ABSTRACT

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Six female and 5 male subjects performed a maximal effort 100 yd. butterfly time trial. The purpose of the test was to investigate if there was a link between the swimmer's forward velocity and the amount of time between the end of the downward portion of the first kick and the finish of the outsweep of the hands. Subjects were filmed underwater from the front in order to best show the movements of interest. The sequence was then analyzed on a stop action/single frame advance VHS player. A constant frame speed of 30 frames per second was utilized. No statistical difference was found in the comparison between the timing pattern and velocity. Other comparisons between the change in the subject's 2nd and 4th length were studied, such as: the increase in the swimming time, and number of strokes. None of the comparisons were significant. A paired t-test did show a significant increase ($P = .01$) between the subjects 2nd and 4th length velocities. Individual difference variables may be the reason for these differences.
FORWARD VELOCITY IN RELATION TO A SPECIFIC TIMING SEQUENCE IN BUTTERFLY SWIMMING

A MANUSCRIPT STYLE THESIS PRESENTED TO THE GRADUATE FACULTY UNIVERSITY OF WISCONSIN-LA CROSSE

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTER OF SCIENCE DEGREE

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THESIS FINAL ORAL DEFENSE FORM

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We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

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The candidate has successfully completed his/her final oral examination.

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INTRODUCTION

Swimming, like other sports, has changed with the development of technology. Technological advances in kinematic analysis have changed the way scientists and coaches understand swimming propulsion. Technology such as high speed filming and underwater windows in pools have opened many doors for swimming research. Due to recent advancements, previous theories of stroke mechanics have become discredited (3,11). These changes have resulted in new coaching and teaching techniques.

Underwater filming has changed the way coaches interpret stroke mechanics. Videotaping, which has replaced filming, has also become a useful and powerful teaching tool that provides a great amount of technical information to scientists, coaches, and swimmers. Underwater filming has helped change the theory of swimming propulsion from a push/pull dominated theory of statics to a theory of hydrodynamics. This paradigm shift has been influenced by recent advancements in swimming technology. New information now available from these sources helped change the way scientists and
coaches perceived stroke mechanics (3,8). The action/reaction theory of propulsion theorized that the best way to maximize propulsion was to apply force from the hand 180° from the direction of movement in a straight back pattern. In the lift/drag theory of propulsion, the hand moves more vertically and horizontally in relation to the body as opposed to backward (1,2,11,12). Sweeping movements of the hands produce moments within the stroke where propulsion is either lift or drag dominated (11,12). The total amount of force produced by the combination of lift and drag forces is the resultant force (1,2,7,8).

**Butterfly Stroke**

The butterfly stroke was derived from the breaststroke in 1952 (3). The butterfly requires a simultaneous over the water recovery of the arms, a paired arm propulsive pattern underwater, and the dolphin kick.

The butterfly is the second fastest racing stroke and when it first emerged many coaches believed it would someday be faster than the front crawl. With advanced filming technology, researchers have proved this was mechanically impossible mainly because the
double arm pull results in an inconsistent pattern of propulsive force (3,7).

Fluid dynamics plays a large role in limiting the velocity of all swimmers (2,7,8). The butterfly, unlike the front crawl, allows for forward trunk deceleration during the arm recovery portion of the stroke cycle. Deceleration occurs when there is no propulsive force being applied by either arms or legs, thus creating a start/stop pattern of force development. A lack of consistent force production causes the average forward velocity to be lower than the front crawl stroke.

Timing is also a critical factor for reducing deceleration in the butterfly stroke (9). A swimmer who can reduce the time spent in the deceleration phase can use more energy toward the propulsion phase, resulting in faster performance times (1,3,6,7,8,9).

This study focused on the relationship between forward velocity and the timing sequence in the butterfly. The specific sequence analyzed was the timing of the completion of the outsweep of the hands and the finish of the first downward kick. To diminish deceleration, the finish of the propulsive part of the
kick should coincide with the first propulsive part of the arm stroke (7,9). Proper timing of the sequence would minimize the decrease in forward velocity, and thus require less energy to maintain the same velocity throughout one stroke cycle. In summary, swimmers who coordinate the kick and arm stroke correctly will spend less energy overcoming inertia caused by a decrease of forward velocity (3). Butterfly swimmers using this timing will use more energy to produce forward velocity thereby making them more efficient and faster swimmers.

