

# Swimming Stroke Mechanics: A Biomechanical Viewpoint on the Role of the Hips and Trunk in Swimming

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## Introduction

The stroke profile of the competitive swimmer remains somewhat of a paradox. When viewed from above water, 'efficient' swimming by an accomplished athlete looks like smooth, unhurried movement of the arms and legs. From underwater, however, even the most cursory glance tells a different story. Hands and legs, shoulders and hips travel through the water in complex three dimensional patterns of movement that make 'cause and effect' determinations difficult.

One apparently 'current' coaching controversy is the role of the trunk, specifically the hips, as far as contributing to the propulsive forces generated during swimming. Recent coaching publications have emphasized the rotational movements of the hip and trunk during swimming as being desirable, fundamental and important. This controversy, however, is far from current in that discussions of body and hip roll can be documented back as far as the 1930's (3). Although lagging behind coaching discussions, the contention that the hips and hip rotation are responsible for propulsive forces is slowly being addressed in the research world. Does conscious and voluntary rolling of the hips, particularly when swimming the Freestyle (Front Crawl), enhance the swimmer's ability to exert propulsive force (12)? Maybe, or maybe not, much as the early literature on this topic debated. The purposes of this paper are to (1) examine the anatomical and biomechanical factors associated with spine stability as they apply to swimming and (2) consider the implications of emphasizing hip and body roll during front crawl swimming.

## The Skeletal Framework for Swimming.

In order to examine how the axial skeleton or trunk enables the arms and legs to generate propulsive forces, several fundamental concepts need to be established.

### *Concept One: Muscles need a stable base of support from which to exert contractile forces.*

Skeletal muscles perform multiple functions. Muscle contact. When they do so, they generate and transmit force to external objects and change joint angles. Muscular contraction involves shortening of the muscle, and thus, most muscles cross at least one skeletal joint if not two. Most commonly then, for the muscle to perform its duty, it is necessary to be anchored on at least one end to a relatively stable or immovable platform (bone or set of bones). This stable end is commonly close to the spine, and is referred to as the muscle's "origin". This end is also referred to as the "proximal attachment", in contrast to the opposite end, which is referred to as the "distal attachment" (5,8,18,20). However, this is commonly the case as the proximal attachment point tends to be relatively 'fixed' itself by contact to the ground or other external surface. The more powerful the muscular contraction needs to be, the greater the need for the proximal attachment of the muscle to be anchored to some stable base. Only in this way, can the muscle generate a significant force against some object or medium.

An appropriate example of this would be an astronaut who is circling the earth in a zero gravity environment. The astronaut trying to generate force against the floor or wall of the vehicle simply cannot do so unless is tied or tethered to some immovable platform. Pushing against any set object will only cause the untethered astronaut to move in the opposite direction. Because it takes very little force to do so, the astronaut who is floating in space cannot generate resistive forces. Even tightening a loose screw becomes a major problem.

An excellent example of this "bioengineering" is illustrated when the muscles that control movements of the human shoulder are examined (19). Because the primary functions of these muscles are to move the arm, they all have their distal

attachments on the upper arm bone, the Humerus. However, these muscles' proximal attachments, are located near the center of the body, in two general locations. They attach to the ribs and spine or, they connect to the shoulder girdle, which is comprised of the clavicle and scapula (5, 9). Muscles that apply the most force, the so-called "prime movers" of the shoulder, tend to have their proximal attachments on the ribs and spine. Most of the large muscles important in aquatic locomotion, (front crawl swimming) fall into this category. These are the Pectoralis Major and Latissimus Dorsi muscles.

In contrast, the smaller shoulder muscles, such as the deltoids, and the (in) famous "rotator cuff" muscles, attach to shoulder girdle (5,9). When compared to the Pectoralis and Latissimus muscles, it is clear that they do not have the ability to generate anywhere near the forces the larger muscles controlling gross arm movements can. The bottom line in terms of muscular force generation is muscle cross sectional area. In general, bigger the muscle, the greater the force is that it can produce. However, the essential point here is that when muscles contract and generate forces, the more stable the base the better able they are to generate this force specifically when it comes to doing work on the external environment. If there is no stable base, the forces generated are inconsequential. The stable base for the shoulder tends to be the spine and or shoulder girdle.

