Analysis of Movement (Parts 1&2)

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Introduction

Competitive swimming is a sport which requires a high degree of coordinated movement, as well as effective and efficient technique. Although there are four different strokes commonly used in competition, this movement analysis will focus on one of the first strokes commonly taught; the crawl stroke, which is also referred to as the freestyle. In the crawl stroke, the individual is face down in the water, and the arms move unilaterally, although the same movement is mirrored on either side in an alternating rhythm (Lauer, Figueiredo, Vilas-Boas, Fernandes, & Rouard, 2013). Beginning with the shoulder joint fully flexed or abducted, so the arm extends beyond the head, with the elbow nearly straight and the bicep close (not more than about 2-3 inches away) to the ear, the shoulder is rotated forward, and the arm travels through the full range of motion in the anterior aspect until it is fully extended, maintaining a slight bend in the elbow, until the thumb just brushes the lateral aspect of the thigh, near the proximal end of the vastus lateralis. The shoulder then continues its' arc toward the dorsal aspect, coming out of the water and rotating slightly so that it may re-enter the water at full extension, with the bicep again coming in close proximity to the ear, with the elbow extended. The hand and wrist should remain extended throughout the movement, and in line with the forearm.

The movement of the legs also alternates bilaterally, with the legs extended and the knees straight. Each leg should kick anteriorly and posteriorly, and the hips should roll about the longitudinal axis to the same extent as the shoulders. The hips do not allow full range of motion, instead allowing only a few degrees of flexion and extension, or about 30cm of travel forward and aft. The knees should be allowed only minimal flexion, with the majority of the movement coming from the hip joint. Additionally, the hips and the shoulders should roll about the longitudinal axis at roughly the same degree (Mark R. , 2012).

In this series of movements, the hands act as paddles, maintaining propulsion by pushing against the water in much the same way as a paddle wheel on a turn-of-the-century riverboat would. The feet and legs also aide in propulsion, although to a lesser extent, and the overall movement should give the appearance of clean, straight lines without excessive roll about the longitudinal axis in either the shoulders or hips, nor should there be excessive flexion about the waist or elbows.

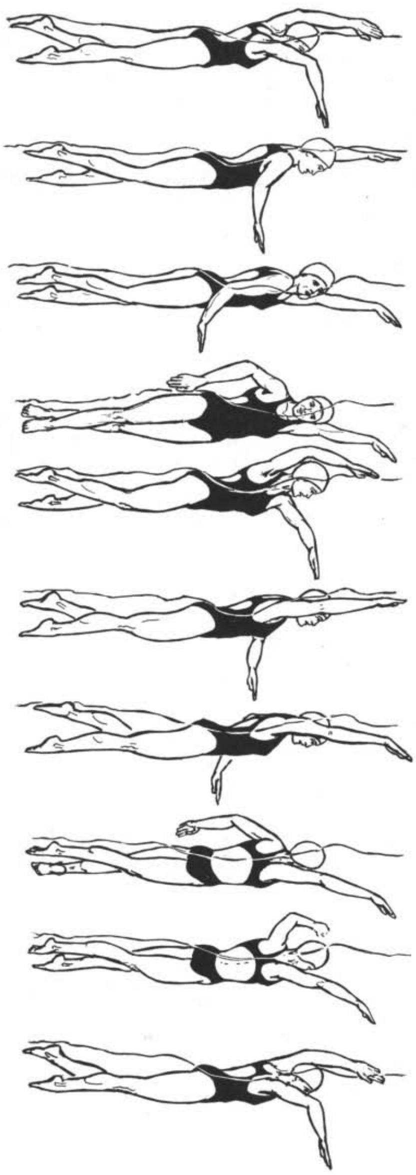

Figure 1: Illustration of the major movements of the crawl stroke (Heinlein & Cosgarea, 2010).

Goal of movement:

As with any swimming technique, the overall goal of the crawl stroke is to propel the individual through the water as quickly and efficiently as possible. Since water has a higher coefficient of drag than that of air (owing to its' almost 1000 times greater density), efficiency and economy of motion is especially important, as the overall energy cost of improper form is very high (Toussaint, Roos, & Kolmogorov, 2004). There are a number of external ways in which to make the motion of both the arms and legs more efficient, such as the use of hand paddles and/or flippers, but this paper will focus solely on the underlying biomechanical aspects of the motion without augmentation.

