OPTIMIZATION OF SWIMMING STARTING PERFORMANCE

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The criterion measure of competitive swimming performance is time, measured to the nearest one hundredth of a second. Swimming time can be broken into the following phases: starting time, turning time, glide time and swimming time (Hay, 1985). There exist critical segments of a race (other than the actual stroking) where time is of the utmost importance: starts, turns and motions performed to contact the touchpad at the end of a race (Guimaraes and Hay, 1985). Swimming coaches often direct their endeavours for performance amelioration solely on the improvement of stroke mechanics while neglecting starts and finishes. Although the possibility of self-optimization (by the athlete alone) exists, the implementation of biomechanically designed strategies can aid the coach and competitor to improve performance. The purpose of this treatise is to present a coaching scheme designed to optimize starting performance through analysis using both a biomechanical factor model and computer model.

FACTORS MODEL

In terms of fluid dynamics, the angle of attack is the absolute value of the difference between the angle of path of the center of gravity and the angle of trunk. A body moving in a fluid at an angle of attack of zero degrees presents the least possible frontal surface area and Gallivan and Hoshizaki (1986) have suggested that horizontal velocity may be conserved by minimizing the angle of attack at entry and arching the back soon after entry begins. The vector sum of drag, lift, bouyancy and gravity forces determines the resultant velocity of the swimmer's center of gravity at this time. Alterations in the angle of attack at and during entry produce the path and velocity requisite for the starts of various events. For this reason, the angle of attack was selected as the criterion variable of the factors model depicted in Figure 1.

The factors influencing the angle of attack at entry are related to three distinct components: (1) actions performed while on the starting blocks, (2) actions performed while in the air and (3) actions performed while entering the pool until the first propulsive movement is made. Although one must bear in mind that some of the factors influencing (2) are caused by (1), they will be treated independantly.

The kinematic pattern of the movements of the limbs, torso and head (e.g. the angle of body lean at takeoff) as well as the kinetic pattern of force application ultimately result in the velocity and angle of path of the center of gravity during the flight phase of the swimming start. The resultant velocity and the block height are the sole factors which contribute to the angle of path of the center of gravity at entry. The angle of the trunk at entry is determined by the flight time and the angular velocity at takeoff. The swimmer's angular velocity depends on the torque (resultant vector of force application) applied to the starting block and the moment of inertia of the swimmer. The moment of inertia is dependant upon the length and mass of the competitor's body segments and their three-dimensional orientation in space.

Once in the water, the competitor must decide (based on kinesthetic information) upon the most efficient time to begin stroking (WT or glide time), while maintaining a streamlined body position. Although the criteria for optimal depth and body position vary with the stroke, it is not advisable to begin stroking too early (wasted momentum) or too late (must accelerate to race velocity). Despite the efforts made by the swimmer to minimize reaction and movement times, horizontal displacement and velocity during entry (consequently performance time) can be negatively affected by a poor entry into the water (Gallivan and Hoshizaki, 1986).

FACTORS MODEL OF ANGLE OF ATTACK AT ENTRY

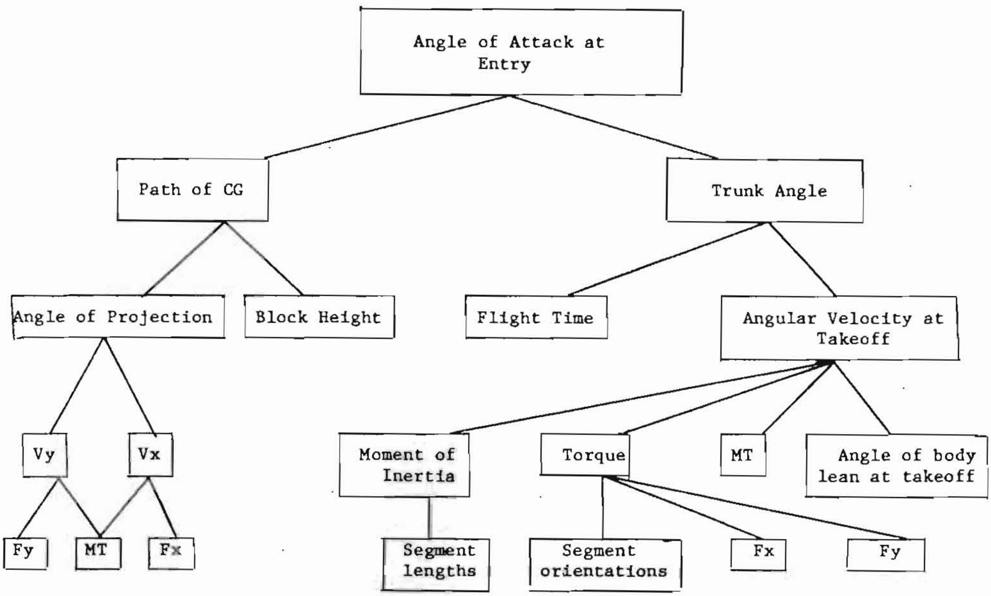

Figure 1: Factors model of the angle of attack at entry.