**Concept Two:** *When exerting propulsive movements in swimming, the axial skeleton or "trunk" provides the only available stable base of support.*

Spine specialists and physical therapists are very familiar with the concepts of spine stabilization. When dealing with lower back injuries, of which there are many and frequent, patients are taught to stabilize the spine and use it as a stable platform. When they do so, they can effectively move while minimizing pain and further trauma.

To borrow a concept from structural engineering, the trunk, which includes the hips, is viewed as a "semi-rigid cylinder" held in place by "guide wires." These guide wires are needed to maintain the natural curves in the spine. The muscles located in the front and lateral sides of the trunk are the Rectus Abdominis, Internal and External Obliques, and Transverse Obliques. The muscles located in the back include the major spine extensors, which are the Erector Spinae. Although these muscles function in bending and twisting, they also provide postural stability. This is particularly so when the upper and lower extremities (arms and legs) exert forces, such as during pulling, lifting and carrying (10,15,16).

Therefore, if the muscles of the arms and legs are to be effective in generating propulsive forces while swimming, it would stand to reason that all necessary steps must be taken to maintain the trunk as a stable base of support.

**Essential Point:** Regardless of the three dimensional body position, effective use of the arm and leg muscles for

propulsion requires maintaining the trunk in an anatomically stable position relative to the arms and legs.

**Concept Three:** The body can be viewed as a series of linked segments, connected by the skeletal joints. When functioning effectively this linked system can help transmit inertial forces. The forces exerted against the environment and generated by the muscles attached across these links result in motion.

The terms "kinetic chain" or "kinematic chain", are engineering terms that refers to rigid bodies that are linked together. This term was adopted by the rehabilitation community to describe the cooperative movements of the anatomical segments of the human body. "Closed kinetic chain" activities are defined as those movements that take place with the distal anatomical segment held relatively immobile. "Open kinetic chain" activities are defined as movements where the distal anatomical segment moves freely during the activity, such as during kicking during swimming (10). However, due to their inherent vagueness, these terms are now used sparingly. What has evolved from this is the "Segmental Interaction Principle". *This principle supposes that the potential and contractile energy generated within the various segments can be transferred the during the motion between segments (11). Consequently, what is ultimately important is the manner in which each link contributes to the final result. The final results are observable and effective body movements.*

When the 'linked chain' model is applied to land-based activities, the primary base of support is usually the ground. There exists then, the need to maintain a firm foot-plant with the ground during an effective golf swing. When performing swinging movements with the body, such as during a gymnastics routine, there must be an immovable platform present. The platform is represented by a fixed bar, beam or the ground. A hand, knee, foot or toe must be in contact with this 'anchor' to be able to generate or impede inertia. At any rate, in order to generate maximum muscular external forces as a means to push, pull, kick, or throw an object (or the body itself), some part of the body must be stable, immobilized or anchored. The better anchored at one end of this segmented chain, the more powerful is the force that can be exerted at the other end.

Where does the energy (potential and kinetic energy) of the applied muscular force of the limb originate? It is common to assume that the muscles surrounding the joint are responsible. This is true to a certain extent, but their contribution turns out to be relatively minor. According to the "Segmental Interaction Principle" much of the energy originates from the base of support or anchor. This energy is transferred via the body segments, usually from the proximal to the distal segments (11). Everything there is to know about how this transfer of energy is not known, but if a movement is initiated, for example, while standing on the ground, the energy that is

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harnessed comes from the force that pushes against us by the ground. The reaction force supplied by the ground is referred to as "ground reaction force" (GRF) and can be measured by using a force plate (4,7,23)

If GRF is present, then a sequential series of movements takes place, which, for most land-based activities includes the rotation of the hips, trunk, and shoulders. Each successive link will summate to amplify GRF and produce surprisingly powerful movements, such as the swing of a racket or bat. However, in the absence of GRF, when there is no 'firm footing', the energy must originate from some part of the body that is held in a stable position. In most cases, when GRFs are absent, the trunk must take over the role of the ground, or stable platform, from which the linked segmental system can work.

*Essential Point:* A commonly used principle in biomechanics states "proximal stability is needed for distal mobility" (10,11). What this implies is that when a muscular force is generated, in this case at the end of the hand or foot, the requirement is that the other end of the chain, whether the immediate end, or further back along the segments, remains relatively stable. It does not imply or require that it remain immovable. But it is clear that the less stable the proximal end is, the less effective muscular force can be generated at the distal end of the chain. The inertia of the torso is substituted for normal ground reaction forces.

