

## **Kinematic Analysis of Peak Velocities in the Breaststroke as a Function of the Timing of the Kick**

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### **ABSTRACT**

*The purpose of this study was to determine the effects of the timing of the Breaststroke kick on intra-cyclic velocity fluctuations. Researchers examined peak hip velocities of Breaststroke swimmers to determine any significant velocity drop-offs and magnitude of velocity regained between different kicking techniques. Subjects performed swimming trials with three different kick protocols: a conventional kick, a late kick, and a delayed late kick. Video analysis was used to analyze peak and minimum hip velocities within one Breaststroke cycle for each trial. Data was analyzed using ANOVA repeated measures analysis. Major findings of this study were that due to smaller percentages of hip velocity drop-off, greater swimming efficiency may be achieved when the kick is initiated during the insweep or early recovery arm phases and that video analysis and verbal cueing are viable tools to help swimmers improve their regular stroke technique.*

### **Introduction**

The Breaststroke can be broken down into three phases, the Kick, the Pull, and the Glide. When these three phases are completed in succession, a swimmer has completed one full cycle of the Breaststroke. The variations in the overall swimming velocity throughout one Breaststroke cycle are a good indicator of the swimmer's stroke efficiency; the more efficient a swimmer's stroke is, the better they will perform (17). A number of current studies have examined the coordination of the arms and the legs during the Breaststroke cycle (4, 8, 19). The earlier studies mainly focus on periods of propulsion provided by each phase and how they affect the acceleration and deceleration of the entire cycle. The most recent study by van Houwelingen et al. noted swimmers are capable of manipulating their arm-leg coordination resulting in intra-cyclic velocity variations. However, their results were inconclusive.

During the 2016 Olympics, British swimmer Adam Peaty won the men's 100-meter Breaststroke race in world-record fashion using a kick technique that performs the kick phase of the Breaststroke later than it is conventionally taught. To our knowledge, there is currently no research that examines how the timing of the

initiation of the kick, when occurring during different phases of arm pull can affect the propulsion, acceleration, and consequently intra-cyclic velocity of the Breaststroke.

The lack of research regarding analysis of the timing of the Breaststroke kick is likely due the relatively new nature of this technique. However, given the surprising effect this technique has had on Adam Peaty's gold-medal, world-record performance at the 2016 Olympic games, it is clear that this technique should be investigated to determine if his performances were the result of training, or improved technique.

Kinematic analysis provides invaluable information for both swimmers and coaches; video playback allows them to immediately review a swimmer's technique and obtain feedback for making corrections, and digital analysis allows a swimmer's stroke efficiency to be formally evaluated and improved (3-5, 7, 16). The hip has been validated as the most reliable anatomical landmark to use for measuring intra-cyclic velocity and its changes within a stroke; the frame-by-frame analysis that can be utilized in accompaniment with the recorded intra-cyclic velocity fluctuations allows researchers to pinpoint which aspects of the technique are contributing to the fluctuations in order to make improvements (3-5, 7, 16, 19).

Currently there are no published studies that examine the effects of the timing of the Breaststroke kick during specific pull phases on intra-cyclic velocity fluctuations. The expectation is that this research can lead to improved stroke efficiency and consequently faster swimming times. The purpose of the study is to determine the effects of the timing of the Breaststroke kick on intra-cyclic velocity fluctuations. The expectation is that through this investigation it can be determined if the timing associated with a "late kick" can provide higher overall swimming speeds than the "conventional kick" technique.

## **Methods**

### Participants

Subjects were recruited from an NCAA Division I swimming team (4 males & 5 females). Inclusionary criteria: Breaststroke must be one of their primary competitive events; they must have reached NCAA Division I levels of competitive experience. Exclusionary criteria: Non-experienced competitive swimmers; injury that prevents swimmer from swimming with normal technique; Breaststroke is not a primary race event for the swimmer.

