The Role of Hip Rotation in Freestyle Swimming

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Introduction

Hip rotation in freestyle swimming is a somewhat controversial topic as there is limited agreement on the effectiveness of extensive hip rotation in the front crawl (Pritchard 1993; Hilgers 1996). The question to be addressed in this paper is to examine some of the potential roles of hip rotation in the front crawl stroke- if it is useful in increasing propulsion. It is also possible that it occurs as a reaction to the torques produced by the body during the stroke. An attempt will be made to compare the timing of shoulder and hip rotations between freestyle swimmers and overhand throwing athletes, to determine if the mechanisms of inertial lag and muscle stretch could apply in swimming. This question will be addressed from a theoretical perspective, by examining the trunk roll occurring in the stroke of skilled swimmers and reviewing some of the literature that has examined trunk rotation in other activities.

Hip rotation refers to rotation of the pelvic girdle around the long axis of the body, also called hip roll or pelvic rotation (Newsome 2010a). Observation of elite crawl swimmers only heightens the controversy, as some top swimmers use extensive hip rotation (Ian Thorpe), while others use very little hip rotation (Grant Hackett).

Shoulder Girdle Rotation

There is no such controversy related to shoulder girdle rotation, as all top freestyle swimmers use extensive shoulder girdle rotation in which the shoulder joints rotate around the long axis of the body passing through the spine (Newsome 2010b). The shoulder girdle is an incomplete bony ring that consists of the clavicles, the sternum, and the scapula, especially the spine of the scapula. The shoulder girdle forms an incomplete ring around the upper torso, as the scapula has no firm bony attachment to the spine, just a muscular connection.

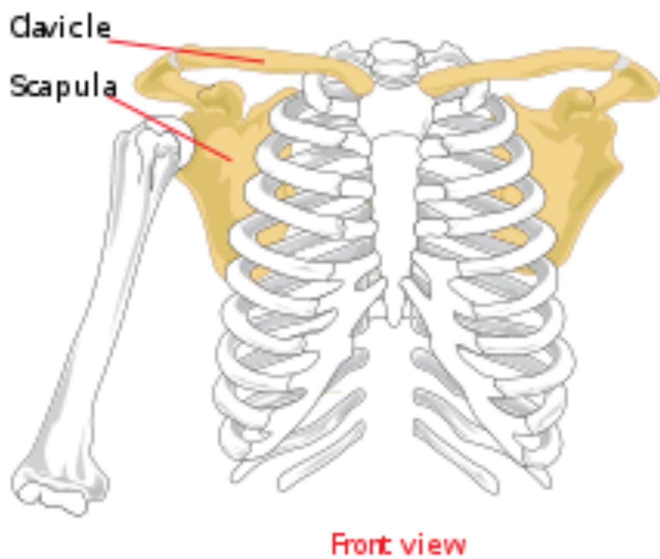

Figure 1. The shoulder girdle forms an incomplete bony ring consisting of the sternum, clavicles, and scapulae.

For many years swimmers were taught to pull themselves through the water with the trunk flat, using their arms alone, with little rotation (Pritchard 1993; Hines 2010). For example, the popular use of kickboards in swim training train a swimmer not to rotate their hips, and focus more on the arm stroke (Pritchard 1993). However, most modern coaches advocate a significant range of hip rotation to improve streamlining and stroke efficiency (Hilgers 1996; Newsome 2010a). A recent review of body roll has reported that the shoulders roll considerably more than the hips (Cappaert, Pease et al. 1995; Psycharakis and Sanders 2010), likely due to the greater mobility of the shoulder girdle compared to the pelvic girdle. It has also been suggested that the kicking actions in the free style dampen the hip rotation action- that the kicking action applies a torque to the hips that limit the range of hip roll (Sanders and Psycharakis 2009).

The ideal angle of the shoulder girdle to the water surface during the freestyle stroke is greater than 45 degrees to the horizontal, or 45 degrees to the surface of the water. Mean values of 58º for shoulder roll and 36º for hip rotation were reported at a swimming speed of 1.6 m/s (Yanai 2003). Shoulder girdle rotation is readily justifiable as a necessary part of the stroke compared to hip rotation as it is required for efficient arm recovery. As the arm completes the power stroke and is raised out of the water for recovery, the shoulders rotate toward the recovery arm to allow it to recover fully while out of the water (Newsome 2010b). The greater the shoulder roll the higher the arm will recover and the more efficient the recovery by producing a shorter radius of rotation of the recovery arm (Psycharakis and Sanders 2010). When the recovery arm has the elbow flexed and the elbow pointing upward during mid swing the moment of inertia about the shoulder axis is minimized and less muscle torque is required to rotate the arm forward into the next stroke. Less muscle fuel (ATP) used on the recovery means that the swimmer will have more fuel to perform the power stroke that actually propels him through the water, decreasing fatigue.

Increased body roll will also decrease the drag forces acting against the swimmer, due to a reduction of the frontal area of the swimmer that is underwater and facing the direction of movement (Newsome 2010b). The smaller the area oriented to the direction of motion, the less the drag force (Hay 1993). When the body is rolled onto the side, the effective cross section is decreased as the top shoulder, torso and arm are out of the water. The assumption is that rolling the body will not force the legs closer to the bottom of the pool. If the legs move down relative to the shoulders, then the cross section of the body facing forward will increase and drag will increase. With increased drag, the swimmer will have to work proportionately harder in order to maintain their top speed in the water. Recall that drag forces (water resistance forces) are proportional to the cross sectional area of the swimmer that is facing the direction of motion (Hay 1993).