#### How does this apply to swimming stroke mechanics?

When a swimmer is floating in the water, there are only very small forces that effectively represent ground reaction forces. Because water is displaced when a force acts upon it, the resultant ground reaction forces are very limited in magnitude. Without a stable base or without feet firmly planted, the ability to push, pull, or throw any object (or the body) is significantly decreased because the magnitude of the summated forces generated are also limited. This observation should not surprise anyone, especially anyone who has attempted to throw or hit a ball while standing on a slippery floor. One might speculate that bowling on ice might be more visually entertaining and physically challenging than it is on a wooden floor!

#### Exerting muscular forces in the water

A pilot study conducted at our laboratory, was initially designed to examine the biomechanics of water polo throwing techniques. However, it demonstrated what the effects are when GRFs are progressively decreased.

Using high-speed video cameras, a subject was filmed while performing an overhand throwing action using a water polo ball. The subject was first filmed while standing on the ground, and then in progressively deeper water. The final ball throws were made while floating in deep water. The subject making the throw was a member of the women's varsity track

& field team who specialized in the javelin throw and therefore familiar with the proper mechanics of throwing.

The data was analyzed using a motion analysis system (Peak Performance Technologies, Denver, CO). The velocities of the ball at the point of release are shown in the graph (Figure 1). The data obtained from the analysis are shown in Table 1.

**Table 1.**

| Body Position                                 | Velocity (meters/sec.) | Velocity (miles/hr) |
|---|------------------------|---------------------|
| Standing on land—power stance                 | 20.03                  | 44.8                |
| Standing on land—parallel foot plant          | 18.17                  | 40.65               |
| Hip depth                                     | 15.56                  | 34.8                |
| Mid-chest (sternal) depth                     | 16.03                  | 35.8                |
| Shoulder depth                                | 13.63                  | 30.49               |
| Suspended in deep water using a buoyancy vest | 12.23                  | 27.36               |

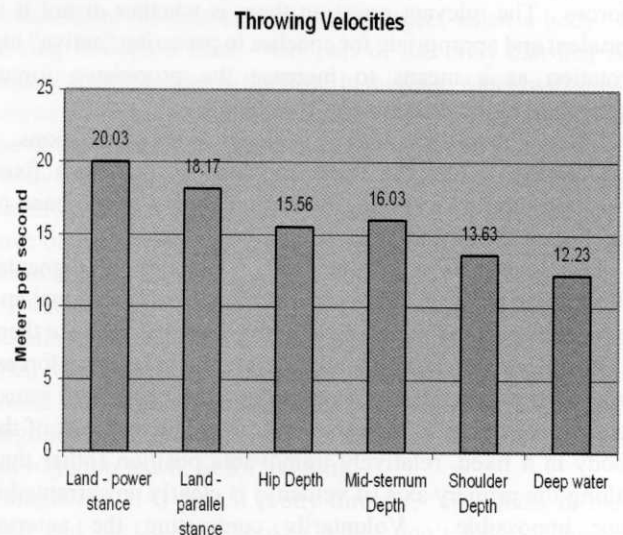


Figure 1—Comparison of Throwing Velocities while standing on land and at varying depths of water, and when floating in deep water.

As the subject stood in progressively deeper water, changes in GRF had a marked effect on the velocity of release of the ball. The value shows a steady decrease in the velocity of the ball at the point of release. The highest velocity (~20 m/sec) coincide with the most common stance for throwing or hitting actions on land, i.e. standing with one foot placed ahead of the

other. The least 'anchored' position occurred when the subject was required to throw the ball while suspended in deep water, supported by a floatation vest. This latter position resulted in the lowest ball velocity (~ 12 m/sec). The drop in velocity is concluded to be primarily due to the absence of nearly all GRF. The decrease in ball velocity between the "grounded" and "ungrounded" throw was approximately 40%.

This demonstration extends the preliminary discussion of muscular contractions, forces and "anchoring". In the absence of a "platform", muscular forces can still be generated through limb movement and muscular work. However, the transfer of this movement energy is limited by a relative lack of proximal stability. The only "base of support" is the muscular and skeletal anchor represented by the trunk. The muscular & axial platform provides the anchor from which muscular forces are initiated. Needless to say, this anatomical platform is less than perfect in comparison to the ground.

### *The focus on "hip" action in swimming.*

It is reasonable to conclude that in the absence of GRF, the hips and lower lumbar region act as stable base against which the muscles of the upper and lower extremities generate forces. The relevant question then, is whether or not it is prudent and appropriate for coaches to prescribe "active" hip rotation as a means to increase the propulsive forces generated at the distal end of the chain?