**Purpose of the Study**

One purpose of this study was to examine the relationship between the timing pattern of the stroke sequence in collegiate butterfly swimmers and the velocity they maintain over the last 25 yards of a 100 yard time trial. A second purpose was to demonstrate the effectiveness of collecting and analyzing swimming stroke data with equipment that is readily available to swimming coaches.

**Need for the Study**

The study was performed to derive information that would help swimmers swim faster. The benefits of redirecting the limited amount of force that a swimmer
possesses while overcoming inertia to create propulsion, will improve the swimmer's performance. Swimmers who possess proper timing can limit the amount of time spent decelerating in the water and maximize the time they spend maintaining velocity in the water. Physics tells us that it takes less energy to keep a body in motion than to overcome inertia (5). Butterfly swimmers who constantly have to overcome inertia will tire more rapidly and deplete the amount of energy resources they could use for racing (7).

Data were collected by video taping a 100 yard butterfly time trial from below the water surface. A front view of the final 25 yards was used for evaluation. The front view was selected because the finish of the kick and the finish of the outsweep are visible (4). By counting the frames of the tape which operated at 30 frames per second, the tape showed the change in the timing sequence between the first and last 25 yards of the time trial. Swimmers who have a smaller timing difference should possess a more consistent swimming time over the last 25 yards than those swimmers who have a large timing difference.

This study has applied value since underwater
videotaping is possible in any pool where an underwater window and camcorder are readily available and the information can be easily extracted from the tape. With this procedure, the information gathered could be immediately available for analysis and direct transfer to the swimmer.

METHODS

Subject Selection

The subjects included five male and six female collegiate swimmers between the ages of 19 and 22. All subjects were college athletes and experienced butterfly swimmers who raced butterfly during the competitive season at the NCAA Division III level.

Testing Procedures

Data were collected at the University of Wisconsin-Stevens Point Natatorium. All subjects were instructed to warm up individually in preparation for a 100 yard butterfly time trial. Each swimmer then performed a 100 yard time trial by completing 4 lengths of a 25 yard course. They were instructed to swim the fastest possible time over the entire race course. They started in the water by pushing off from the wall. The trial was finished when the subject's hands touched
the wall after the fourth length. The times the swimmer achieved over the second and last 25 yards were used for the investigation.

**Timing of Subjects**

The swimmers were started with a horn, and overall 100 yard times were recorded. Intermediate lap times were recorded on the second and fourth lengths by two hand held watches. Split timers were instructed to start their watch when the swimmers feet left the wall at the start of the second and fourth lengths. The running time was stopped when the swimmers touched the wall with their hands at the completion of the fourth length. Lane ropes were used to keep the subjects in a straight line and to minimize turbulence.

**Filming**

A Magnavox camcorder shuttered at 1/1000 was used to perform the filming through a window 4 feet wide by 4 feet tall and three feet below the water surface. The swimmer's course was positioned to approach the window during the second and fourth 25 yards of the time trial. The front view provided the best view of the finish of the outsweep and completion of the kick (4).
**Instrumentation**

The Magnavox camcorder employed a frame speed of 30 frames per second. The mean of two hand held stop watches was used to determine the split time over the second and fourth 25 yards. A Panasonic AG6300 VHS player with stop and single frame advance was used to determine the timing difference between the finish of the downbeat of the first kick and the completion of the outsweep of the hands. A single frame advance feature was used to count the number of total frames that separated the two actions measured. Two evaluators simultaneously counted the frames one at a time. Data were used whenever both evaluators counted the same number of frames between the actions. Every stroke during the second and fourth lengths was used for the analysis. A study by Pai, Hay, and Wilson in 1984 during the British Commonwealth Games, also utilized frame counting for data collection (10). Pai et al. (1984) replayed films of various races measuring different stroke rates by counting the number of frames for each arm cycle (10). The Pai et al. (1984) study helped model this research.
Statistical Analysis

Subject characteristics were summarized by a paired t-test and three Wilcoxon correlations. The paired t-test was used to analyze the difference in swimming time between the second and fourth lengths. Correlations between the timing sequence and the lap time on the second and fourth lengths were computed. A second correlation between the stroke count and the lap time on the second and fourth lengths was also computed. A third correlation between the timing sequence and the number of strokes taken between the second and fourth lengths was computed.