What is pelvic rotation?

Hip rotation, or pelvic rotation here refers to the rotation of the pelvic girdle around the longitudinal axis of the body passing through the middle of the spine. The pelvic girdle consists of the paired hip bones, the sacrum and the coccyx, with the hip bones being fused anteriorly at the pubic symphysis. The pelvic girdle forms a complete bony ring around the lower torso that can rotate as a single unit around the longitudinal axis of the body that passes through the spine. Swimmers who use hip rotation will rotate the hip joints around this stationary longitudinal axis of the body

Figure 2 . The pelvic girdle, a bony ring consisting of the sacrum and hip bones and including the following parts: 1) sacrum, 2) ilium 3) ischium 4) pubis 5) pubic symphysis 6) acetabulum 7) obturator foramen 8) coccyx

Hip rotation is controlled by the muscles that act on the pelvis and these muscles attach to the legs inferiorly and the trunk superiorly. These muscles include: the erector spinae group, quadratus lumborum, the abdominal obliques, transversus abdominus, latissimus dorsi, psoas major, iliacus, rectus femoris and sartorius.

Hip rotation will occur with the same timing as shoulder rotation- as the right arm recovers the body rolls to the right, and as the left arm recovers the body rolls to the left. However, during the freestyle stroke hip rotation should occur slightly in advance of shoulder rotation, so that hip rotation starts first, then the hip rotation is caught up to and passed by the shoulder girdle. If the timing of these rotations is staggered, the sequenced upper and lower body rolls will be more effective in placing the trunk muscles on a stretch. A recent research study reported that the hips and shoulders move through different ranges and reach their maxima at different times (Psycharakis 2006). Since the shoulders and hips start and finish the roll independently from each other, sequencing of these movements is likely (Sanders and Psycharakis 2009).

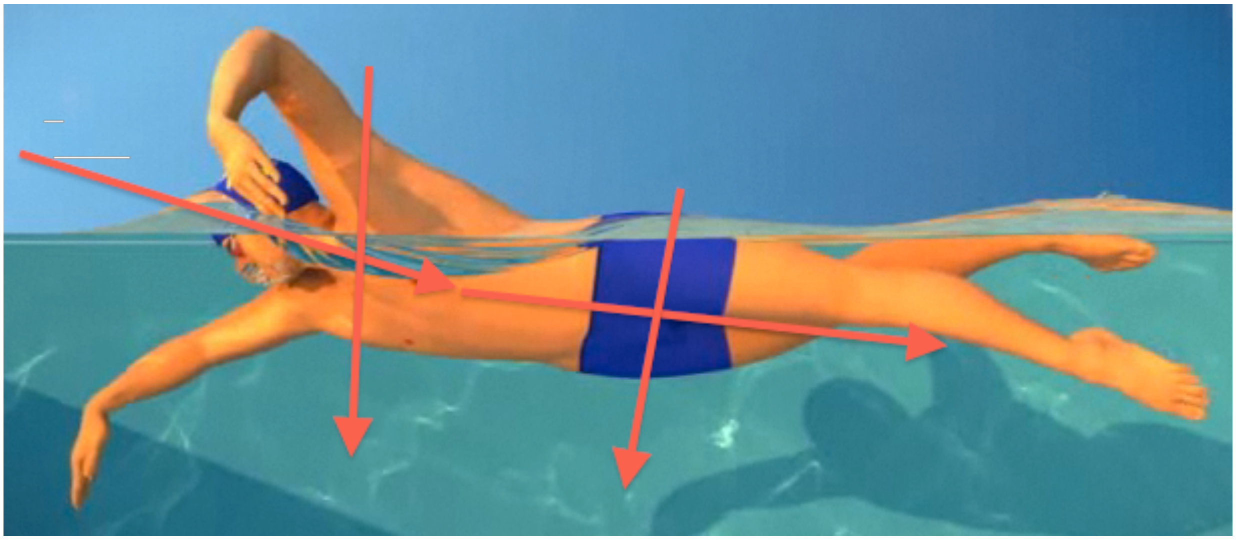

Figure 3. Hip rotation occurs slightly in advance of shoulder rotation in order to place the trunk muscles on a stretch. Photo from: http://www.swimsmooth.com/intermediate.php.

Hip rotation will also change the direction of the foot movement during the kick. In normal body-prone freestyle kicking the legs and feet kick primarily in an upward -downward direction, so that the soles of the feet face upward for most of the stroke. When the body is rotating around the long axis, the feet spend part of the kicking cycle facing sideways (Figure 3). Most swimmers rotate their body (hips and shoulders) along the long axis so that they spend most of their time on their sides (Gmunder 2004). For example, when the right arm is in recovery, the hips are facing to the right so the tops of the feet are also facing the right side for part of the cycle. Since the propulsion from the feet primarily occurs as the water is pushed backwards, foot propulsion forces are likely unaffected by the change in orientation of the feet. The hip rotation allows the feet to kick in a sideways direction, that may help to cancel the sideways sway of the torso created by the forward swing of the recovery arm (Psycharakis and Sanders 2010).