Let us address this point by asking a series of questions.

Question 1: Can the trunk and hips be held in a fixed position during swimming thus simulating a stable base or anchor on the ground?

The answer is a simple "no". Evoking fundamental Newtonian physics, "for every reaction there is an equal and opposite reaction" it can be hypothesized that because there is no anchor and there are only trivial ground reaction forces, any forces generated at one end of the chain will cause equivalent forces at the other end. Holding any part of the body in a fixed, relatively immovable position (other than along the primary axis of velocity) is clearly unwarranted if not impossible. Voluntarily contracting the anterior abdominal muscles or unilaterally contracting the posterior trunk muscles with the intent of preventing the rotation of the trunk is useless and will only interfere with necessary resultant bilateral movements of the arms and legs. Perhaps a case in point here: When was the last time one you over heard a swimmer complaining of "exhausted hip rotators" following a competitive event?

Question 2: Is hip rotation 'voluntary' and consciously initiated or is it 'involuntary' and or only reactionary?

The question is not "how much should we roll" but rather "how much emphasis should coaches place on 'voluntary' hip and body rotation?" It is well known that hips "roll" or rather there is rotation around the central axis during crawl

swimming. Indeed, the origin of the multicolored 'panel' swimsuit stems from Counsilman's early filming of swimmers in the early 1960s. His wife was asked to sew a contrasting side panel on a standard suit so that he could analyze, quantify and thereby understand the importance of hip and body "roll."

However, to pursue this specific question, let's consider a concept which takes into account the difference between actions that are purposefully initiated, and those movements of the body that occur only as a result of movements or counter to those made when exerting propulsive forces with the hands and feet. In other words, we face in this discussion the proverbial "chicken or the egg" conundrum.

Obviously, for fast, proficient swimming, the hands and feet must be coordinated and placed in reasonably well-established patterns during swimming. The muscles that perform these movements are viewed as "initiators" because they have to consciously be activated in order to complete the desired movement. In the freestyle, when the hand is introduced into the water and guided to full extension it is a conscious motion. When the hand "catches the water" and forces are generated against the water, these are voluntary and intended. All of these movements are initiated and or facilitated by a combination of muscles associated with the Shoulder Girdle and Glenohumeral joints. Over time, the movement is learned and remembered. Different parts of the CNS direct and coordinate these movements partially dependent upon how much 'thinking' and or how much 'remembering' takes place.

In contrast to the movements that are consciously make, there are 'reactive' movements of the body that that athletes unconsciously initiate in response to the primary initiated movements. A land-based example of this would be the forward movement of the legs when a volleyball player jumps vertically upwards and returns the ball over the net. Following the principle of "transfer of angular momentum," the player's legs must move forward in response to the forward motion of the arms or the athlete will begin to rotate and execute a forward summersault.

Coaches are well aware of this effect and are careful to instruct swimmers not to swing their arms too low and too vigorously over the water during the arm recovery in the crawl stroke. They want their swimmers to minimize lateral trunk and leg motion that occurs in response. Counsilman acutely hypothesized that swimmers with poor shoulder flexibility had to use a wide recovery and because of this tended to swing their buttocks from side to side. Compensation for this required crossing over action of the feet that would counter act the swinging of the hips and allow the center of mass to move with little wiggle.

Any force that is exerted perpendicular to the long axis of the body will have the effect of causing body roll. Therefore, while the "initiators" begin and control arm movement, other parts of the body, particularly the torso, exhibit rotating movements. Ideally, because the joint segments are linked

together, these rotating movements should be confined to the longitudinal axis and take place in the transverse plane.

When we observe the freestyle and backstroke from a "head-on" view, it is clear that this rolling action is an integral part of the stroke. However, it is also evident that when the body is made to roll more than a certain degree, extraneous movements emerge. The argument presented here is that hip roll is "in reaction to" rather than the "initiator of" propulsive forces generated during swimming. This is indirectly related to a general lack of a stable anchor while in the water.