Movement technique:

One of the reasons swimming is considered such a great training method is that all strokes inherently use all the major muscle groups of the body, leading to a total body workout in minimal time. A comprehensive discussion of all the possible nuances of movement is outside the scope of this paper, but in regards to the major biomechanical aspects of performing the crawl stroke, the primary movers are the shoulders, arms, hands, hips, knees, and ankles.

Throughout the movement of both arms, the torso should remain relatively flat and in line with the surface of the water, maintaining a neutral head position to facilitate breathing on either side. The shoulders should be relaxed and allowed to rotate freely, with the primary movement of the shoulder in the sagittal plane (Hamill, Knutzen, & Derrick, 2015). Additionally, the torso and hips rotate (roll) in the transverse plane, also referred to as the longitudinal axis.

Although many muscle groups are involved in the crawl stroke movement, some of the primary actors and agonist/antagonist groups are:

Shoulder: the primary actors in this movement include the rotator cuff and glenohumeral joint, including the trapezius, rhomboids, and serratus anterior (Heinlein & Cosgarea, 2010). Later in the pull though, the latissimus dorsi are involved, as well as the supraspinatus and deltoids. In the arms, the primary lever systems consist of the movement around the glenohumeral and elbow joints (Hamill, Knutzen, & Derrick, 2015).