One author has suggested that “Like a baseball player, a swimmer initiates the stroke at the hip (with hip rotation), following quickly with the shoulders and arms” (Hilgers 1996). However, there is little agreement on the optimal timing of the shoulder and hip rotations, as it has been recently suggested that the torso, shoulders and hips should all roll together as one (Newsome 2010a; Young 2010a). Repeated observation of elite swimmers suggests that a sequenced roll is more common and likely more effective in stretching appropriate trunk muscles. A recent study examining the body roll of males and females in swimming found that males produced and earlier hip roll, while females hip and chest roll occurred almost simultaneously (Lee, Mellifont et al. 2008). A recent review concluded that swimmers roll their shoulders significantly more than their hips, therefore shoulder roll and hip roll should be calculated separately in swimming (Psycharakis and Sanders 2010).

Hip Rotation in Throwing (R handed thrower)

Hip rotation, or pelvic rotation is a key component in all events that require the overhand throwing pattern, in which the body rotates to face forward from a sideways position, leading with the pelvic girdle and following with shoulder girdle rotation. Some skills in which this pattern is seen include baseball pitching, softball pitching, water polo shooting, javelin throwing, tennis serving and volleyball spiking. The objective of these sports skills is to optimize the velocity of the throwing arm and hand during the force producing movements, to maximize the speed of the ball or other implement at release.

Figure 4. Skilled pitcher showing pelvic rotation leading shoulder girdle rotation, placing the anterior trunk muscles on a stretch.

Hip rotation contributes to the force of the throw by placing the anterior trunk muscles on a stretch initially that then act more strongly in assisting shoulder girdle rotation during the throw. Fast and effective shoulder girdle and trunk rotation will assist in maximizing the lateral rotation in the throwing shoulder by leaving the throwing arm and hand behind, which will maximize the range of medial rotation during release of the ball or javelin (Figure 4). Hip rotation in throwing consists of rotation of the pelvis from a position facing sideways to the direction of the throw, to a position in which the pelvis faces the direction of the throw. Highly skilled athletes perform a full range of over 90 degrees of hip rotation during their skill, including a backswing in which the hips are rotated away from the direction of motion, and a forward swing in which the hips are rotated in the direction of the throw prior to the forward motion of the arm (Feltner and Dapena 1986).

As the forward motion in throwing begins, the thrower will first move the front hip linearly in the direction of the throw, leaving the throwing arm and hip behind. Since the pelvis is leading the motion of the trunk, the mid trunk and shoulder girdle are left behind the front hip (Figure 5). This lag of the throwing arm and shoulder will create a stretch on the muscles of the trunk and anterior shoulder. This stretch will ensure a more forceful contraction of the trunk and shoulder muscles due to the stretch reflex as well as the stored elastic strain energy created in these muscles. The step forward onto the left foot is the beginning of the force producing movements of the throw.

This step forward is followed by rotation of the pelvis around the fixed front hip, which forms the axis of rotation for pelvic rotation. The front foot is planted in front of the thrower, and the pelvis rotates around this fixed front foot. The pelvic rotation is initiated by the drive from the back foot, but rotation is primarily produced by the strong action of the trunk muscles pulling the right side of the trunk forward (Figure 5).

a b c d

Figure 5a-d. Sequence of pitching motions showing pelvic rotation leading shoulder girdle rotation that stretches the anterior trunk muscles.

For a right handed thrower, the pelvis rotates to the right on the backswing and to the left on the forward swing. Pelvic rotation will precede the rotation of the shoulder girdle, so in throwing the left hip will start the rotation of the pelvis, and this hip rotation is followed by the left shoulder rotating to the left. These rotations of the pelvis and shoulder girdle must occur sequentially, with the hips initiating the rotation while the shoulders lag behind with their rotation starting later in the sequence (Figure 5).

Trunk Muscle Involvement

The lag of distal body segments behind proximal segments is known as 'inertial lag', which is the trailing of the distal segments due to their inertia (Whiteley 2007; Southard 2009). The lagging of distal segments is a sign of a skilled performer, as it places a stretch on the muscles connecting the proximal to the distal segments. In throwing, for example, the pelvis rotates forward first, leaving the mid trunk and shoulder girdle behind (Figure 5b). This lag places the anterior trunk muscles on a stretch, and produces a more powerful contraction of these muscles to rotate the trunk forward and bring the shoulder girdle around to face the target. Inertial lag occurs at several points in throwing, as the shoulder girdle rotation then leaves the throwing arm behind the body in shoulder lateral rotation (Figure 5c). This position places the anterior shoulder muscles, including the shoulder medial rotators on a stretch, providing for a more forceful contraction to bring the shoulder girdle and pitching arm forward into the throw. In swimming the hips initiate the rotation, placing the anterior trunk muscles on a stretch as the shoulder girdle lags behind the hips initially.