Descriptive data were also utilized in this study. This was necessary because of the discreet nature of the variables within the study and the low number of subjects. Descriptive data were important to make the study applicable to coaches who do not always have the capability to statistically analyze data.

RESULTS

Both inferential and descriptive data were used in the study. A paired t-test and three Wilcoxon rank correlations were used to analyze the data, while the discreet nature of the measurements along with the
small sample size necessitated a descriptive analysis as well.

A paired t-test was used in comparing the time of the swimmer's second and fourth lengths. For each swimmer, a significant difference ($P = .01$) was found in the time change between the second and fourth lengths with the fourth length significantly slower than the second. Wilcoxon rank tests were then used to analyze the relationships between the change in swimming time to the change in frame count, the change in swimming time to the change in the number of strokes, and the change in the number of frames to the change in the number of strokes between their second and fourth lengths. No significant differences were found in any of the mathematical comparisons.

Each subject swam slower on their fourth length than on their second length. Eight of 11 subjects took more strokes on the fourth length than on the second length. For eight subjects, these results coupled with the decrease in velocity seem to show that there was a decrease in the amount of effective propulsive force the swimmer produced on the fourth length. Seven of 11 subjects demonstrated a smaller time (frame) difference
Table 1. Differences between the subject swimming time, number of frames in the timing sequence and number of strokes between the second and fourth lengths.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Time</th>
<th>Frames</th>
<th>Strokes</th>
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<tbody>
<tr>
<td>1</td>
<td>+0.43</td>
<td>-0.14</td>
<td>+1</td>
</tr>
<tr>
<td>2</td>
<td>+1.56</td>
<td>+0.57</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>+0.39</td>
<td>+0.34</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>+0.97</td>
<td>-0.50</td>
<td>+1</td>
</tr>
<tr>
<td>5</td>
<td>+3.10</td>
<td>-0.50</td>
<td>+1</td>
</tr>
<tr>
<td>6</td>
<td>+0.88</td>
<td>-0.12</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>+0.36</td>
<td>-1.07</td>
<td>+1</td>
</tr>
<tr>
<td>8</td>
<td>+0.52</td>
<td>+0.21</td>
<td>+1</td>
</tr>
<tr>
<td>9</td>
<td>+0.66</td>
<td>-0.38</td>
<td>+1</td>
</tr>
<tr>
<td>10</td>
<td>+1.48</td>
<td>+0.91</td>
<td>+1</td>
</tr>
<tr>
<td>11</td>
<td>+1.18</td>
<td>-0.91</td>
<td>+1</td>
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in the timing sequence on the fourth length than on the second by an average of .69 or .02 of a second. The four swimmers that increased their timing sequence difference also increased by an average of .64 frames or a difference of .02 of a second.
DISCUSSION

Since the data showed that there were no significant differences between the forward velocity of the swimmer and the timing pattern sequence, other factors may account for the decrease in the swimmers forward velocity (100% of subjects) and increase in the number of strokes during the fourth length (73% of subjects). Each subject showed a decrease in effective force production during the last portion of the trial. This was evidenced by the increase in time over the same distance and by the increased number of strokes. Since force equals mass multiplied by acceleration and since the subject's mass is constant, a reduction in the arm acceleration applied to the water must have diminished. There are several factors that could be involved in this process, including physiological changes in the body due to fatigue, psychological factors associated with muscular discomfort, biomechanical changes within the stroke, and technological factors in the sensitivity of the equipment used (3,7,8).

The physiological construct that most likely accounted for the decrease in forward velocity would be
a decrease in muscle PH due to acidosis (3,7).
Acidosis of the muscle will reduce the contractile speed of the muscle thus decrease the amount of force it can produce. Acidosis of muscle contributes to an increased amount of calcium needed for muscular contraction, reduces the rate of ATPase activity, inhibits phosphofructokinase (PFK) activity, and slows the removal rate of lactic acid (7). Each of these will cause a decrease in the rate of contraction within muscle thereby reducing the amount of force produced during contraction (7,8).