COMPUTER MODEL

Tables 1,2 and 3 contain measured and predicted values for the block, flight and entry variables contributing to the angle of attack at entry. The values were obtained through analysis of starting data presented by Hobbie (1980) and Wilson and Marino (1983) followed by subsequent analysis using a modified version of the mathematical model of Gallivan and Hoshizaki (1986). The model used anthropometric input data measured from a varsity swimmer. The projection velocity of 4.5 meters/second approximated the mean projection velocities of the two previously mentioned starting studies. The selection of the optimized

TABLE 1
OPTIMAL BLOCK FACTORS

	Freestyle	Butterfly	Breaststroke
ANGLEA	25 deg	30 deg	30 deg
ANGPRO	-2 deg	+2 deg	+4 deg
VELPRO	4.5 m/s	4.5 m/s	4.5 m/s

Legend: ANGLEA = angle of body lean, ANGPRO = angle of projection of the center of gravity, VELPRO = resultant velocity of projection.

TABLE 2
OPTIMAL FLIGHT FACTORS

	Freestyle	Butterfly	Breaststroke
ANGVEL	110.0 deg/s	120.0 deg/s	140.0 deg/s
FTIME	0.36 s	0.4 s	0.4 s
ANGTRU	30.0 deg	35.0 deg	45.0 deg
ENTVEL	5.84 m/s	5.85 m/s	5.76 m/s
ENTANG	50.4 deg	50.3 deg	51.2 deg
ANGATT	20.4 deg	15.3 deg	6.2 deg
FDIST	1.69 m	1.84 m	1.87 m

Legend: ANGVEL = angular velocity, FTIME = flight time, ANGTRU = angle of trunk at entry, ENTVEL = resultant velocity at entry, ENTANG = angle of path of center of gravity at entry, ANGATT = angle of attack at entry, FDIST = horizontal flight distance.

TABLE 3
OPTIMAL ENTRY FACTORS

	Freestyle	Butterfly	Breaststroke
MAX D	0.65 m	0.81 m	1.25 m
DEPTH (1.2 s)	0.27 m	0.64 m	1.23 m
GLIDE	2.14 m	2.26 m	2.45 m
TOTDIST	3.83 m	4.10 m	4.32 m
TIME	1.20 s	1.20 s	1.20 s

Legend: MAX D = maximum vertical depth, DEPTH (1.2 s) = vertical depth after 1.2 seconds, GLIDE = horizontal glide distance, TOTDIST = total horizontal displacement, TIME = reference time of 1.2 seconds.

angles of projection for the butterfly and breaststroke starts was based upon criterea for flight distance and angle of path of the center of gravity at entry. The simulated data demonstrate the seemingly insignificant alterations in the angle of body lean at takeoff, angle of projection, angular velocity during flight and angle of attack at entry which produce optimal vertical depths for the particular stroke at a reference time of 1.2 seconds after departing from the starting block.

COACHING SCHEME

The modification of all block and flight factors by the swimming coach can be realized through the following coaching scheme. Performance objectives of freestyle, butterfly and breaststroke starting techniques vary with the rules governing the events. Breaststrokers should enter the water with a trunk angle of 45 degrees and dive to a depth of approximately 1 to 1.5 meters in order to minimize the velocity retarding effect of wave drag. This objective necessitates a slightly positive (from horizontal) angle of projection from the starting block, combined with greater rotation while airborne in order to produce a smaller angle of attack at entry. Raising the angle of body lean (the angle formed between the hips and the starting block) performs two functions: 1) the reduction in movement time, since the swimmer does not fall as far forward before takeoff (Wilson and Marino, 1983) and 2) the augmentation of angular velocity during flight, permitting a greater degree of body rotation in preparation for entry. The angle of attack at entry can be minimized by piking (reducing the moment of inertia) momentarily during the flight phase, thereby adjusting the angle of the trunk close to the angle of path of the center of gravity. The butterfly swimmer should enter the pool with a trunk angle of approximately 35 degrees and attain a maximum depth of 0.8 to 1.0 meters in preparation for the powerful underwater kicking. This objective may be achieved via an angle of projection at or slightly above zero combined with the desired trunk angle at entry. The underwater kicking should commence just prior to race pace and serves two purposes: 1) it creates horizontal impulse and velocity without use of the arms and 2) it permits the swimmer to select the precise time for the first powerful arm stroke.

In the freestyle events, the swimmer should enter the water with a trunk angle of 30 degrees and achieve a maximum depth of approximately 0.5 to 0.65 meters in order to be near the water surface during the glide phase. A slightly negative angle of projection combined with the desired trunk angle at entry is sufficient to achieve the freestyle starting objective. During the glide phase, the vertical component of lift and bouyant force will push the streamlined form of the swimmer towards the surface. Kicking and stroking should begin at about the time when horizontal velocity slows to race pace and the swimmer can proceed with his/her racing strategy.