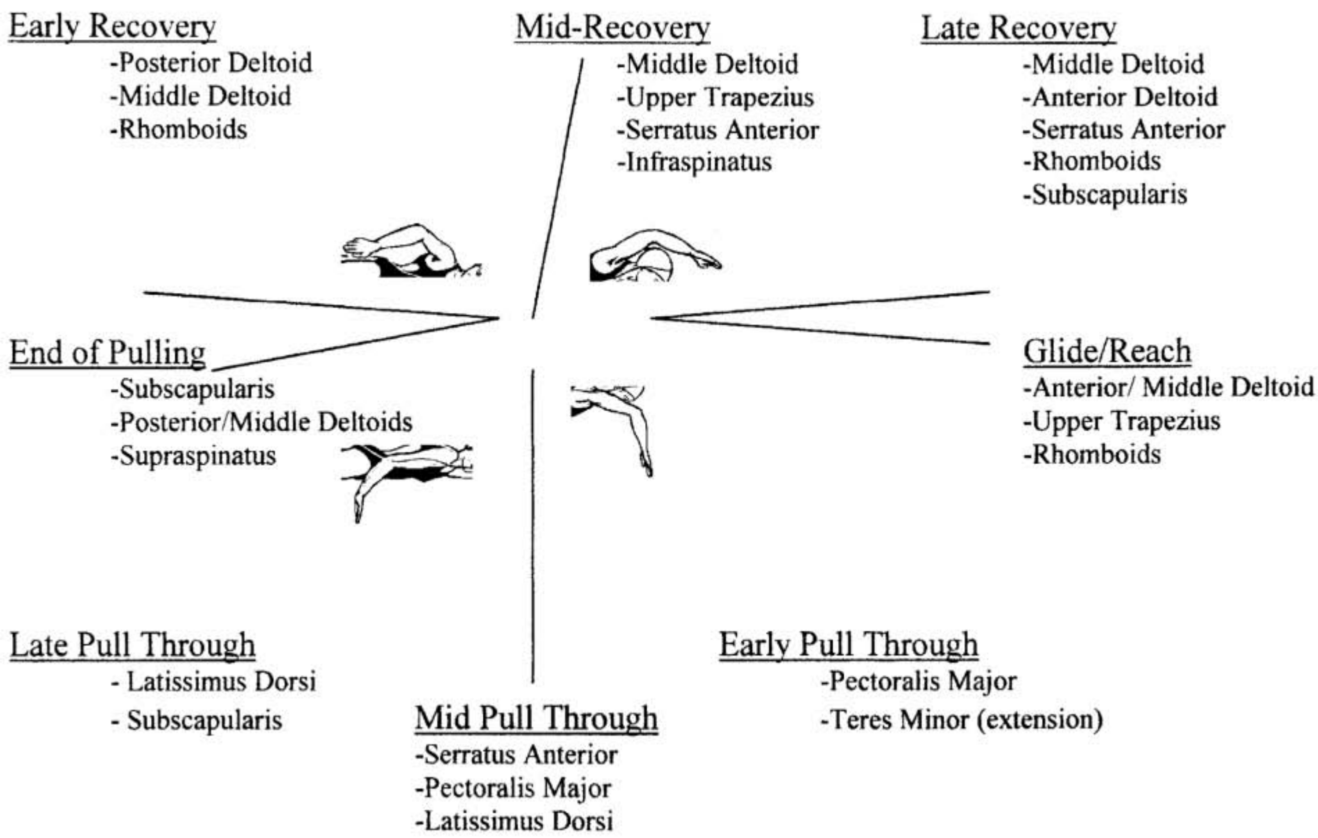

Figure 2: The major muscle actors involved in each of the different movement regions of the crawl stroke (Heinlein & Cosgarea, 2010).

Hips: Although the range of motion is markedly less in the hips than the shoulders, the major muscle groups of the quadriceps and hamstrings remain engaged throughout the kicking motion. The major plane of motion here is also the sagittal plane, and the lever systems consist of the hips and knee joints.

Characteristics of efficient technique:

In general, the most efficient technique should look straight and clean to the observer, with extension and flexion of the shoulders maximized. Furthermore, splashing should be minimized, avoiding at all times any appearance of "flailing", bent or uncoordinated arm movements, or excessive flexion in the hips or waist.

Common errors:

Dropped shoulder: A dropped shoulder leads to inefficient technique, and if left uncorrected, can also lead to shoulder pain, particularly if the individual starts to push "downward" too hard during the pulling portion of the stroke (Mark R. , 2012).

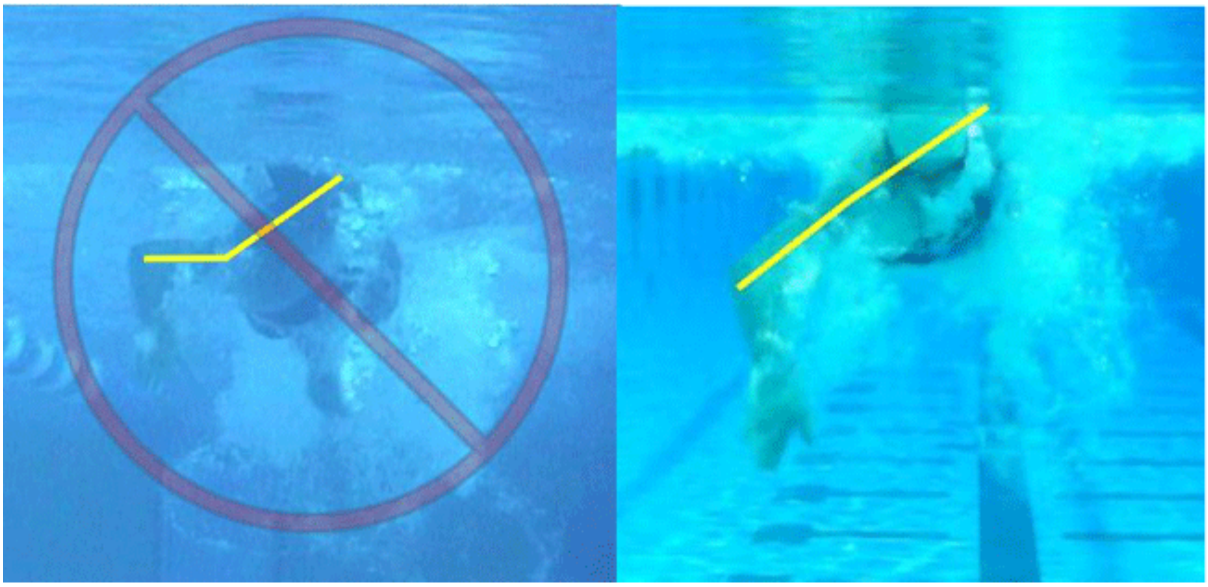

Figure 3: Note the excessive drop in the shoulder in the left image, whereas the right image shows a straight line through the head, shoulder, and upper arm (Mark R. , 2012).