Acidosis of muscle tissue is uncomfortable at best and in many instances painful. An inexperienced swimmer may have a lower pain tolerance for the stimulus and be forced to slow their speed prematurely during the race (7).

Biomechanical and hydrodynamic factors related to fatigue that were not evaluated in this study could have also played an important role in the decrease in velocity. Factors such as hand pitch (angle of attack) or body position were not analyzed.

A technological factor in this study involved the use of the specified equipment. Video tape analysis at
30 frames per second may not be sensitive enough for this analysis. High speed film with the capability to analyze motion at hundreds of frames per second may have yielded more specific data.

APPLICATIONS

This study was designed to be easily reproduced so that coaches could readily obtain stroke information and quickly disseminate the information to swimmers. A pool that includes an underwater window or coach scope, any camcorder that can be shuttered with a tripod, and a tape player with frame by frame advancement capability are the only critical equipment needed. Besides the specific timing sequence that this study investigated, underwater analysis of a swimmer's stroke mechanics will allow the coach to view and evaluate a large variety of phases and aspects within the movement.

This study demonstrated that many individual differences were present in these movements. Coaches need to be conscious of the specificity of training and teaching that is needed for each athlete, especially at the advanced levels. Each athlete needs different training formats and stroke information in order to
reach full potential.

In this study stroke length was demonstrated to be an important factor in forward deceleration with 8 out of the 11 subjects taking more strokes on the fourth (and slower) length of the time trial. Maglischo (1993) states that acidosis causes a deceleration in races of 100 to 200 yards in length. If acidosis is a contributing factor, then specific training during the season that is geared toward improving the acid buffering capacity of the muscles and delaying acidosis is important (7). Training of this type will delay the muscle fatigue that is caused by lactic acid accumulation, and reduce the onset of deceleration associated with acidosis (7). Race pace is also an important factor in performance and should be closely looked at for each individual swimmer for each race. A swimmer who swims too fast in the initial phase of the race will experience acidosis earlier in the race thus forcing a premature deceleration in their velocity (7).

In summary, swimmers who possess an efficient stroke technique, adequately train to enhance their buffering capacity, and possess an awareness of proper
potential. Coaches need to treat and train swimmers on an individual basis especially at the advanced level to better insure their success.
REFERENCES


APPENDIX A

REVIEW OF LITERATURE
Review of Related Literature

The following review of literature was divided into three sections. The main headings were presented in the following order: general concepts of fluid dynamics, mechanical aspects of the butterfly stroke, and fluid dynamic concepts specifically related to the butterfly stroke.

**General Concepts of Fluid Dynamics**

Swimming has changed radically over the last 30 years. Scientists and coaches (3,7) have switched their paradigms regarding swimming propulsion. Swimming has gone from the push/pull, action/reaction concept to a concept involving lift and drag forces (2,8). The action/reaction model was prominent until the 1960's (3). This model was specifically based on Newton's third law of motion (i.e., for every action there is an equal and opposite reaction). Scientists and coaches have since cast a doubt on this model. The most current theory is one that involves a combination of lift and drag forces (1,3,7,8). Lift and drag are the same forces that act on airplane wings or a thrown discus. Swimming propulsion is similar, only the viscosity of the fluid is different.
When swimmers start to move through the water they will encounter resistance. How swimmers present their bodies to the water is critical in how much resistance they will encounter \((3,6,7,8,12)\). There are three types of drag resistance that will act upon a moving swimmer: surface drag, form drag, and wave drag \((1,2,5,7,8)\).

**Surface Drag**

Surface drag is surface resistance caused by the water flowing over the swimmer's skin. As the swimmer moves through the water, the layer of water directly next to the skin, or boundary layer, is disturbed. The process of slowly mixing the water in close proximity to the boundary layer of the swimmer requires that the swimmer exert a force on it, and in reaction the water must exert a force on the swimmer. The magnitude of the force depends on a number of factors that could include: velocity of flow relative to the body, surface area of body, smoothness of body, and type of fluid involved \((1,2,3,5,7,8)\). The water molecules that collide with the swimmers' skin, hair, and suit slow forward velocity. A 1989 study done by Sharp and Costill verified the negative effect of frictional drag. Their results concluded that swimmers who reduced their frictional drag by shaving body hair had lower blood lactic acid levels and longer stroke lengths on similar swimming performance tests than swimmers who did not shave. Swimmers who minimize
blood lactate levels are able to delay forward deceleration caused by acidosis of the muscle tissue.

