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Coaching Applications

How Can Asymmetries in Swimming be Identified and Measured?

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Abstract

This paper reviews methods of identifying and measuring asymmetries in swimmers. A model of factors associated with testing asymmetries in swimming was used as a basis for discussion. The testing includes 'dry-land' assessment and assessment of the swimmer while swimming.

Introduction

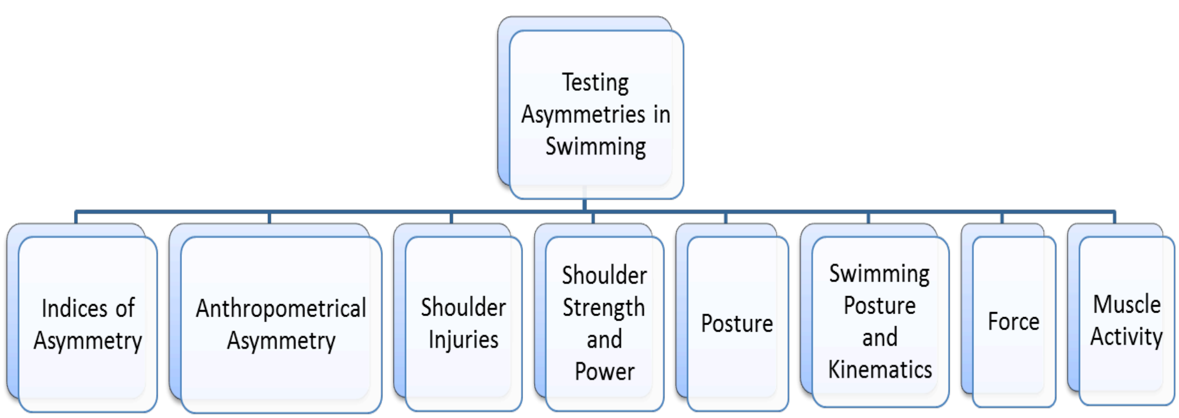
Four general questions need to be addressed with regard to asymmetries in swimming.

1. What are the likely causes of the asymmetries?
2. How can asymmetries be identified and measured?
3. Do the observed asymmetries affect performance?
4. What interventions can be administered to correct the asymmetries?

In the previous article we discussed the first question. In this one we look at how asymmetries can be identified and measured.

When considering what should be recorded or measured reference to the model below is useful.

Figure 1. A Model of Methods of Testing Asymmetry in Swimmers



Indices of Asymmetry

There are a wide variety of variables that can be measured to indicate asymmetry. To enable the measures to have meaning and comparability across individuals and populations, some indices have been developed. A simple formula is frequently applied to obtain a 'symmetry Index' (SI) as the difference between right and left sides as a percentage of the mean of the measurement:

$$SI\% = ((R-L)/(R+L))*2*100$$

A variation of the same principle is to divide by the maximum of the two values obtained for the right and left sides:

$$SI\% = ((R-L)/(\max(R,L)))*100$$

Anthropometrical Asymmetry

Asymmetries can present themselves in an individual's anthropometry, for example leg length discrepancies and differences in limb sizes, particularly in athletes competing in unilateral sports such as tennis. However, asymmetries also exist in bilateral sports such as swimming. Several methods exist for quantifying anthropometry and therefore anthropometrical asymmetries. The International Society for the Advancement of Kinanthropometry (ISAK) has a standardized protocol that allows detailed quantification of limb lengths, breadths, and circumferences alongside skinfold measures, using simple and portable equipment. A limitation of the ISAK method is that the standard protocol is to take measurements on only the right side of the body. Therefore, a repetition of the protocol on the left side would be required to measure asymmetries.

Technological advances have led to developments of more sophisticated equipment for anthropometrical assessment. For example, three-dimensional laser scanners use laser technology to scan the entire body surface and provide a detailed analysis of the body's shape and volume. A limitation of 3D scanners is that they are unable to provide a direct measure of the composition of the body, i.e. they are unable to distinguish between adipose (fat) and other body tissue.

However body composition can be assessed by 'dual-emission X-ray absorptiometry' (DXA) commonly pronounced as 'dexa'. The swimmer lies horizontally and an x-ray beam passes through the bone and soft tissue. DXA scans allow detailed assessment of both body shape and composition, including the bone density, mass and composition of individual limbs.

Shoulder Injuries

Given the cause and effect relationships among muscle and joint function, asymmetry, and injury of the shoulder joint, many assessement procedures have been developed. Researchers commonly use questionnaires as well as clinical inspection of posture and muscle/joint function, and isokinetic testing of internal and external rotation.