Poor extension:

When there is poor extension, either caused by a lack of flexion of the shoulders or extension in the elbows, the stroke length is lessened. A reduced stroke length shortens the length of the pull-though, reducing the overall amount of work that can be done for each stroke. The exception to this rule is that the elbow should flex during the recovery portion of the stroke, in order to allow the forearm to move to the fully extended positon prior to water insertion with minimal movement required during the recovery. In practice, this allows the fingertips to "skim" the top of the water, and produces minimal fatigue (Lauer, Figueiredo, Vilas-Boas, Fernandes, & Rouard, 2013).

Improper hand position:

If one imagines a paddle wheel (where the paddle or blade is perpendicular to the direction of travel) vice a propeller (where the blade is nearly parallel to the direction of travel) it is easy to see the effect of hand position on the overall effectiveness of propulsion. Since the idea here is to push the maximal amount of water with the hand (in accordance with Newton's third law of motion- every action must have an equal and opposite reaction), for maximal effectiveness, the hand should be perpendicular to the direction of travel through the water, and the surface area should be maximized. Additionally, turbulent flow cannot be discounted when dealing with fluids with high density and coefficients of friction such as water, so while the preceding statement is true for the "pull" section of the movement, while the arm is being drawn through the water from the head toward the thigh, the initial entry of the hand to the water must be done at a slight angle so that the turbulent flow (which increases drag) can be minimized. Once the hand is established in the ideal configuration (this can be felt by the swimmer as a decreased resistance), additional movement should be minimized to prevent unnecessary vortex formation (Kudo, Vennell, & Wilson, 2013).

Too much roll in shoulders:

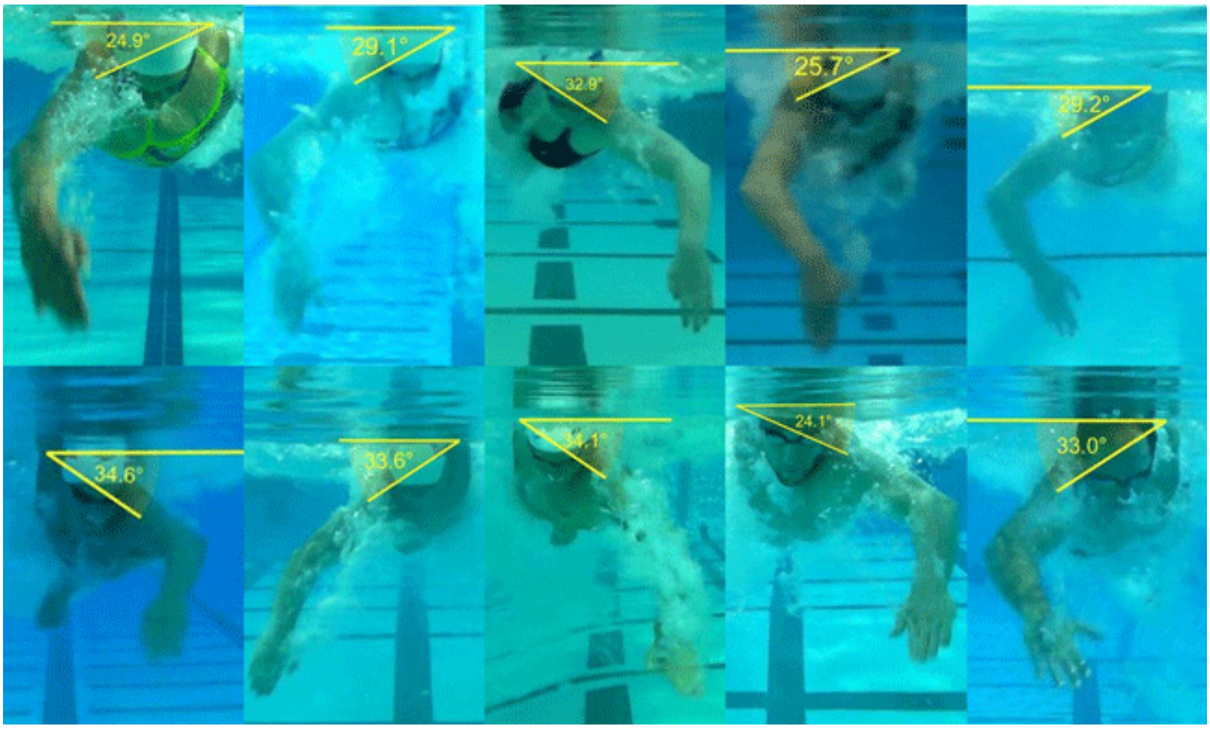

Figure 4: Visual representation of the ideal amount of roll in the shoulders about the longitudinal axis. Note that all subjects avoid excessive shoulder drop and maintain a roll angle of approximately 30° (Mark R. , 2012).