**Form Drag**

A reduction in a swimmers form drag can improve performances without the initiation of more force by the swimmer (7). In regard to form drag, body position is the major factor. The shape that the swimmers present their body to the water is directly related to the amount of form drag they will possess. The smaller the amount of surface area the swimmers present to the water, the smaller the amount of form drag encountered. Three items that influence form drag are: cross sectional area of the body perpendicular to the direction of the flow, shape of the body, and smoothness of the surface (1,2,5,6,7,8,12). Therefore, as swimmers present their bodies to the water during motion, the two aspects of form drag they need to be aware of are the horizontal and lateral alignment of their body. Poor alignment either laterally or horizontally will increase body drag by allowing the water to push against a greater amount of body surface area thereby slowing forward velocity.

**Wave Drag**

Wave drag is a resistance force that only occurs in water. It occurs when swimmers are at the surface and propelling themselves. When the swimmer moves through the
water, splitting the two medians, air and water, it creates a wave. This wave of water then acts as a resistance force against the swimmer \(1, 2, 3, 5, 7, 8\). Bow waves are created from the head and trunk of the swimmers as they move forward \(2\). Swimmers who drag the back of the hand and arm forward through the water during entry can experience as much as a 30% speed reduction to wave drag.

**Momentum**

While in motion swimmers possess momentum. Force produced by the swimmer’s arms and legs in the water will give them acceleration and movement. The amount of force the swimmer exerts on the water to produce acceleration and increased velocity will help dictate how much drag force the water exerts on the swimmer \(6, 12\), and the faster a swimmer travels the more drag force will be exerted \(3\). A swimmer who can maximize applied force while minimizing drag force will better maintain forward velocity \(7, 8, 12\). The momentum that a swimmer possesses is dependent on the swimmers forward velocity. The greater the forward velocity the greater the momentum and constant momentum is a critical factor in swimming efficiency. Swimmers who apply propulsive force to the water in an inconsistent manner are less efficient than swimmers who do not. An uneven application of force provides periods of acceleration as well as periods of deceleration. The swimmers will then
move with a series of acceleration and deceleration phases, stopping and starting motions. Starting and stopping movements are less energy efficient and require more energy for the same amount of forward velocity. With each arm stroke the swimmer applies force to overcome inertia. The more deceleration the swimmer possesses in their stroke the more inertia they have to overcome to accelerate to their previous velocity. This requires a great deal of energy that could be more efficiently utilized to maintain forward propulsion (3,7,8).

**Butterfly Mechanics**

There are five major actions that make up the butterfly stroke. They include: the arm stroke, dolphin kick, timing of the arms and legs, body position, and breathing. The arm stroke itself consists of four components. These components include: the outsweep, insweep, upsweep, release, and recovery of the arms (7).

The arm stroke is performed with a rhythmical arm pattern where both arms stroke together. The butterfly stroke uses a simultaneous double arm over the water recovery much like a simultaneous double arm freestyle. The legs coordinate as one in downward and upward thrusts producing both forward and upward propulsion (8).
Outsweep

The outsweep of the arms occurs after the entry. The hands enter the water with the elbows slightly flexed. The hands enter pitched 45° to the water with the thumbs and index fingers entering first and the palms facing outward (8, 14).

During the outsweep the hands travel forward momentarily before sweeping out. The hands continue to sweep out and forward until the catch is made outside of the shoulders. The outsweep is not a propulsive movement, its purpose is to place the hands in a propulsive position for the insweep (7).

Insweep

The insweep begins outside of the shoulders with the catch and ends when the hands stop sweeping in under the body. The elbows bend to approximately 90° as the hands move close together under the body. There are two distinct parts of the insweep. The first includes a downward motion of the hand and the second an inward motion. During the first part of the insweep the fingers start to point toward the bottom of the pool with the thumb leading the way. The air foil design of the hand deflects the water backward thus providing propulsion. The second part of the insweep includes the hands moving inward under the body. The palms face inward with the thumbs leading the movement. The water
flows across the hand from the thumb to the little finger as the hands are swept in under the body. This movement and the angle of attack of the hands provide forward propulsion (7).