Questionnaire items include gender; age, years of competitive swimming; age of commencing competitive swimming; weekly training hours; average daily swimming distances; preferred hand; current status with respect to shoulder pain; history of shoulder pain; severity of shoulder pain.

Clinical inspection includes scapular winging; palpation for swelling; painful 'trigger' points and crepitus; active and passive range of motion (internal and external rotation and retroflexion). Checking for impingement (pinching) of the muscles and tendons against the bony framework of the shoulder is conducted using the 'Neer' and the 'Hawkins and Kennedy' impingement tests. Shoulder joints are also tested for laxity (looseness).

Shoulder Strength and Power

Force, torque (the turning force) and power (the rate of doing mechancial work) can be measured on land using dynamometers including sophisticated systems such as 'Kin Com', Cybex', and 'Biodex'. These machines can measure torques at preset rates of joint rotation. This is termed 'isokinetic' testing. Internal and external rotation strength are important measures for swimmers because there is a tendency for the internal rotators to become strong from swimming training. If this strength isn't balanced by an increase in the strength of the external rotators the swimmer may develop poor posture as well as increase the risk of shoulder injuries.

There may also be differences between right and left shoulder strength. This can affect swimming technique and timing. For example, it is common for the shoulder with the higher internal rotation strength to have a longer catch and pull phase duration than the other arm.

Posture

Postural alignment of the spine and body is often measured by land based measures including the angles between the vertebra indicating lordosis (excessive curvature of the lower spine when viewed form the side) and kyphosis (excessive curvature of the upper spine when viewed from the side) using two gravity-dependent inclinometers. One inclinometer is attached to the region of the 1st and 2nd thoracic spinous processes and the other to the region of the 12th thoracic and 1st lumbar spinous processes. While the angle of kyphosis may not affect the shoulder range, the joint/soft tissue stiffness associated with kyphosis could affect shoulder range.

Postural and spinal assessment can vary from visual assessment (e.g., New York State posture rating scale) to measurement using instruments. Key factors influencing the reliability of postural form include subject awareness of the assessment process. Therefore, distracting the swimmer's attention from postural assessment by having them walk may enable a more reliable assessment of their postural form than when standing still.

Measurement of lordosis and kyphosis is an important land based measure. However, the extent to which land-based posture is reflected in the posture adopted when swimming is unclear. The interactive effects of land based training, swimming training and competition on postures adopted during swimming requires investigation. As such, the capability of land based postural measurement in explaining dynamic postures in swimming must be established in conjunction with the effect on performance. This has major implications for evaluating the efficacy of training and/or postural interventions to improve swimming performance.

'Forward shoulder' posture among swimmers is associated with strengthening of the anterior shoulder muscles that is not balanced by equivalent strengthening of the posterior shoulder muscles. The test uses a 'double square' instrument to measure the distance of the front tip of the acromion process from the wall against which the swimmer stands facing outwards. The square is simply a builder's square with the square projections sliding along a graduated steel rule. One square is placed vertically along the wall and the other suspended vertically from the rule to make contact with the marked anterior tip of the acromion.

To measure scapular upward rotation as an indicator of shoulder mobility digital inclinometers or standard goniometers may be used. Inclinometers may also be used to measure thoracic kyphosis angle as the sum of the readings obtained from placing the inclinometer along the spinous processes of T1-T2 and T12-L1.

The movement of the thoracic spine contributes to, and is essential for, shoulder movement. Scapular dyskinesis, that is, abnormal movement of the shoulder blade, has also been found in some overhead athletes with shoulder pain, and in these cases it has been shown that there is a change in temporal characteristics of activation and recruitment patterns of the lower trapezius. Electromagnetic tracking devices (Innovative Sports Training, Inc., Chicago, IL.) may be used to quantify the resting position of the scapula in three-dimensions based on digitising anatomical landmarks with a stylus. The landmarks used are: spinous process of the 7th cervical vertebra, the flat portion of the acromion process bilaterally, and the midshaft of the posterior humerus bilaterally. Digitial photographs combined with digitising marked points on the body may be used to measure various angles to assess the posture in a seated position.

Tests of flexibility are highly relevant for swimming. For example, measures of the range of internal rotation when the arm is abducted to a horizontal position are commonly obtained as these are related to the ability of the swimmer to achieve a high elbow throughout the front crawl stroke cycle. Similarly, the range of rotation of the upper body around its axis is important in the pull phase of front and back crawl. Internal rotation is important for making an early catch with the elbow high throughout the stroke. A combination of thoracic spine extension, shoulder extension, and the ability to draw the shoulders back are important for achieving a high elbow position at the start of the stroke, recovery, and for attaining a streamlined position. Hip internal rotation and outward rotation of the lower leg are relevant for breaststroke swimmers to enable a large surface area to generate force in the kick. Similarly the range of motion of the hip and ankle are important in breaststroke.