Tables 4,5 and 6 illustrate the objectives for each of the three strokes starting from the blocks in terms of the factors contributing to the actions performed on the blocks, in the air and at entry. A sign convention (+,0,-) has been adopted to facilitate understanding the tables, with + or - signifying a increase or decrease in the respective factor. Underneath each column (dependant variable) of the tables are given reference values for each column. The reference values pertain to freestyle starts and were selected for two reasons: 1) freestyle data had previously been collected by Hobbie (1980) and Marino and Wilson (1983) and 2) most swimmers compete in freestyle events from time to time and the scheme is designed to subtly alter a freestyle start to produce a butterfly or breaststroke start.

TABLE 4
OBJECTIVES OF BLOCK FACTORS

STROKE	MT (0.5 sec)	ANG LEA (25.0 degrees)	ANG PRO (-2.0 degrees)	ANG ENT (50.0 degrees)
freestyle	0	0	0	0
butterfly	0	+	+	0
breaststroke	0	+	++	0

Legend: MT = movement time, ANG LEA = angle of body lean at takeoff, ANG PRO = angle of projection of the center of gravity, ANG ENT = angle of path of CG at entry.

TABLE 5
OBJECTIVES OF FLIGHT FACTORS

STROKE	FT (.36 sec)	ANG VEL (110 degrees/sec)	ANG TRU (30.0 degrees)
freestyle	0	0	0
butterfly	+	+	+
breaststroke	+	++	++

Legend: FT = flight time, ANG VEL = swimmer's angular velocity at takeoff, ANG TRU = angle of trunk at entry.

TABLE 6
OBJECTIVES OF ENTRY FACTORS

STROKE	ANG ATT (20.4 degrees)	ENT VEL (5.85 meters/sec)	GT (0.9 sec)
freestyle	0	0	0
butterfly	-	0	+
breaststroke	--	-	+

Legend: ANG ATT = angle of attack at entry, ENT VEL = velocity at entry, GT = glide time.

APPLICATION

The sole difficulty to be surmounted by the coach is recognizing when the swimmer has successfully met the criterea (either time, distance or angle) for each phase of the start. Although the block, flight and entry factors are inter-related, the coach and swimmer should work on the variables individually during the alteration phase. The session should commence with the swimmer performing several freestyle starts while the coach makes a checklist of approximations of the values of the six block, flight and entry factors listed in Table 7 and comparing these with the suggested values listed in Tables 1 through 6. Modification of the freestyle start to the breaststroke or butterfly start begins with an attempt to increase the angles of body lean and projection as per Tables 1 and 4, by using relevant teaching cues. Despite the fact that the angle of projection of the center of gravity can only be calculated by cinematographical analysis, the coach can obtain a fair idea of the center of gravity by watching a point on the swimmer's body between the navel and hips. An unsuitable angle of projection will result in a decrease in both flight distance and flight time. The angle of body lean can be raised or lowered through cues such as, "Leave the blocks earlier ... later". If the angle of body lean is too low, it may result in under-rotation during flight with the swimmer compensating by having to pike for a longer period of time or performing a "flat" entry. It must be stressed that the angle of path of the center of gravity is determined by the actions occuring on the blocks and that the value of practise time on the blocks must not be underestimated. When the coach feels that the changes in the angles of projection and body lean have been successfully implemented, the flight phase must be attended to.

Given that the takeoff velocity does not vary significantly with changes in the angles of body lean and projection, flight time will be lengthened and angular velocity will be increased. The task of the coach and swimmer becomes the adjustment of the duration of the pike, effecting an optimal trunk angle at entry. The trunk angle (Tables 2 and 5) can be easily estimated by imagining a line passing from the shoulders to the hips. Special attention must be paid to body position (angle of trunk and streamlining) at and during entry so that frontal surface area is minimized. The effect of an overly long pike phase would be a near vertical angle of trunk at entry and the consequent loss of horizontal velocity, while a short pike will create a somewhat flat and shallow entry. Teaching cues and knowledge of results must be given to the athlete following each trial.

The final adjustment is that of producing optimal vertical depth and glide time (Tables 3 and 6). The coach, stopwatch in hand, should stand one or two lanes from the block in order to estimate the depth attained by the swimmer. The swimmer should be advised to "feel" their depth and horizontal velocity and to try to time their first propulsive movements with that of race pace. An entry which is too deep will result in a terrific loss in horizontal velocity in an effort to surface, while a shallow entry is reflected in decreases in both the total distance of the start and the time to first stroke. Arching the back during

TABLE 7
COACH'S CHECKLIST

	FREESTYLE	BUTTERFLY	BREASTSTROKE
Angle of lean		+	+
Angle of projection		+	++
Angle of trunk at entry		+	++
Maximum depth		+	++
Time to first stroke			
Total distance			

entry will serve once again to minimize frontal surface area and the retarding effect of drag force. Markers set along the pool deck can be used to gauge the total distance of the start, while the stopwatch provides the time until first stroke. The coach should record the measurements of all the variables on a sheet similar to Table 7 following each practise trial and day to facilitate the learning process.

The following recommendations must be made at this point: 1) several teaching sessions should be utilized by the coach in order to effect the starting optimizations, 2) peer teaching is a valuable tool and will reduce wasted time, and 3) teaching cues, knowledge of results and positive reinforcement must be furnished constantly. Optimal starting performance can be produced through the implementation of the simple scheme presented here, to the benefit of swimmers of all age groups and ability levels.

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