**Upsweep**

The upsweep begins at the finish of the insweep and ends when the hands leave the water. During the upsweep the hands change their pitch from facing in to facing out at approximately a 70° angle of attack. The water moves across the hand from the little finger to the thumb. The elbows stay flexed approximately 45° during the upsweep.

There are two phases of propulsion during the upsweep. During the first phase the hands sweep back, up, and out from underneath the neck back to the hips. The hands face out with the little finger leading the movement (14). The second propulsive phase is when the hands sweep up toward the surface. The hands are then pitched out, back, and upward to maintain an angle of attack that will provide propulsion (7).

**Release and Recovery**

The release is made as the hands relinquish pressure on the water next to the thighs. The palms turn to let the hands slice out of the water, little finger first with a minimum of resistance. During the recovery the arms sweep forward over the water in front of the shoulder where the
hands enter. During the recovery the little finger leads the hand out of the water with a minimum of upward movement (7).

**Dolphin Kick**

There are four kicks for each arm cycle in the butterfly stroke, two downward and two upward beats. There has been debate over the amount of forward propulsion, if any, the kick actually provides. Maglischo (1982) suggests that the downward beat of the first kick may be the only phase that increases forward velocity (8). The down beat of the second kick is smaller and may only maintain hip elevation (8). Neither upbeat phase of the kick provides forward propulsion (8).

**Upbeat Phase**

The upbeat phase of the kick starts with the knees at full extension at the conclusion of the downbeat. Hip extensors start the thigh moving up while the lower leg remains straight. The legs then sweep upward and inward until they are in line with the trunk. The major muscles acting during the upsweep are the gluteus maximus and the hamstrings (8).

**Downbeat Phase**

The downbeat is initiated by flexing the hip joint as the feet pass above the level of the body. Flexion of the knees will cause the muscles in the lower legs to become
relaxed and able to generate more power. The relative angle between the hips and trunk should start at 75°. The knees and feet are then accelerated downward creating forward propulsion. The downbeat ends when the legs are completely extended. During the downbeat the feet should be pitched upward and inward as much as possible (8). This will deflect the water back as well as down generating forward propulsion. The downbeat also starts with the knees slightly separated then gradually coming together through the downbeat phase, allowing for greater foot supination and force production (7). The first kick is propulsive even though the direction is mainly down. The downward force enables the hips to remain high in the water to decrease drag. The first downbeat phase comes during the outsweep and ends just prior to the catch while the second takes place during the upsweep of the arms (8).

Timing of the Stroke

The timing of the butterfly includes two dolphin kicks for every arm stroke. The downbeat of the first kick is executed during the entry and outsweep phases and completed with the catch (1,2,3,5,7,8,11). The upbeat of the first kick takes place during the downsweep and insweep phases of the stroke. The second downbeat is synchronized with the upsweep phase of the arm stroke. The second upbeat occurs during arm recovery. Proper timing of the arm stroke and
kick is a critical factor in maintaining constant forward propulsion (7).

The first downbeat phase of the kick is longer and more powerful than the second downbeat phase (7,8). The first upbeat is then likewise longer than the second upbeat. Equal effort should be placed into both downward kicks (7). It is body position, not effort, that allows a greater force to be produced during the first downward kick. The head and shoulders should remain down during the first two hand sweeps to allow for a longer upbeat phase of the first kick (7).

Body Position

Body position during the stroke should remain as level as possible in order to decrease form drag and maintain a higher velocity during the propulsive phases of the arm stroke (2). Hips will travel up and forward through the surface during the downbeat of the first kick and outsweep of the arms. This enables the kick to produce forward propulsion. The purpose of the second, smaller kick could be to produce enough force in order to keep hips elevated in the water and again reducing form drag (8).

Breathing

The breath in the butterfly is taken with the face forward. The face breaks the surface during the completion of the insweep and stays above the water through the first
half of the recovery. The chin must stay close to the water surface in order to maintain proper streamlining. The head drops back down into the water just prior to entry.