Similar to the preceding error, proper technique in swimming is all about maximizing power while minimizing the amount of drag, all of which reduce the amount of work required for the motion. In this error, the individual is allowing too much roll about the longitudinal axis. While this doesn't add to the drag per se, it does increase the amount of work, since in increases the amount of displacement of the shoulders. Ideally, the individual should maintain a degree of roll which allows for maximal extension, while minimizing the amount of work done. In this case, the proper amount is roughly 30 degrees roll in both the shoulders and the hips (Mark R. , 2012).

Part II- Analysis to improve performance:

Although swimming (including the crawl stroke) is an activity that encompasses most of the major muscle groups in the body, as well as relying on coordinated movement of both the arms and legs, an overwhelming majority (as much as 90%) of the force production is created through the movement of the arms (Dubois, Thiela, & James, 2012). For this reason, this portion of the paper will focus primarily on the force production and injury potential of the shoulders, arms, and hands.

Perhaps one of the first components of force production in the crawl stroke that must be understood is the action of the hand through the water. The hand can be thought of as a plane (or blade), with the flat edge of the plane held nearly perpendicular to the direction of travel. Unlike the wing of an aircraft, though, where lift is created by a drop in air pressure as the air travels over the unequal surfaces of the wing, there is no lift force at work in the swim stroke, and propulsion is created by the hand literally pushing against the water (Rushall, 2002). This suggests that in order to improve performance and force production, the ideal hand position would maximize the surface area of the hand. Keeping the hand as flat as possible while turned to be perfectly perpendicular to the direction of travel maximizes the effective area of the hand, allowing it to push against the greatest amount of water, increasing the forward propulsion. The key to force production in the crawl stroke is that the hand is held relatively steady whilst pushing through the water, rather than “cutting” or “gliding” as an aircraft wing or hydrofoil is designed to do (Kudo, Vennell, & Wilson, 2013). Additionally, since the primary propulsive force is generated by the hand during the propulsive phase, it is unsurprising that an increase in speed is accompanied by an increased stroke frequency (or faster arm stroke) and vice versa (Seifert, Toussaint, Alberty, Schnitzler, & Chollet, 2010).

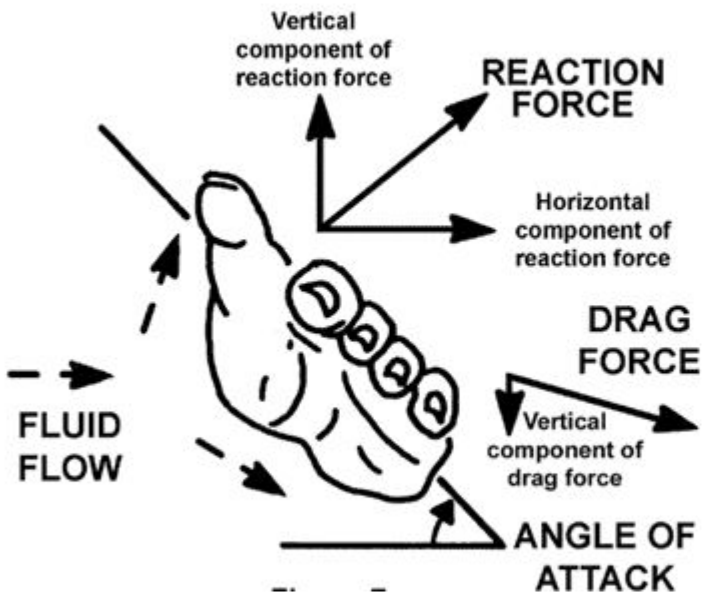

Figure 5: A schematic of the various forces at work on the hand during the propulsive phase of the stroke. Note that there is no lift force, rather that the primary forces are the reaction force and the drag force (Rushall, 2002).