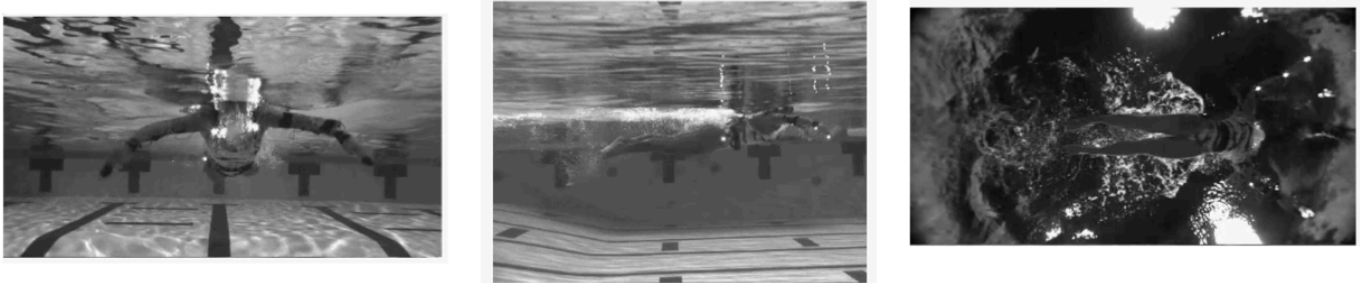
### Design

This study utilized a single-subject design by examining the effects on peak velocity during the Breaststroke with three different trials of executing the kick during different phases of the stroke. The independent variable was the timing of the kick (conventional, late, or delayed late) and the dependent variables were

maximal knee flexion angle, peak arm velocity, peak leg velocity, time to complete kick, percentage of velocity drop-off, and percentage of velocity regained.

### Measures

Three high-speed digital cameras (Baumer Model HXG with CMOS sensors), installed in custom housings (The Sexton Company, Salem, Oregon) were used for filming swim trials. All 3 housings were attached to custom-designed mounting frames and positioned so as to provide the three required fields of view (Figure 1).



**Figure 1.** Synchronized frames of the three camera angles used to film swimming trials.

Camera 1 was used for recording the frontal, or head-on view, of the subject's progress and was mounted on a vertically oriented frame. The camera was positioned at a depth of 0.48 meters (1.57 feet). Camera 2 was mounted on a horizontal platform that rested on the bottom of the pool at a depth of 2.13 meters (7 feet). The camera was aligned vertically, i.e. pointing upwards to the surface and provided a transverse view of the subject's progress. Camera 3 was mounted on a laterally positioned frame that was bolted to the concrete deck of the pool. The camera was positioned at a depth of 0.48 meters (1.57 feet), similar to the depth of Camera 1. The lateral orientation of Camera 3 provided the data for the progress of the subject in the longitudinal plane of motion. The distance the subject was required to cover in each trial varied between 11.89 and 13.71 meters (39 to 45 feet). This distance was determined by placing the camera that was used for recording the frontal, or head-on view of the subject at a distance of 13.71 meters (45 feet) yards from the side of the pool from which the subject was required to push-off at the start of each trial. Subjects were instructed to swim directly towards this camera, approaching it as close as possible without colliding with the camera. The cameras were controlled via dual 9.14 meter-long (30 feet) Gigabit (GigE) Ethernet cables connected to a desktop computer located on the pool deck. Each camera had two cables - one cable was assigned to camera control and another cable was used for frame synchronization. Unlike the limitations relating to maximum functional lengths inherent when using Firewire cabling, GigE cabling does not have a length restriction, which allowed for optimum placement of the underwater cameras in the pool.

Rotational joint segments were identified using a custom-designed string of light emitting diodes (LED's), housed in waterproof housings. The LED's were duct taped

to the body and powered by a battery pack attached to a belt worn by the subject at the waist. Templo (Contemplas, Kempten, Germany) motion capture software was used for capturing and recording the video data. A second software package, Motus, (Contemplas, Kempten, Germany), was used for digitizing, data analysis, and generating “reports”. This software included a “Multi 2-D” (M2-D) feature, which enabled multiple cameras to be synchronized. Each sequence was digitized using a combination of auto-tracking and manual modes. IBM Statistical Package for the Social Sciences (SPSS) version 23 was used to run statistical analysis.

After obtaining approval for the study from the University of Hawai‘i at Mānoa University Institutional Review Board for the Study of Human Subjects, Breaststroke subjects were recruited from the University of Hawai‘i at Mānoa Intercollegiate Swimming Team. Subjects reported to the pool at a scheduled time, and signed a consent form. Prior to videotaping, each subject was shown a previously digitized swim trial so as to familiarize them with the outcome of the videotaping and resulting “report.” Following the recording of each subject’s anthropometric data, the LED lights were taped on to specific anatomic landmarks (bilateral fingers, wrists, elbows, shoulders and right hip). The subject was provided with sufficient time to swim a few warm up laps to get accustomed to swimming with the taped LED light strings.