The sequential action of the hips in swimming, followed by the shoulders is important because it places the diagonal muscles of the anterior trunk on a stretch prior to the arm entering the water. The left hip leading the trunk rotation will place the diagonal abdominals on a stretch, with the left external oblique and the right internal oblique being placed on stretch initially (Figure 3). Also placed on stretch as the hips lead the trunk are the rectus abdominus, left quadratus lumborum, iliacus and psoas major. This stretch has several important roles to play in increasing the force of the trunk rotation, as it will help to store elastic strain energy in the anterior trunk muscles. This elastic strain energy can be stored by the actin and myosin filaments, as well as the titin and nebulin fibres of the sacromeres, also by the tendons of each of the muscles. This strain energy will be added to the electromechanical contractile force being produced by the breakdown of ATP to produce contraction of these trunk muscles and will increase the angular velocity of trunk rotation. This initial stretch on the anterior trunk muscles produced by the inertial lag will also recruit the stretch reflex from the muscle spindles, which will further enhance the force of the trunk muscle contraction (Enoka 1994). The stretch reflex occurs when a muscle is stretched fast and forcefully, firing the sensory nerve endings of the muscle spindle and producing a reflex contraction of the muscle that has been stretched.

The muscle stretch will further enhance the role of connective tissue in storing strain energy to enhance the arm pull. Connective tissue is one of the most important tissue types in the body, containing cells, matrix and collagen fibres. Connective tissue is the material between the cells of the body that gives tissues form and strength. This "cellular glue" is also involved in delivering nutrients to the tissue, and in the special functioning of certain tissues. Connective tissue surrounds many organs, including muscles, ligaments, tendons and intestines. Cartilage, blood and bone are specialized forms of connective tissue (Eustice 2005). The collagen fibres embedded in connective tissue are somewhat elastic fibres that can store strain energy, and then release that strain energy to increase muscle force when the stretch is released. Connective tissue comprises a significant volume of muscle tissue, and there are three layers of connective tissue that surround the various components of skeletal muscle (epimysium, endomysium and perimysium). There are also three connective tissue layers that surround the various layers of the tendons (epitenon, mesotenon, endotenon) that can also store energy upon stretch (Nordin and Frankel 2001). The muscular system has the potential for significant strain energy storage and release following the stretch of a muscle group, which can be utilized if the proximal segments move in advance of the more distal segments (Figure 6). As the range of motion of the trunk and shoulder segments increases, the time of force application and the amount of applied force also increases, increasing the impulse being applied by the trunk and arms of the pitcher.

As well as enhancement of muscle force, hip rotation will train and condition the trunk and shoulder muscle groups, especially the latissimus dorsi, the pectorals and the oblique abdominals. As the swimmer utilizes a greater range of pelvic and shoulder rotation in the stroke, core fitness levels will also increase due to greater involvement of the trunk muscles. This enhanced core strength will likely improve the performance of all swimmers in training. One coach has suggested that “increasing the strength, speed, range and timing of their (swimmers) hip rotation was the surest way to improve performance and reduce injury” (Pritchard 1993). He further noted that their concentration almost exclusively on increasing the speed and power of the hips produced improvements in stroke count and swimming speed, and helped to eliminate arm and shoulder injuries (Pritchard 1993).

Figure 6. Skilled pitcher showing the pelvic rotation leading the shoulder girdle rotation, which places a stretch on the anterior trunk muscles.

As the diagonal trunk muscles forcefully contract to rotate the trunk to the left and forward into flexion, their contraction also serves to stiffen the trunk. This greater stiffness of the trunk will provide a firm and stable base on which the throwing arm muscles can pull through release. Most of the shoulder muscles originate from the scapula, clavicles and rib cage, and attach to the arm to produce the arm movements. Since the large throwing muscles (latissimus dorsi, pectoralis major, teres major, subscapularis) have their origins on the trunk and their insertions on the throwing arm, they require a firm base on which to pull. For example, the latissimus dorsi muscle originates on the thoracic spine and thoracolumbar fascia and inserts in the bicipital groove of the humerus. As the latissimus dorsi is strongly contracting to medially rotate the humerus, the origin and attachments of the latissimus are helping to stabilize the posterior trunk to provide a firm base on which to pull during the arm stroke. As well, the back extensors are strongly contracted to provide trunk stability for the pull of the shoulder muscles. 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. 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 (Prins 2007).

It has also been suggested that the largest propulsive forces on the hands are produced during the peak velocity of hip rotation . The hip on the propulsive side is rotating downward, toward the bottom of the pool during the peak force producing position of the arm on that side. The rotation of the hips down and forward can help to pull the arm on that side closer to the hips. The movement of the arms backward through the water is likely facilitated by the hips helping to pull them down and forward (Figure 7).