Scoliosis of the spine (curvature of the spine when observed from behind the swimmer) can be measured by the Cobb method which relies on the ability to extrapolate lines parallel to the end plates of the vertebrae. While this can be done readily from X-Rays, it is less accurate when relying on palapation. However, visual inspection when the subject bends forward with legs together and arms hanging can reveal the presence of scoliosis as asymmetries in rib or paraspinal muscle height. Asymmetries of spinal origin can be evident as the hips or shoulders not being level, waist crease asymmetry, rib prominence, asymmetry with spinal flexion, and leg length discrepancy.

Swimming Posture and Kinematics

To examine the posture and kinematics (measures of distance, speed, angle etc) during swimming, digitisation of video recordings is commonly used. The methods can be categorised into two-dimensional (2D) approaches and three-dimensional (3D) approaches. Two-dimensional approaches can be conducted with just one camera placed with its optical axis perpendicular to the plane of the motion of interest. However, more than one camera is often used to obtain above and below water views or different perspectives simultaneously, for example, front and side views. 3D approaches require muliple camera views and calibration of the 3D space in which the motion occurs. If data from both below water action and above water action are sought, a minimum of four cameras (two above and two below), synchronised to sample at the same instant, are required.

2D methods are much less time consuming to set up, calibrate, and process the data, than 3D methods. However, 3D methods enable mathematical transformations to any perspective and reference frame whereas 2D analyses are limited in the flexibilty of the measurements that can be made. Further, 2D methods are generally less accurate and reliable due to errors in measuring any movement or positon that is not within the plane that has been calibrated. In both methods automatic tracking of marked landmarks is problematic, particularly for underwater views where a reduction in contrast and interference of the image with bubbles and turbulence are prevalent. Therefore, manual digitising, or a time-consuming combination of automatic tracking and manual digitising, is usually required for all but the most simple scenarios with small numbers of points to be digitised.

Examples of Two-Dimensional Video-Based Approaches to Studying Asymmetry

Various 2D studies by Didier Chollet and Ludovic Seifert and their colleagues have shown asymmetries in timing, indicated by differences in the 'Index of Coordination' between right and left sides. For example, breathing to the preferred side creates a greater asymmetry than breathing through a frontal snorkel, no breathing, and bilateral breathing. Breathing to the non-preferred side creates an even greater asymmetry. Similarly, arm dominance creates asymmetries in coordination and timing with the duration of the catch and pull phase being longer as a pecentage of the time for the stroke cycle for the dominant arm (51.7%) than the non-dominant arm (48.4%). Thus, 2D methods can be useful to indicate temporal asymmetries in the coordination of the stroke. Results of these studies also highlight the need to consider swimming pace when assessing the presence of asymmetries.

A battery of kinematic variables that change in response to strength deficits, including those induced by fatigue, in front crawl swimming have been established by Jacqueline Thow at the Centre for Aquatics Research and Education (CARE) of Edinburgh University. These variables include the duration of the pull phase, the depth of the pull, the body's horizontal alignment and the shoulder roll maximum angle. Simple measures of posture and limb positions are digitised from the video frames corresponding to meaningful and indentifiable temporal events. The measures can be obtained readily from commercial packages such as Dartfish, Quintic, and Silicon Coach. The battery of tests can be used to identify asymmetries and postural deficits during swimming and to assess changes over the course of a race due to fatigue.

A 2D video approach to quantify postures during the glide phase of starts and turns has been developed by Roozbeh Naemi and colleagues at CARE. The method employs automatic tracking of joint markers during the glide. A 'glide factor' indicating glide efficiency is calculated based on the rate of deceleration of the body during the glide. By asessing the postures in relation to the glide factor combined with qualitative inspection of the video using 'Glidecoach' software, feedback is given to swimmers to modify their posture and maximise glide performance.

Examples of Three-Dimensional Video-Based Approaches to Studying Asymmetry

Three-dimensional video techniques have been used to quantify asymmetries in, for example, the phase durations of front crawl swimming among elite and novice swimmers, and shoulder and hip roll, where the roll can be affected by breathing side preference even in non-breathing cycles. One of the advantages of using 3D analysis techniques to measure roll is that the roll of the shoulders and hips can be quantified separately. Researchers at CARE have shown that hip roll was much less than shoulder roll in freestyle swimming.