However, there are other forces and biomechanical aspects to consider, including the primary movers of the shoulder joints. For the purpose of clarity, the portion of the stroke where the forearm and hand are in the water will be referred to as the propulsive phase, while the portion where the hand is out of the water is referred to as the recovery phase (Dubois, Thiela, & James, 2012). The shoulders aid in propulsion by providing the lever arms of the system. Since the propulsive force can only be provided by the hands during the propulsive phase, the shoulders need to allow for the maximal possible distance of travel. This can be obtained by maintaining flexibility in the glenohumeral joint, while allowing the elbow joint slight flexion for economy of movement, but the swimmer should seek maximal range of motion for the shoulder from flexion to extension throughout the propulsive phase (Lauer, Figueiredo, Vilas-Boas, Fernandes, & Rouard, 2013). Additionally, the recovery phase should be expedited, with elbow flexion allowed in order to improve the economy of movement by reducing the length of the moment arm.

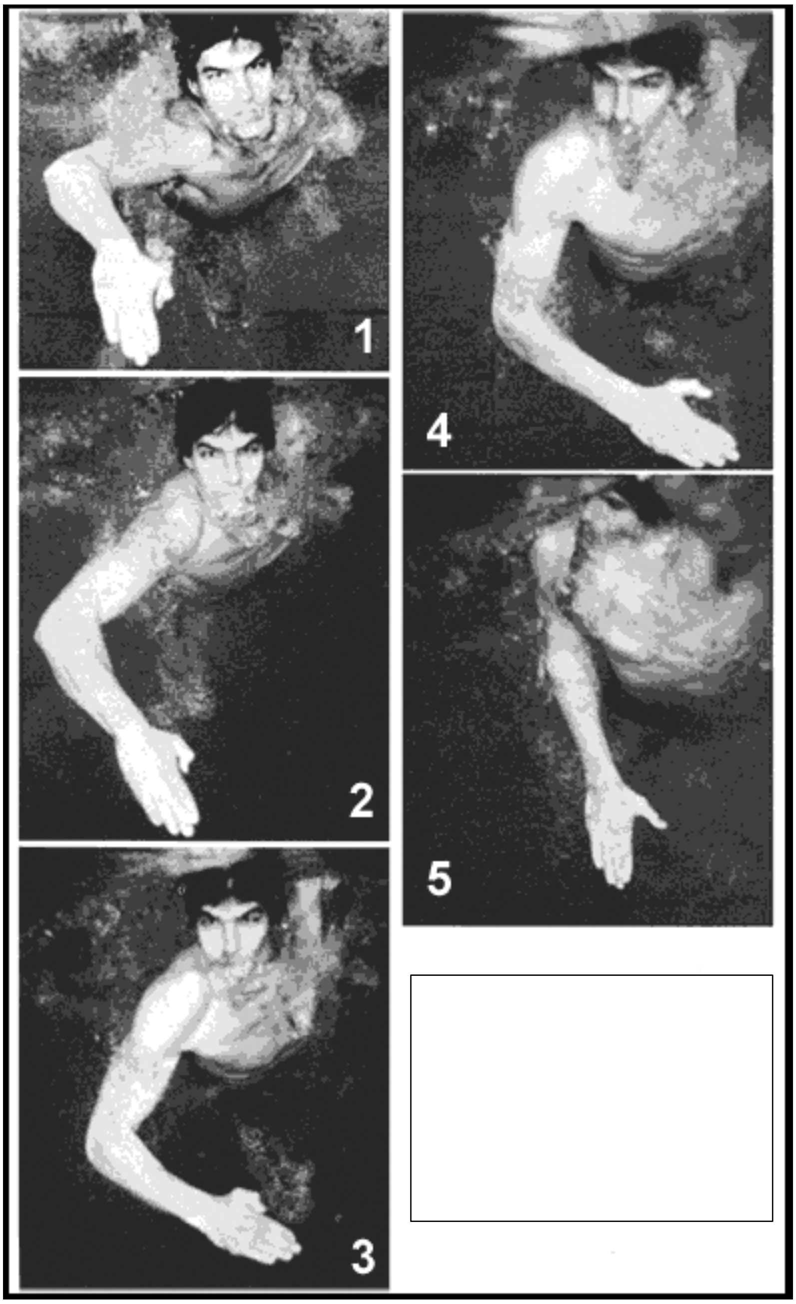

Figure 6: In these images of Olympic swimmer Mark Spitz from 1971, one can clearly see both the hand flattened and moving perpendicular to the direction of movement, as well as the straight shoulder angle and full range of motion employed in the glenohumeral joint (Rushall, 2002).