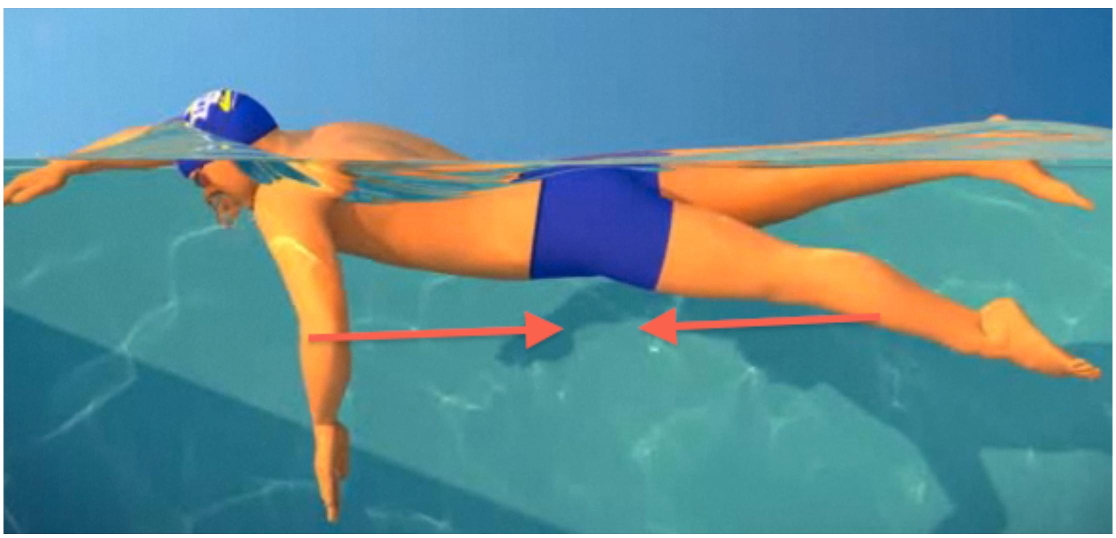

Figure 7. As the left arm pulls back on the water, the hips rotate to the right to help pull the arm back. (Photo from: http://www.swimsmooth.com/intermediate.php).

Pelvic (hip) rotation in swimming

Hip rotation in swimming has a somewhat similar purpose to hip rotation in throwing, except that throwing occurs from the ground and swimming occurs in the water. The thrower uses the ground to take up any angular momentum that they produce from the trunk and throwing arm while throwing the ball. As the hips rotate forward assisted by the push off from the back foot, the ground resists that torque from the back foot. However, the swimmer does not have the ground to take up any torques and resulting angular momentum they might produce, although the water has the ability to take up some angular momentum by applying torques to the body. Angular momentum in swimming is a vector representing rotation around the long axis of the body in a specific direction, and is a measure of the amount of angular motion that an athlete or object possesses. Angular momentum is the product of moment of inertia multiplied by angular velocity, and is constant in an athlete who is airborne or suspended in the water. The faster the athlete rotates, and the further the limbs are spread from the axis through the trunk, the greater the angular momentum. However, because of the torques applied by the water to the body and limbs of the rotating swimmer, angular momentum would be reduced to zero within a very short time.

The angular momentum produced by the trunk and arms of the swimmer is taken up by the leg kick in the front crawl (Hay 1993). It has been suggested that the widespread popularity of the six beat kick in the freestyle can be accounted for in terms of the swimmer's need to conserve angular momentum around the long axis of the body (Eaves 1971). As the swimmer's right arm and right shoulder go down into the water and the left arm and shoulder come up (near the beginning of the pull with the right arm), the left leg and hip must also go down. As seen in Figure 8, the upper trunk has angular momentum to the left (CCW) around the long axis, which has to be taken up by the legs rotating CW around the same axis to maintain constant angular momentum. In Figure 8, left leg and hip move down and the right leg and hip come up, to provide the necessary conservation of momentum during the stroke. The hip rotation that has occurred in Figure 8 has helped to increase the contribution of the legs in taking up the angular momentum produced by the trunk. The distance of the legs from the longitudinal axis has increased somewhat due to the hip rotation, which will allow them to produce more angular momentum per kick by increasing their moment of inertia around the long axis, to take up more of the trunk rotation.

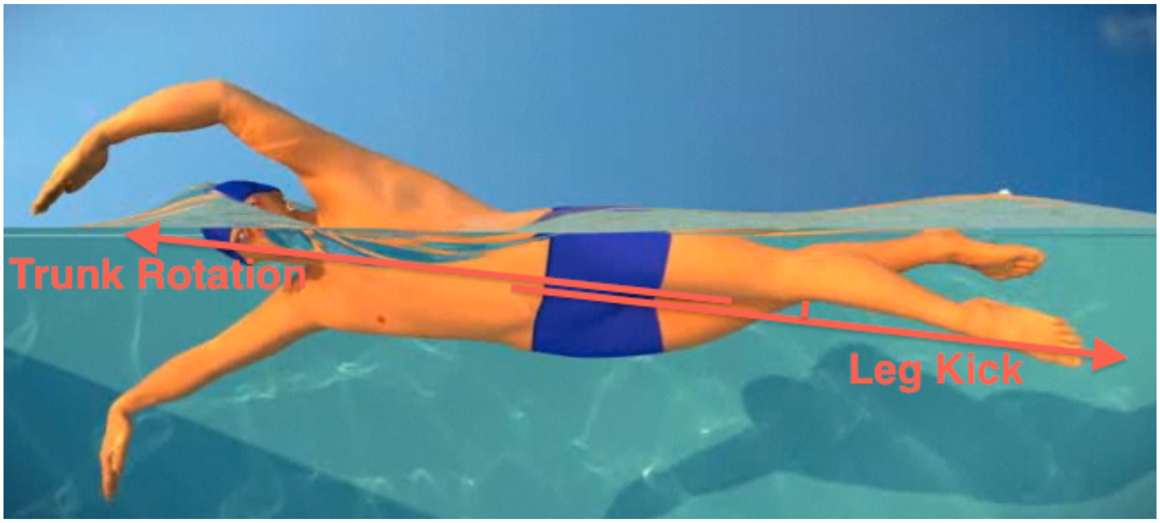

Figure 8. The angular momentum produced by the trunk rotation to the left (CCW) is taken up by the angular momentum produced by the kicking of the legs (CW) (Photo from: http://www.swimsmooth.com/intermediate.php).