**Fluid Dynamics Involving the Butterfly**

Swimmers propel themselves through the water using push/pull and lift/drag forces to accelerate the body forward. The four swimming strokes are inherently different from each other in terms of fluid dynamics. The front crawl allows for body roll in the water. This transversely rotated body position that is presented will decrease the resistance that the water can apply to the swimmer (2). The front crawl operates with a flutter kick and alternating arm movements. In the front crawl one limb is always in the water producing a propulsive force. Likewise the alternating movement of the kick applies constant forward propulsive force.

The back crawl is similar in that the arms and legs move alternately. Body roll is again apparent in the backstroke allowing the body to slice through the water with less resistance than is it were traveling flat. Again, the back stroke provides a situation where there is always a force arm in the water producing forward acceleration. Force application is relatively constant.

The breast and butterfly strokes are performed without the aid of transverse body roll, therefore resistance drag
is increased (2). During the stroke, the arm and leg actions are also performed simultaneously in the same plane of motion. The breaststroke uses an underwater arm recovery with the legs performing a whip kick action. The butterfly requires an over the water recovery coupled with a dolphin kick.

The butterfly has some definite mechanical disadvantages compared to freestyle. The main disadvantage is that there is a relatively large period of time in the stroke with no forward propulsion because of the mandated double arm recovery rule. Only the kick may provide some forward propulsion during the end of the arm recovery. The timing of the kick and the arm strokes is essential for a fluid motion (7). A properly timed stroke will produce less deceleration time and produce more horizontal force.

**Timing of the Stroke**

There are several techniques a butterfly swimmer can use to help reduce deceleration. In the butterfly one involves proper timing of the stroke, specifically the coordination of the finish of the propulsive part of the first kick and the initiation of the propulsive phase of the arm stroke. Such timing would minimize forward deceleration and maximize swimming performances (7,9,10). This coordination is an essential part of the stroke. Poor
timing at this phase of the stroke is a distinguishing performance limiting factor (1, 2, 3, 5, 7, 8, 10).

The first downward kick of the butterfly is propulsive (7, 8). The downbeat occurs during the hand entry position of the stroke. With the downward portion of the kicks propulsive phase the body accelerates until the kick is completed. The body will then decelerate until the propulsive portion of the arm stroke acts. Timing between the arms and leg is essential in maintaining forward velocity since it lessens the amount of energy used to overcome inertia and then uses it for forward propulsion.

The best way to capture the timing aspect between the kick and pull pattern is from a front underwater camera view. From this angle the outsweep, catch, and insweep portions of the stroke can be easily seen. This angle also adequately shows the completion of the downbeat of the first kick. With this information, the time difference between the two can be calculated.

**Summary**

While swimmers propel themselves through water, they create resistance in the form of drag. This resistance is a limiting factor in the swimmer’s ability to maintain forward velocity. Resistance the swimmer encounters will increase and decrease with the swimmer’s forward velocity. Swimmers
who minimize drag with optimal body position will maintain higher velocity.

While moving, swimmers possess momentum, and constant momentum is a critical factor in stroke efficiency. Swimmers who apply a force in a consistent manner are more efficient. The butterfly is an inefficient stroke because both arms pull and recover simultaneously, generating periods of acceleration and deceleration. One technique to help prevent deceleration in the butterfly would be to apply the propulsive force of the arms at separate times than the propulsive forces of the legs. One point in the stroke where this technique may be critical is during the outsweep of the hands. During the outsweep, the hands do not produce acceleration, but downward motion of the feet does. Ideal timing of the stroke couples the finish of the kick with the start of the insweep. This timing would allow less time for maintain a more constant forward velocity.
who minimize drag with optimal body position will maintain higher velocity.

While moving, swimmers possess momentum, and constant momentum is a critical factor in stroke efficiency. Swimmers who apply a force in a consistent manner are more efficient. The butterfly is an inefficient stroke because both arms pull and recover simultaneously, generating periods of acceleration and deceleration. One technique to help prevent deceleration in the butterfly would be to apply the propulsive force of the arms at separate times than the propulsive forces of the legs. One point in the stroke where this technique may be critical is during the outsweep of the hands. During the outsweep, the hands do not produce acceleration, but downward motion of the feet does. Ideal timing of the stroke couples the finish of the kick with the start of the insweep. This timing would allow less time for the body to decelerate. Less deceleration time makes the swimmers more energy efficient while allowing them to maintain a more constant forward velocity.
REFERENCES


APPENDIX B

RESEARCH DESIGN
Hypothesis

1. There will be no relationship between the timing of the kick and the completion of the outsweep with the swimming velocity over the first and fourth 25 yards of a 100 yard time trial.