Aside from the force production potential of the arms and (to a lesser extent the legs), the other primary consideration for the swimmer in terms of energy efficiency is drag management. Since the human body is hardly a perfect hydrofoil, reducing the effect of drag is an ongoing battle. Specialized swim suits can help, by reducing the coefficient of friction between the skin and the water, but form drag, or the drag caused by the shape of the body as it moves through the water, still provides the larger impact on energy efficiency (Toussaint, Roos, & Kolmogorov, 2004).

Finally, in terms of efficiency as well as drag reduction, the glide position of the body is of chief concern. Since we've already established that drag is a primary force inhibiting forward momentum, maintaining as close to optimal glide position is a key factor in energy efficiency. The primary consideration in this regard is to maintain a neutral head position (with neither excessive neck flexion nor extension) and minimal flexion in the hips. Hip flexion, or "dropping the legs", causes excessive drag, and does not allow for optimal kicking technique (Hochstein & Blickhan, 2014). However, this is not to imply that the swimmer should maintain a rigid body posture throughout the stroke, as a moderate undulatory motion actually improves the effectiveness of the stroke, in much the same way that a dolphin's body continually oscillates in the water to assist in providing forward momentum (Hochstein & Blickhan, 2014).

In summary, the key to efficient and effective movement in the crawl stoke is to avoid excessive rotation (more than 30 degrees) around the longitudinal axis, maintain a straight line from elbow to elbow (and through the head), and to maximize the length and effectiveness of the propulsive phase through shoulder range of motion and optimal hand position (Mark R. , 2012). Furthermore, the body should be allowed to undulate gently and naturally, in order to promote maximal efficiency, while still avoiding any excessive or "flailing" movement.

Injury prevention:

Since the glenohumeral joint is both the primary mover and the major force producer (as it is located at the stationary end of the axis of rotation, and is therefore subject to increased torque) in this movement, overuse and acute injuries in swimmers are most common in the shoulder and rotator cuff (Pink, Edelman, Mark, & Rodeo, 2011). Specifically, the most common injuries include supraspinatus tendinopathy and glenohumeral instability (Heinlein & Cosgarea, 2010). In this case, the overall goal is to increase both the stability and strength of the joint while maintaining flexibility. Because the glenoid fossa provides such a small area of contact between it and the humeral head, the shoulder relies heavily on the surrounding musculature for support, stability, and strength (Hamill, Knutzen, & Derrick, 2015). In particular, most swimmers who report shoulder injury from the crawl stroke complain of pain during the first half of the propulsive phase (Heinlein & Cosgarea, 2010; Pink, Edelman, Mark, & Rodeo, 2011). In order to stabilize the joint, the muscles of the rotator cuff need to be strengthened (University of Washington Department of Orthopedic and Sports Medicine, 2014). Exercises to improve the strength of the rotator cuff can include the military or shoulder press, upright row, or seated dumbbell press. Shoulder rotation exercises with weights or dumbbell shrugs can also help strengthen the rotator muscles and the girdle elevators (Hamill, Knutzen, & Derrick, 2015).

In addition to instability of the shoulder joint, swimmers might experience pain during their stroke from overuse injuries, which may cause them to adopt a wider hand-entry and pull-through, in order to alleviate pain from an inflamed supraspinatus. However, as the position of arm during the propulsive phase widens, it increases the chances of humeral hyperextension, or the “dropped shoulder” seen in figure 3 (Pink, Edelman, Mark, & Rodeo, 2011). Furthermore, strain on either the elbow or wrist might develop with prolonged poor technique, however, the exercises prescribed above (with proper coaching and technique) should aid in promoting good overall efficiency and effectiveness.

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