Whereas in throwing the purpose of hip rotation is to maximize the speed and power of trunk rotation to enhance the action of the throwing arm, in swimming the purpose is to enhance the action of the pulling arm. As the swimmer rotates the trunk to the right while the right arm is in recovery (Figure 9), this rotation is initiated by the rotation of the right hip to the right. This rotation of the right hip initiates the rotation of the pelvis to the right, and the hip rotation should start just prior to shoulder girdle rotation. Assuming the hip rotation precedes the shoulder rotation, there should be a time lag in the action of the shoulder girdle in rotation. This lag will produce a stretch on the anterior trunk muscles, and some of the posterior trunk muscles, and this stretch will help to stiffen the trunk. As the anterior trunk muscles are stretched and lengthened, they experience an eccentric muscle contraction to control the lengthening in preparation for shortening. As the right arm is recovering and the diagonal trunk muscles are stretched due to the lag between the pelvis and the shoulder girdle rotations, this stretch and accompanying eccentric contraction will stiffen the trunk. The trunk has now been stiffened and provides a more rigid base on which the shoulder muscles of the left arm can pull. The shoulder muscles that are required to pull more strongly on the stiffer trunk include: latissimus dorsi, deltoid, subscapularis, pectoralis major, and teres major. These muscles all cross the shoulder joint to attach on the trunk.

As the right arm is recovering, the left arm is pulling back in the initial phases of the power stroke (Figure 9). Since the trunk has been stiffened by the stretched muscles due to the lag between the shoulder girdle and pelvic rotation, the left arm has a firmer base on which to pull. Any decrease in pelvic rotation or decrease in shoulder girdle rotation will lessen the effects of the stretched trunk muscles in stiffening the trunk. A decrease in the stretch on the anterior trunk muscles will decrease the rigidity of the trunk and reduce the effectiveness of the pull of the shoulder muscles of the power arm.

Increased hip and shoulder rotation will also increase the length of the arm stroke by increasing the arm reach forward. As the trunk rotates toward the recovery arm, the lead arm is reaching forward and extending fully into the next stroke. The reach is extended by almost the length of the shoulder girdle as the recovery shoulder is back while the lead shoulder is well in advance (Figure 9). A swimmer who concentrates on extending the arm fully at the beginning of each stroke will have a longer stroke length and will swim more efficiently. Also, when you place your arm in the water in a more biomechanically correct position, there is less stress on the shoulders. If the arm is placed directly in front of the lead shoulder and the hand is pulled directly back toward the shoulder, lateral torques about the shoulder joint are minimized and the forces on the shoulder are decreased. This technique will also greatly reduce the risk of injury (Hilgers 1996).

Increased hip rotation also increases the effectiveness of the pectoralis muscles and latissimus dorsi at the shoulder joint. As the swimmer rolls to the left side, the left hip then leads the torso in rotation while shoulders are left behind. As the swimmer rotates away from the right side, which is then left behind with the right arm extended forward, there is a greater stretch on both the pecs and latissimus dorsi. This stretch, produced by the hip rotation to the left, will help to produce a stronger contraction in the pectoralis and latissimus dorsi during the force producing phase of the right arm. It is notable that the pectoralis major is lengthened by the hips rotating to the left, with the lead shoulder in flexion and the torso rotating away from this arm. The latissimus dorsi is tightened by virtue of its attachment to the thoracolumbar fascia (Middleditch and Oliver 2005), which is stretched by the rotation of the hips to the left. The pelvic attachment of latissimus dorsi is via the thoracolumbar fascia. When the lead arm is in an elevated position there is a stretch on latissimus dorsi with an increase in tension of thoracolumbar fascia. This increase in tension is further enhanced by other movements such as posterior rotation of the pelvis (Middleditch and Oliver 2005). It is likely that increased hip rotation in a skilled swimmer will increase the tension produced by these important shoulder muscles, and increase the propulsive force of the stroke.

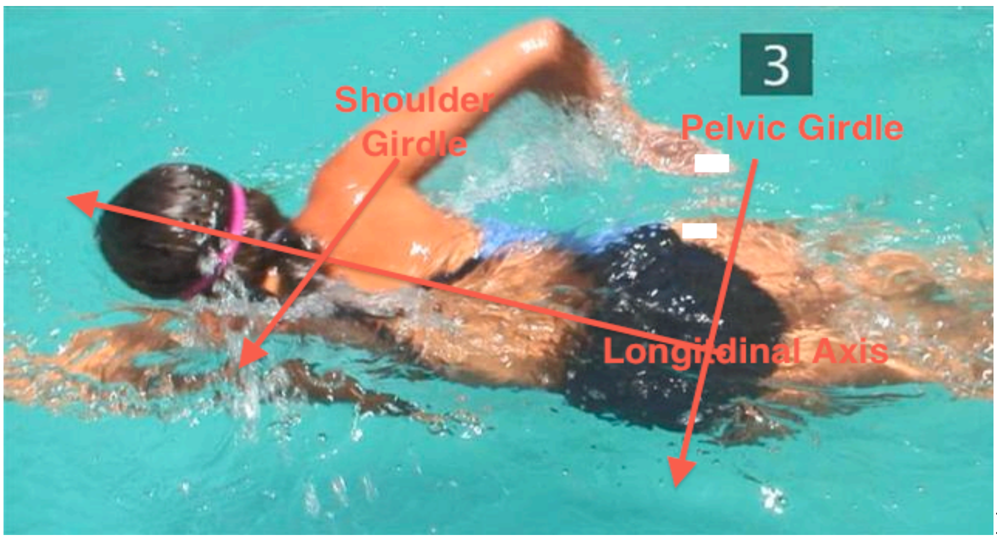

Figure 9. This young swimmer shows good hip rotation to the right, leading the shoulder girdle rotation. This hip rotation has produced a stiffer trunk on which the left arm can pull.