Force

The force produced by a swimmer throughout an individual stroke provides an insight into the effectiveness of their technique, as it can be used to explain the magnitude of intra-stroke velocity fluctuations that are evident within a swimming stroke. Methods of measuring force and power output in swimming may be categorised as direct or indirect techniques. The former includes measurement of swimmers actually swimming, and measurement of forces and power of simulated swimming actions on land using devices such as swim benches and swimming ergometers. Measurement of forces applied to the hand paddles can indicate asymmetries in the contributions of the arms.

Direct Measurement of Force in Swimming

Direct force measures in swimming generally involve some limitations leading to error. Swimmers can be tethered and the net force measured by force transducers connected to the tether. However, there is a concern that the forces generated by a tethered swimmer are considerably different from those generated in free swimming due to the different velocity of the swimmer relative to the water. Also, because the tether is attached to a point of the body, for example, the hips, it does not represent the effect of the propulsive actions on the acceleration of the centre of mass of the whole body. Despite the limitations of tethering techniques, they can be useful to indicate whether the limbs on one side of the body generate more force than those of the other side.

A popular method of measuring active drag is the Meaurement of Active Drag (MAD) system developed and applied extensively by Huub Toussaint, Peter Hollander, and colleagues. The system comprises a set of instrumented underwater plates against which a swimmer pushes using stroking actions resembling the front crawl. At constant speed the impulse applied (average force multipled by the time the force is applied and equivalent to the change in momentum of the swimmer) is equivalent to the impulse resisting the swimmer and therefore enables the active drag to be determined. Unfortunately, the swimmer's technique is altered by pushing against the plates, the mechanism of generating force differs from that of pushing against the water, and the kick is not considered as athletes hold a pull buoy between their legs. Further, only the front crawl can be analysed. However, the system is useful in quantifying the swimmer's resistive drag and indicating bilateral asymmetries in generation of force in front crawl.

A simple way to estimate active drag force in all swimming strokes is by swimming at maximum pace twice – once swimming in the usual way and once towing a hydrodynamic body that creates an additional, known resistance. The active drag is based on the difference in speed achieved in the two conditions. The limitation of this method is that the intra-stroke velocity fluctuations and therefore the drag force fluctuations aren't quantified.

Bruce Mason at the Australian Institute of Sport has recently developed a method of obtaining net forces acting on a swimmer throughout a stroke cycle with a reduced level of tethering, as well as towing the swimmer at a slightly higher velocity than their maximal swimming velocity. This method allows for quantification of active drag and propulsive forces throughout a stroke cycle. Using this method left to right asymmetries in the timing and magnitude of maximum and minimum net forces during a freestyle stroke have been revealed in many elite male swimmers.

Impulse generated by the hands during swimming can be indicated by pressure transducers attached to the swimmer's hands. These can be useful in showing bilaterally asymmetrical production of force and impulse generated by the upper limbs of swimmers while swimming in a relatively natural and unconstrained manner.

Indirect Measurement of Force and Power in Swimming

Given that net force of a swimmer is equal to the acceleration of the centre of mass of the body multiplied by the swimmer's mass, estimates of force can be obtained from motion of the whole body centre of mass. The accuracy of the estimate depends on the accuracy of digitising the body landmarks, the accuracy of the estimates of mass and centre mass locations within the body segments of individual swimmers, and the success in eliminating the small random errors in the digitising process by data smoothing.

Net forces can also be derived from velocity measured by 'velocimeters'. A sensor measures the velocity of a wire trace attached to the swimmer's hips. This method has been applied successfully by Carl Payton to assess bilateral asymmetries in the force produced by single arm amputee paralympic swimmers. The system can also be used to measure passive drag based on the rate of decay of velocity during the glide phase of starts and turns.

Muscle Activity

Muscle activity can be measured using electromyography (EMG). The level of activity of specific muscles is usually referenced to the activity during maximal voluntary contraction (MVC). This can enable differences in muscle activity relative to maximum between equivalent muscles bilaterally and also indicate the extent of involvement of muscles in particular movements and phases of the movement. Because the level of activity and the frequency content of the EMG signal change with fatigue, EMG can be used to assess which muscles are most susceptible to fatigue during a performance and whether there are diffferences bilaterally. EMG can also be used to assess which dry-land exercises are appropriate for developing strength and endurance in the muscles required for each of the competitive strokes in swimming.

Capture of EMG during swimming is problematic due to the need to waterproof the electrodes and the inability to telemeter data through water. However, recent technological advances have enabled the production of electrodes with built-in data storage capacity, for example the system developed by Kine (www.kine.is). This means that a swimmer can swim unencumbered by wires and the data can download once the electrodes are free of the water. This technology opens up the possibilities to study muscle function during swimming.