The subject performed a total of three trials of 3 specified swimming protocols. The three protocols consisted of the following:

Protocol One (Conventional Stroke): The subject, while swimming the Breaststroke, was required to use their regular technique, at an effort that corresponded to the pace they would complete a 100-yard race sprint. In all except a single case, the subject’s “conventional stroke” consisted of the initiation of the kick coinciding with the beginning stage of the insweep, called the “early insweep.”

Protocol Two (Late Kick): The subject, while swimming the Breaststroke, was required to time the initial draw-up of the kick to coincide with the period during which the hands were in the final stage of the second phase of the Breaststroke pull pattern (the insweep), called the “late insweep.”

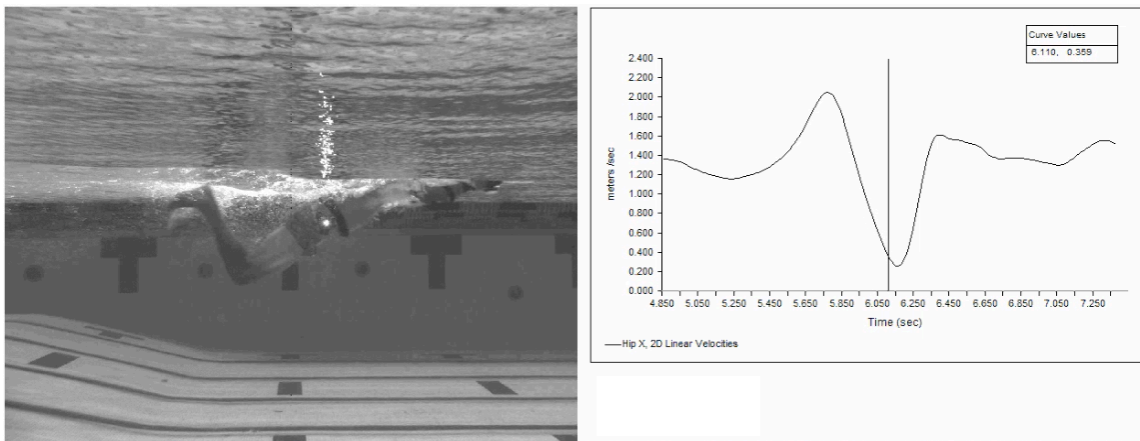
Protocol Three (Delayed Late Kick): The subject, while swimming the Breaststroke, was required to time the initial draw-up of the kick to coincide with the period during which the hands were beginning the “recovery” phase, i.e. hands moving forwards.

Subjects were asked to repeat a trial if they did not meet the criteria for a given condition, with a maximum of three trials per condition, and were given time to rest between trials in order to eliminate fatigue as a confounding variable during the second and third trials.

The video data was then uploaded to the digitizing software, where it was digitized and the footage was synchronized to produce dynamic peak velocity-time graphs to analyze the fluctuations in peak velocities. The trials were compared to each other to record the resulting differences between the peak velocity, the minimum velocity recorded during the effort, and the velocity regained as the next stroke was initiated.

### Statistical Analysis

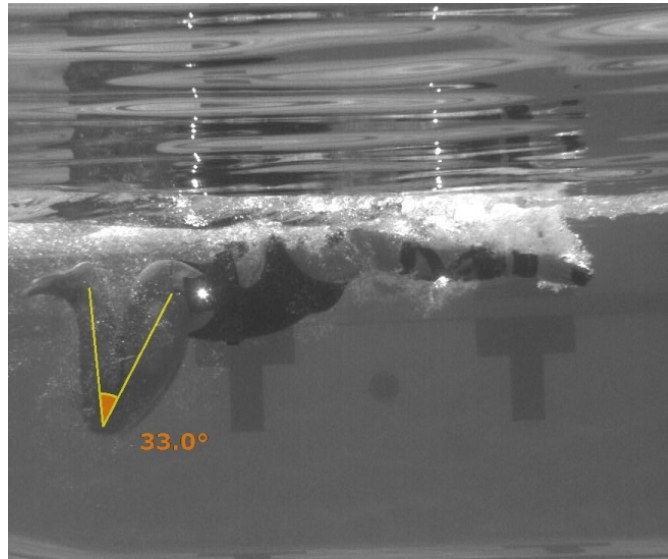
Each subject's stroke was digitized and analyzed using the Motus and Templo software. The percentage drop-off in peak velocity, percentage of the velocity regained, maximum hip velocity generated by the arms, and maximum hip velocity generated by the legs were seen through the use of time-velocity graphs (Figure 2).