Transfer of Trunk Angular Momentum

Angular Momentum is the product of moment of inertia and angular velocity, and is a measure of the quantity of angular motion produced by a body or body segment (Hay 1993). As the swimmer rotates in the water during the stroke, their trunk has a small amount of angular momentum around the longitudinal axis that is the product of the mass of their body and how fast it is rotating. Angular momentum is created by trunk rotation around the longitudinal axis, which is produced by the application of muscle torques from the trunk muscles. As trunk rotation is completed in one direction as the hand exits the water, the trunk slows down rotation to zero before changing the direction of rotation. The amount of trunk angular momentum is decreased to zero before rotation starts in the opposite direction and the angular momentum again increases.

As the trunk angular momentum approaches zero, the system then transfers some of this angular momentum to the less massive distal segment, which in this case is the recovery arm (Figure 10). As the trunk completes rotation to the left, the recovery arm continues to rotate to the left for a short time during recovery to ensure water clearance. In this way the trunk rotation can assist in the rotation of the less massive distal segment by helping rotate the recovery arm up and out of the water (Southard 2009)(Figure 10). The swimmer in Figure 10 has rotated her trunk to her right, her trunk has then stopped rotation, reducing the trunk angular momentum to zero. Some of this angular momentum has been transferred to the right arm in recovery, to assist in rotating the arm counterclockwise out of the water. It should be noted that the changes in angular momentum of body parts are likely very small, since water is a dense medium and the torques required to decrease angular momentum to zero could be provided by the resistance of the fluid medium itself.

Trunk rotation can also transfer some angular momentum from the trunk to the propulsive arm in the water. As the trunk completes rotation to the right, the trunk stops in order to change the direction of rotation (Figure 10). Some of this angular momentum is transferred from the trunk to the propulsive arm, increasing the force of the pull. This transfer of momentum will help the latissimus dorsi, the pectoralis major, and the trunk muscles perform a more powerful stroke. Although this is sometimes described as transfer of power from the trunk rotation to the propulsive arm (Newsome 2010b; Young 2010b), likely the more correct description is the transfer of angular momentum from trunk to propulsive arm.

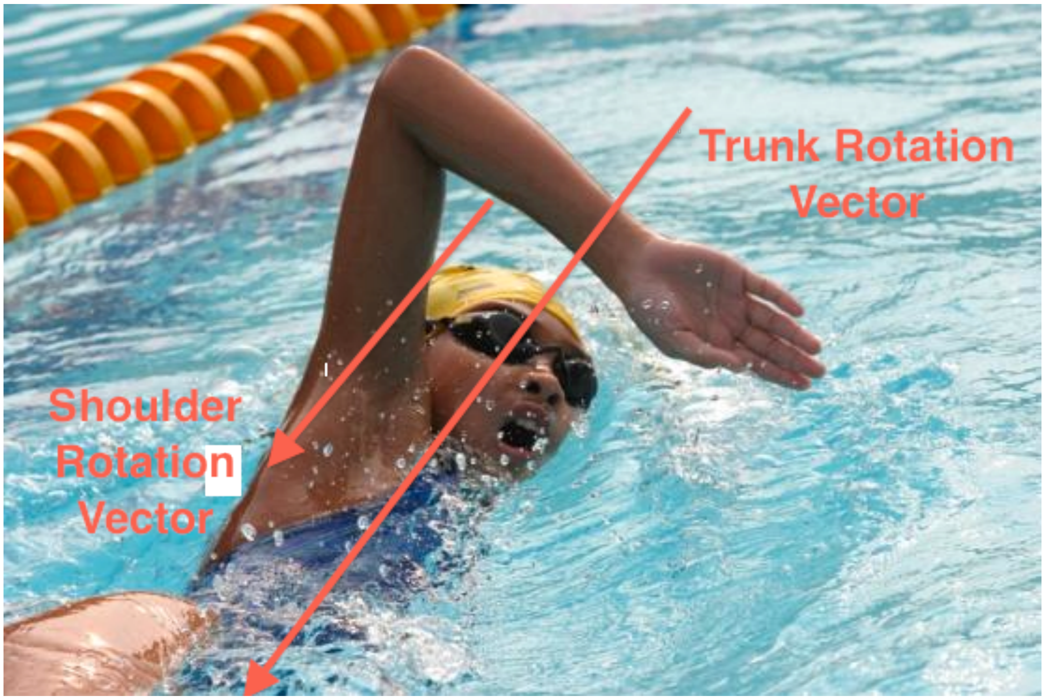

Figure 10. As trunk rotation stops, some of the angular momentum of the trunk is transferred to the recovery arm to assist in optimizing recovery position.