Takaishi in 1935, according to Carlile (3), concluded: "the maximum of rolling is when the power gained by that rolling is applied to the arm movement." This seems to suggest that Takaishi thought power originated from the roll rather than the other way round. Carlile states, however, that later in 1942, Kiputh concluded that "the body should be in a perfectly flat position" and that "there should be no dipping of the shoulders or rolling of the body." Carlile's own view in 1963 was that "roll" is necessary from the perspective of breathing and arm recovery. He states "this type of arm recovery (high elbow)... is not possible unless the body is rolled to some extent around its longitudinal axis." Maglischo's more recent view (13) is that body roll "improves the propulsive forces they (front crawl swimmers) can apply with the stroking arm and it facilitates the recovery of the other arm." This is strikingly similar to the earlier opinions of both Carlile and Counsilman. All of this is being pointed out to illustrate that over the years, many of the greatest coaching minds in swimming routinely discussed and opined upon the importance and or significance of hip and body roll during the crawl stroke.



Figure 2. Frontal view of exaggerated body roll in the Freestyle.

Question 3: Is it possible to have too much roll and are there recognizable symptoms of excessive hip and trunk rotation?

There are characteristics of the stroke that can be observed from both above and underwater that indicate excessive hip rotation.

#### 1. Increase in the lateral "spread" of the feet.

The most serious consequence of the feet spreading apart is its effect on frontal resistance. We see from Figure 2 that as body roll increases, the degree to which the feet spread apart, increases. To the extent that rolling the hips is accomplished by rolling the torso, the torque required for this rotation must come from the reaction force between the water and either the arms or the legs. Since the arms must move in the preferred pull pattern, it follows that the legs must produce the additional torque for rotation. The axial rotational torque produced by the kick increases with increasing separation of the feet. Therefore, intentionally exaggerating the normal roll of the hips will require the feet to be moved farther apart to accomplish this roll. The consequence of this increase in amplitude of the lower extremity limbs is an increase in frontal surface area.

Frontal resistance is another way to describe the resistance produced by the surface area of an object when a body is moving through a fluid. Any part of the body that is aligned at right angles to the flow, in this case water, will slow motion down because it contributes to "form drag", which is one of the resistive force that retards the forward progress of a body moving through a fluid (1,8). Swimmers, and for that matter all athletes who have to contend with the retarding force of air or water, go to extraordinary lengths to minimize "form drag".

Therefore, the orientation of the body should be such that the minimum area of the body and/or limbs should be seen when viewed from the front or "head on". Usually, this frontal view is compromised if the body does not remain in a longitudinal orientation and the arms or legs extend out sideways too much, or for too long.

Maglischo (14) puts it pretty directly, "swimmers in the front and back crawl strokes really don't have a choice between rolling and swimming flat, even if flat body positions produce less form drag. Their choice is to roll or wiggle." His opinion is that "if swimmers try to prevent the trunk and hips from rolling up and down in the same directions as the arms, the trunks and legs will swing out to the side."

#### 2. Arm Recovery.

We can agree that a high arm recovery is preferable to one that takes place low over the water. As mentioned earlier, low arm recoveries invariably result in lateral movements of the torso and legs, particularly if the recovery is made too vigorously. However, conspicuous rolling of the hips is often accompanied by an elevated arm recovery. This is most likely due to the combination of the exaggerated movement of the

torso, including the shoulder complex, and the perception that the “higher the arm recovery the more efficient the stroke”.

### Summary

We know that trial and experimentation must remain the driving force in the evolution of swimming stroke mechanics. However, although the concept of “body roll” is deeply entrenched in freestyle swimming, a strong case can be made to use caution when recommending conscious or ‘over’ rotation of the hips when swimming freestyle. Although it may be useful to measure the degrees of body roll in elite swimmers, quantifying this parameter may be only part of the answer. The current anatomical analysis is consistent with Maglischo’s view that “because the body is suspended in the water, the up and down movements of the arms exert forces on the torso that cause it to follow in the same direction.” The ‘egg’ appears to be the propulsive forces generated by the swimmer and the ‘chicken’ would seem to be body roll. For the present, then, voluntary and intentionally exerted body roll—for the express purpose of generating additional propulsive forces seems to run the risk of reducing the ability of the trunk to provide a stable anchor for the propulsive movements of the upper and lower extremities. It may also result in increased drag forces that ultimately retard forward velocity. Statements like “lead with the hips” are not only ambiguous but are scientifically unsound when taken literally.

On a more visible note, it is evident that exaggerated rotations of the body amplifies frontal resistance and by prolonging the duration of each stroke cycle, may interfere with the rhythmic cadence of the stroke. Therefore, it is concluded that while we continue to experiment and push the limits, untested ideas, especially those that cannot be demonstrated in elite performers, should be viewed with healthy skepticism.

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