**Figure 2.** Time-velocity graph used to analyze velocities of the Breaststroke.

Maximum knee flexion angle and time to complete kick were measured by using Templo's angle measure function on a time-stamped video (Figure 3).

Due to the single-subject design of this study, each subject's own trials were analyzed against each other to note any significant difference in the timing of the Breaststroke kick on peak velocity (note difference in drop-off/regained); for example, subject 1's Protocol 1 trial, Protocol 2 trial, and Protocol 3 trial were all compared against each other, but subject 1's Protocol 1 trial was not compared against subject 2's Protocol 1 trial. For each dependent variable, all of the data variance for each subject was compared against respective data variance for the other subjects for all trials; for example, subject 1's maximal knee flexion angle for Protocol 1 trial was compared to subject 2's maximal knee flexion angle for Protocol 1 trial. The significant difference for each protocol was determined using ANOVA repeated measures analysis with a significance level set to  $p=0.05$  (6).



**Figure 3.** Maximal knee flexion angle calculated in Templo.

Mauchly’s test of sphericity was run to validate the parameters of the ANOVA repeated measures analysis with a significance level set at  $p=0.05$  (6). Greenhouse-Geisser and Huynh-Feldt corrections were used with the Mauchly’s test; Huynh-Feldt correction was used for peak hip velocity generated by the legs, and Greenhouse-Geisser correction was used for all other dependent variables (6).

### Results

Subjects in this study were  $n=9$  NCAA Division I swimmers. Anthropometric data collected for these subjects included: age, height, weight, body mass index, and wingspan. The data is displayed in table 1.

Following the statistical analysis of their trials, the means, standard deviations, and 95% confidence intervals for all variables were calculated and are reported in table 2. Also calculated in table 2 are pairwise comparisons of data to demonstrate significance between the three different kick techniques for each dependent variable

Variable	Mean	SD
Age, years	20.67	1.32
Height, in.	70.34	3.81
Weight, lb.	158.34	16.96
Body mass index, $\text{kg}/\text{m}^2$	22.49	1.56
Wingspan, in.	71.11	5.73

SD=Standard Deviation

**Table 1.** Anthropometric measurements

**Table 2.** Comparison of Breaststroke Biomechanics with Different Kick Techniques.

Measure	C100				DU1				DU2			
	Mean ± SD	CI	p- value		Mean ± SD	CI	p- value		Mean ±SD	CI	p- value	
			DU1	DU2			C100	DU2			C100	DU1
% VDO	91.2 ± 4.9	91.3 ± 3.8	0.02	0.01	86.8 ± 5.0	86.8 ± 3.8	0.02	0.03	82.5 ± 5.2	82.5 ± 4.0	0.01	0.03
%VR	91.1 ± 11.8	91.1 ± 9.1	0.02	0.01	96.3 ± 11.6	96.4 ± 9.0	0.02	0.39	97.3 ± 10.2	97.3 ± 7.9	0.01	0.39
MKF, °	36.1 ± 5.1	36.1 ± 4.0	0.22	0.03	33.7 ± 6.8	33.7 ± 5.2	0.22	0.03	31.6 ± 6.1	31.6 ± 4.7	0.03	0.03
PAV, m/s	2.2 ± 0.5	2.2 ± 0.4	0.10	0.06	1.9 ± 0.3	2.0 ± 0.3	0.10	0.23	1.9 ± 0.4	1.9 ± 0.4	0.06	0.23
PLV, m/s	2.0 ± 0.4	2.0 ± 0.3	0.42	0.27	1.9 ± 0.3	1.9 ± 0.3	0.42	0.43	1.8 ± 0.4	1.8 ± 0.3	0.27	0.43
TCK, s	0.6 ± 0.1	0.7 ± 0.1	0.02	0.05	0.7 ± 0.1	0.7 ± 0.1	0.02	0.36	0.7 ± 0.1	0.7 ± 0.1	0.05	0.36