Assumptions

In the conduct of the study it was assumed that:

1. The swimmers performed the time trial at a maximal effort.
2. The pool was a true 25 yard course.
3. The subjects did not purposely alter their stroke for this experiment.

Delimitations

This study had the following delimitations:

1. The subjects were current collegiate swimmers between the ages of 18 and 23 who attended and competed in the Wisconsin State Athletic Conference or the Wisconsin Women's Intercollegiate Athletic Conference.
2. The subjects were all butterfly specialists.
3. The subjects were physically healthy individuals.
Limitations

The study had the following limitations:

1. The subjects in this study were not randomly selected.

2. The motivational levels of the subjects could not be controlled during the time trial.

3. Individual differences including phenotype can play a roll in stroke mechanics.
APPENDIX C

RAW DATA
Table 2. The number of frames between the timing sequence for each stroke of the subjects (Subj.) second and fourth length (Lt.) and the mean for those lengths.

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APPENDIX D

SUBJECT CONSENT FORM
Informed Consent
Butterfly Swimming Study

I_________________________________________, have volunteered in this study in order to resolve whether a small timing difference between the finish of the downward part of the first kick and the end of the outsweep of the arms is a valid predictor in swimming velocity. I am aware that my involvement in this research study will require only one maximal 100 yard time trial swim in a 25 yard course.

During the trial I am aware that I will be videotaped from underneath the water from an underwater window. I will attempt to perform at my best and to maintain maximum forward velocity. Though this is a maximum performance test I understand that I can stop at anytime.

As with any exercise, there exists possible risks of adverse conditions occurring (i.e., dizziness, shortness of breath, abnormal blood pressures, fainting, chest pain, etc.) during the test. I also understand that I will feel some level of fatigue at the end of the test. If any abnormal signs or symptoms occur during testing, the test will be immediately terminated.

Stretching exercises and warm up swimming will be encouraged both before and after the test to help minimize the risk of injury. A separate warm up pool will be available for warm up and cool down activities.

To the best of my knowledge I am in good health and without any limiting disabilities (i.e., heart or lung) that would prevent me from becoming involved with this test. I acknowledge that I have read the statement above and I understand them fully. I also state that all of my questions to this point have been answered completely. Therefore I consent to participate in this study of my own free will. In addition, I am aware I may cease to participate at any time without any type of consequences.

Signed:_________________________________ Date:____________

Witness:_________________________________ Date:__________
APPENDIX E

DEFINITION OF TERMS
Definition of Terms

Angle of Attack: Angle of the water flow to the plane of the body or hand.

Finish of the First Kick: When the feet are at the lowest point of their downward motion following the outsweep of the hands.

Insweep: The portion of the stroke following the outsweep and before the upsweep. During the insweep the hands move from in front and outside of the shoulders to under the body and together.

Momentum: The quantity of motion that a body possesses. The product of a body's mass and velocity.

Swimming Velocity: The rate in which a swimmer travels.

Timing Sequence: The time between the completion of the hand outsweep and finish of the first downward kick.
APPENDIX F

RECOMMENDATIONS FOR FUTURE STUDIES
Recommendations for Future Studies

This study examined one aspect of many that could cause the deceleration of a swimmer during a race. The findings of this study suggested that individual differences may have the greatest effect on deceleration. Future research of this kind might be aided by:

1. The use of more sensitive biomechanical analysis equipment for collecting more precise data when analyzing sequences within the stroke.

2. The use of blood lactate testing before and after a trial in order to relate blood lactate levels to mechanical efficiency.

3. A longitudinal study exploring the effects of different types of training in relation to stroke mechanics and blood lactate levels.

4. The relationship of stroke length to various biomechanical variables in relation to forward velocity.

5. The use of three dimensional filming in order to analyze biomechanical variables such as hand pitch, in order to calculate the amount of lift and drag a swimmer used during specific moments within the stroke.