To review, angular momentum is a vector representing rotation around the long axis of the body in a specific direction. When the trunk stops its rotation, some of that momentum could be transferred to each of the arms- some to the lead arm and some to the recovery arm. When the trunk stops rotating some of that momentum could be transferred to the lead arm that is now tending to rotate in the same direction as the body rotation (Figure 10). The swimmer in Figure 10 is rotating to his right, producing CCW angular momentum. At the end of this rotation to the right, he will stop rotating his trunk and his angular momentum will be reduced to zero. Some of this angular momentum will be taken up by the leg kick, as described previously. Some of this angular momentum could also be transferred to the lead arm that is about to begin the power stroke. This momentum may be used to assist in positioning the lead arm for the catch and power stroke. This movement consists of shoulder lateral rotation that helps position the hand for the upcoming medial rotation of the power stroke.

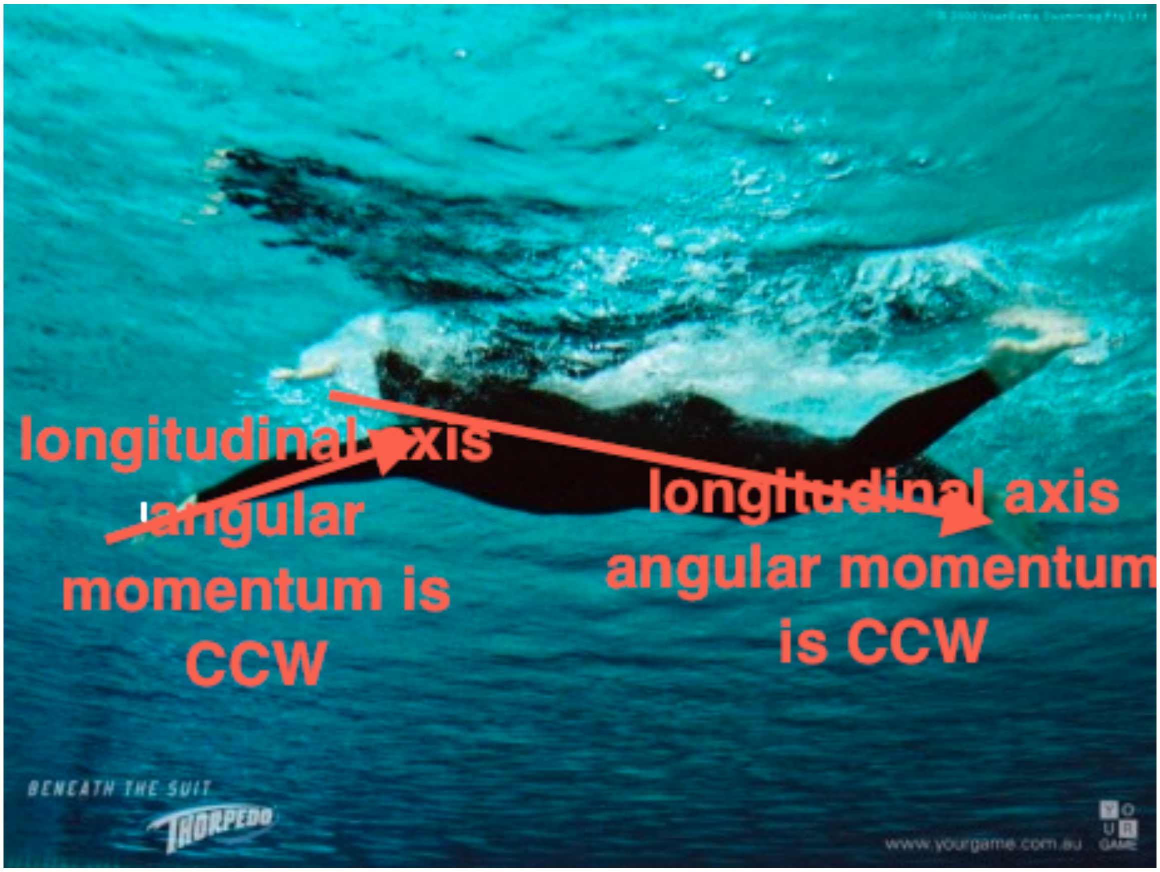

Figure 11. As trunk rotation stops, some of the angular momentum of the trunk could be transferred to the lead arm to help position the hand for the catch.

Potential issues with hip rotation

Although top swimmers tend to use a greater range of hip rotation in their strokes, it is possible for young swimmers to use too much hip rotation. A greater range of hip rotation is most likely to occur during the breathing cycle of the stroke, as swimmers have a tendency to rotate further to the side during breath taking. This will often produce less rotation to the other side and a poor arm recovery on the non breathing side due to lack of shoulder rotation. Young swimmers should be encouraged to perform similar ranges of hip rotation in both directions during the stroke. A greater range of hip rotation on one side may cause the legs to drop further underwater, which will produce greater drag and less efficient strokes. Excessive body roll is also associated with increased frontal resistance due to increased sideways motions of the arms and legs (Prins 2007).

In summary, swimmers are encouraged to use a large range of hip rotation as well as shoulder rotation during the front crawl stroke, as this will improve stroke efficiency and the power of each stroke, as well as swimming speed. Some of the power of the hip rotation may be transferred to the pulling arm. As well, the timing of the hip rotation is important, as the hip rotation must begin early in the stroke cycle in order to precede the shoulder rotation and produce a stretch on the trunk muscles.

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