% VDO= Percentage Velocity Drop-off; %VR=Percentage of Velocity Regained; MKF=Maximum Knee Flexion Angle; PAV=Peak Hip Velocity Generated by the Arms; PLV=Peak Hip Velocity Generated by the Legs; TCK=Time to Complete Kick; C100=Conventional Stroke 100-yd sprint pace; DU1=Late Kick; DU2=Delayed Late Kick; SD=Standard Deviation; CI=Confidence Interval

Comparative Significant Differences

When comparing “Conventional Stroke” and the “Late Kick,” significant differences were seen in the following parameters:

- a) Time taken to complete kick.
- b) Percentage of hip velocity drop-off.
- c) Percentage of velocity regained.

When comparing “Conventional Stroke” and the “Delayed Late Kick,” significant differences were seen in the following parameters:

- a) Maximal knee flexion angle.
- b) Time taken to complete kick.
- c) Percentage of hip velocity drop-off.
- d) Percentage of velocity regained.

When comparing the “Late Kick” to the “Delayed Late Kick, significant differences were seen in the following parameters:

- a) Maximal knee flexion angle.
- b) Percentage of hip velocity drop-off.

To ensure the validity of the significance found in the ANOVA repeated measures analysis, Mauchly’s test of non-sphericity was run. Huynh-Feldt correction was used for peak hip velocity generated by the legs, and Greenhouse-Geisser correction was used for all other dependent variables. Partial eta squared was also calculated to determine how much of the change seen in each variable could be attributed to the condition alone. Changes in kick protocol account for 11-56% of the difference seen for each dependent variable. This data is shown in table 3.

Measure	Mauchly's		Greenhouse-Geisser		Huynh-Feldt	
	Sig.	W	Sig.	Partial Eta Sq.	Sig.	Partial Eta Sq.
% VDO	0.05	0.435	0.01	0.558	0.01	0.558
%VR	0.28	0.695	0.01	0.516	0.00	0.516
MKF, °	0.08	0.489	0.05	0.354	0.05	0.354
PAV, m/s	0.04	0.411	0.07	0.331	0.06	0.331
PLV, m/s	0.11	0.531	0.36	0.110	0.36	0.116

Peak hip velocity generated by the arms was the only variable found significant in the Mauchly’s test of non-sphericity (p=0.04); Greenhouse-Geisser correction was used to determine significance for this variable (p=0.07). Therefore, all the significant values found in the ANOVA repeated measures analysis can be considered valid.

**Discussion**

The purpose of this study was to describe the kinematics of the conventional versus the late Breaststroke kick technique using selected variables to determine the efficiency of each technique. Currently, only one study exists that examines the effects of the timing of the Breaststroke kick on intra-cyclic velocity. However, this

single study by van Houwelingen et al. used subjects that were of “average” competitive experience, and consequently not classified as competing at the elite levels. Their conclusions were limited to stating that “average-level swimmers are capable of adjusting their leg-arm coordination with acoustic cueing and that different timing of the kick does affect intra-cyclic velocity variation” (19). Unfortunately, this study does not specifically address leg-arm coordination, how to replicate the study, nor were they able to explain how these findings could be applied by coaches when training swimmers.

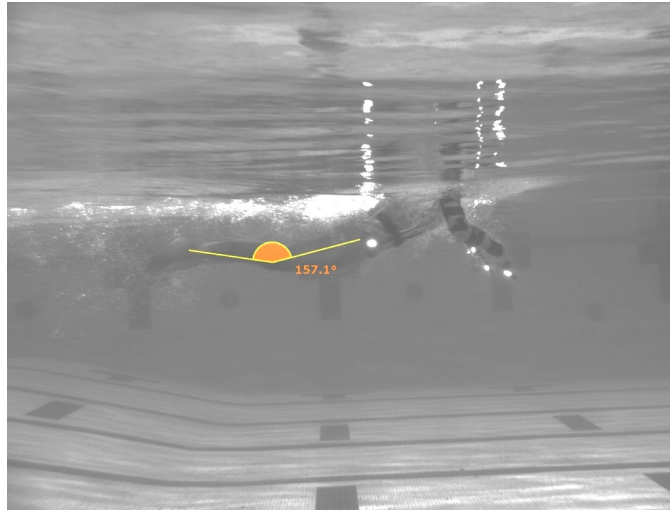
Consequently, our study is the first to have defined parameters to classify leg-arm coordination and incorporate them into a specific variation of the Breaststroke swimming technique.

