sample size is similar to that of previous studies, which used a similar number of swimmers (Holub et al., 2025; Kao et al., 2018; Morouco et al., 2011). Training age, fatigue, swim regimen, sleep, nutrition, class workload, and weight-room training were not controlled factors that may have played a role in testing and even swim performances. Another limitation is that this is a correlation study. The findings themselves do not demonstrate that one variable causes another; they merely show that the variables are associated. In addition, the lack of split times for the backstroke makes it harder to explain our findings, leading to a more speculative discussion. Another limitation of the study is that we did not measure kinematics or fatigue. These components may have strong contributions to the study's results, but they cannot be used to explain the findings because they were not measured. Again, those variables may be used as possible explanations rather than definitive reasons to support the findings of the study.

CHAPTER 6

CONCLUSION

Competitive swimming is an individual sport that requires a great amount of technical efficiency, power output, and aerobic fitness to be successful (Barbosa et al., 2015; Yamakawa et al., 2024). Because of the sport's increased popularity and participation, there is a need for more accurate testing to help swimmers succeed (Cottle, 2017; NCAA, 2025). Using a testing battery may help track an athlete's progress and, if the appropriate tests are selected, may also help determine the focus of dry-land training to improve the athlete's ability in the water. This study attempted to evaluate performance variables and compare them across all 100 yard races for all four strokes. The battery of tests included the IBSQT, 1-RM neutral grip pull-up, plyometric push-up, CMJ, and an eccentric hamstring strength assessment. Total and 50yd splits were taken from all four strokes except the backstroke, which did not have data for the 50yd splits.

The results demonstrated that strength and power of both the upper and lower body may be contributors for freestyle and butterfly, as they had strong correlations for the 50 yd splits and 100 yd swim. It was also observed that strength and power expression decreased over the course of the swim, as evidenced by fewer significant correlations, which may have been in part due to the effects of fatigue. The breaststroke had a different pattern in which, as the swim progressed, strength and power qualities seemed to become more important. The results may be due to the technical demands of the stroke, and as the swim progressed, strength and power qualities became more important. However, this is not definitive, as we did not measure stroke kinematics. The backstroke showed no correlation with performance variables, which was unexpected. This was counter to other studies that found that strength and power are important in the stroke (Carvalho et al., 2023; Keiner et al., 2015). Overall, strength and power from the lower and upper body seem to contribute differently between the four strokes. This may influence training parameters and swimming strategies moving forward.

Practical Applications

Strength and power requirements for competitive swimming have been shown to be important contributors to athletes' success across many components of the swim (Beretic et al., 2013; Cronin et al., 2007; Kao et al., 2018; Keiner et al., 2015). The current study has identified performance variables for 3 of the 100yd strokes in competitive swimming. The performance variables correlated with the respective swim may be used to track progress for that swim. In addition, the findings provide a roadmap for what to train on for dry-land programming and periodization. For the 100y d freestyle, the neutral-grip pull-up may be used for training, as it is significantly correlated with the swim. If the neutral grip pull-up is not an exercise that is possible, increasing back strength through another exercise may be a plan, as it relates to the swim. The CMJ can be used similarly, but rather than using the CMJ itself as an exercise, use its property. For example, the CMJ is used to measure lower body muscular power (Illera-Delgado & Gea-Garcia, 2022; Kao et al., 2018; Kovacova & Brodani, 2019). As it was significantly correlated with freestyle and butterfly, it may provide a practitioner with a direction to consider when training swim athletes. As the eccentric qualities in the performance variables showed little to no correlation with swim performance, eccentric strength in the pool may not be as important as concentric strength. Now, it is not being suggested that eccentric strength or training is not important. But eccentric strength may not serve swim performance as much as previously thought, which could help practitioners choose exercises that are more beneficial to a swimmer's performance.

Implications for Future Research

There are several avenues for future research that can be drawn from this study. Some examples include:

- There is a need for continued dry-land testing across all four strokes. Research has mainly focused on the freestyle stroke as it is the least technique-demanding of all four strokes (Beretic et al., 2013; Born et al., 2020; Hawley & Williams, 1991; Kao et al., 2018; Morouco et al., 2011).

- Researchers should investigate how eccentric strength may contribute to swimming performance. Although eccentric contractions are not primary in swimming, eccentric training may still provide benefits (Gomez-Bruton et al., 2019). The present study found very little to no correlations with any eccentric variables, which begs the question of what importance does eccentric strength have on swimming.

- Research should determine the role of strength and power in the water to help guide training. The technique of each swim stroke is important, as swimming is a skill. However, identifying how strength and power affect swimming may help guide practitioners with training protocols.

- Training studies should be conducted based on the qualities tested to determine their effects on swimming performance. When testing strength and power, it may be beneficial to combine these assessments with a training study to examine the effects of training on the assessments and swimming.

- Specific tests should be selected for certain strokes, as they may help a coach identify a swimmer's strengths and weaknesses. Because strokes may involve different muscles, mechanics, and force outputs, it may be beneficial to have specific assessments for each stroke.

- The time of year should also be considered when testing collegiate athletes. For this study, athletes were competing in the Fall; in future studies, testing athletes around competitions or exams should be considered, as these events may affect assessment results.

- There should be a continued search for key performance indicators for the four strokes and their distances. Distance and the particular stroke will influence how strength and power are expressed, so understanding the key performance indicators may help narrow down the specific assessments chosen for training programs (Almeida-Coelho et al., 2016; Wolfrum et al., 2013).

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