In order to be designated as a “Conventional Stroke”, “Late Kick” or a “Delayed Late Kick”, the time at which the kick reached 160 degrees of flexion was matched with the phase at which the pulling action of the hands coincided with this position of the knee.

During the protocol where the subjects were required to swim using their “Conventional Stroke”, the distinguishing feature was that the initiation of knee flexion took place during the early stages of the second phase of the Breaststroke arm pull. This phase is termed the “early insweep” as compared to the “late insweep” which is the later stage and concluding portion of the propulsive phase of the Breaststroke pull (Figures 4a and 4b).

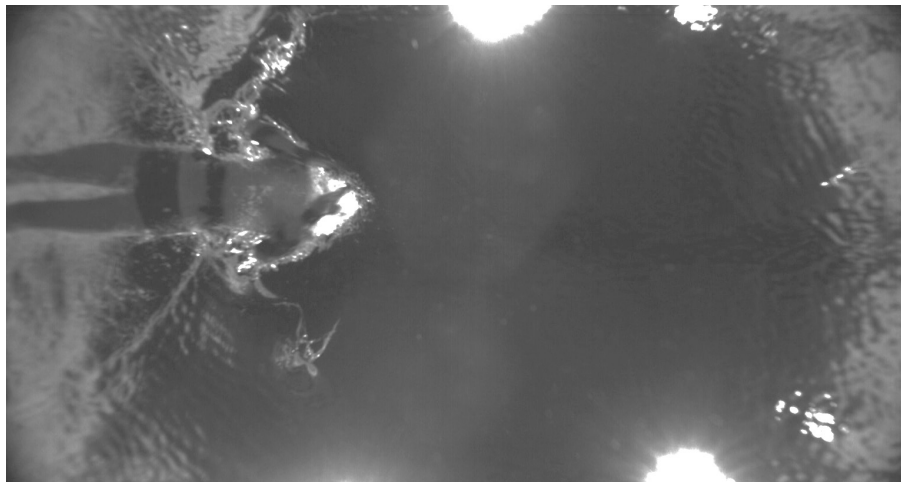


**Figure 4a.** Protocol 1: Close up of hand position during the early insweep.



**Figure 4b.** Protocol 1: Coincident knee kick.

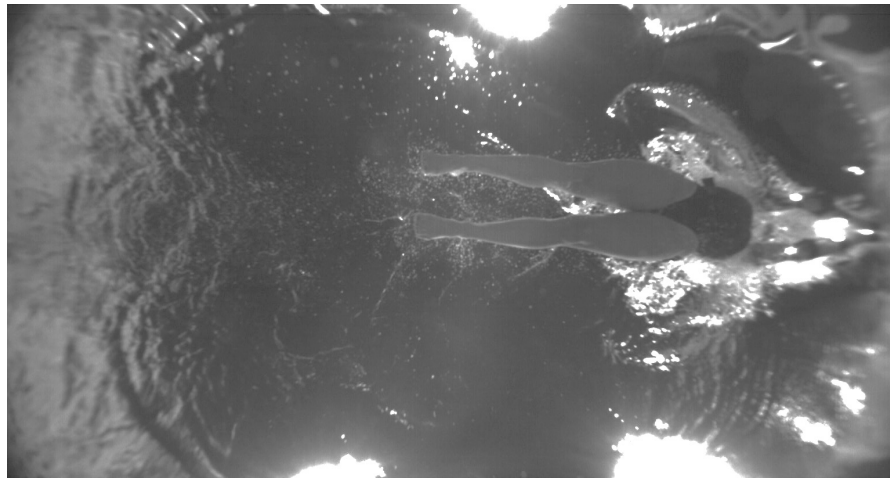
The “Late Kick” was the time the hands were completing the “late insweep” (Figures 5a and 5b) and “Delayed Late Kick” coinciding with the position of the hands when they were starting to be thrust forwards into the recovery phase (Figures 6a and 6b).



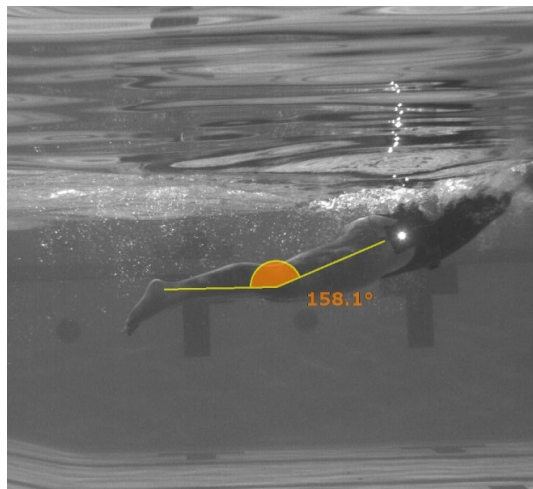
**Figure 5a.** Protocol 2: Close up of hand position during the late insweep.



**Figure 5b.** Protocol 2: Coincident knee kick.



**Figure 6a.** Protocol 3: Close up of hand position during the early recovery.



**Figure 6b.** Protocol 3: Coincident knee kick.

All nine subjects of this study were elite-level swimmers who were all able to perform each specified kick technique with only verbal cueing. The analysis of each subject's trials revealed that the smallest percentages of velocity drop-off were seen during the "delayed late kick" technique. That is, when the three protocols were compared, the third protocol, when the subjects waited until their hands started to be extended forwards, we observed the smallest drop-off in overall hip velocities. The second phase of "least drop-off" was the protocol designated "Late Kick", when the hands were approaching the body, during the "insweep" phase of the arm pull.

The greatest amount of velocity regained was in the late kick technique and the delayed late kick technique. This indicates a smaller velocity variation within one stroke cycle, which indicates a more efficient Breaststroke technique than the subject's normal technique. These findings are in agreement with the conclusions reached by two earlier published manuscripts (4, 19).

There were no significant differences in peak hip velocity generated by the arms or peak hip velocity generated by the legs between the subjects when using either of the three protocols. However, the fastest overall swimming velocities were achieved in the subjects' regular Breaststroke technique trials before they were asked to make adjustments to their strokes. These results were expected because all subjects tested were currently in, or recently concluded, intense training, and were instinctively swimming at their current training velocities.

Maximal knee flexion angle and time to complete kick are two variables that have not yet been studied as it relates arm-leg coordination of the Breaststroke technique and intra-cyclic velocity variations. Maximal knee flexion was significantly different between the regular Breaststroke technique and the delayed late kick technique, but not between the regular Breaststroke technique and the late kick technique. What was observed was that the subjects tended to increase the degree of knee flexion, the later they were asked to kick in their stroke. These changes may be attributed to the perception of the overall stroke cycle taking more time, thereby allocating more time to increase the amount of knee flexion. As expected, this also increased the total durations of the "Late Kick" and "Delayed Late Kick" when compared to the durations of the subjects' kick when swimming their "Conventional Stroke".

In regards to the research questions posed for this experiment, it can be concluded that there is a significant difference between hip velocities as a function of the initiation of knee flexion and hand positions during the Breaststroke pull phase. It can be concluded that there is less of a drop-off in hip velocities, and higher values for regaining hip velocities, accompanying later durations of the pull phase.

### **Practical Applications**

The conclusions derived from this study are in agreement with the current trend in competitive sprint Breaststroke technique. Although the timing of the leg draw-up during the longest competitive distance, the 200 meters, still shows relatively early draw-up of the kick, the findings of this study shows clear differences when there is

a delay before the initiation of the kick when swimming the shorter competitive distances.

This study revealed that by virtue of smaller decreases in the periods of velocity “drop-off”, higher swimming velocities may be achieved when the kick is initiated during the insweep or early recovery arm phases. This study also proves that video analysis and verbal cueing are both viable feedback tools that can be used to help swimmers learn to make adjustments to their regular techniques to become more efficient in the water.

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