Asymmetries in Swimming: Where Do They Come from?

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Abstract

This paper reviews the etiology of asymmetries in swimming. A model of factors related to asymmetries was used as a basis for discussion of the etiology of asymmetries among swimmers. Asymmetries can include bilateral asymmetries and muscle imbalances leading to postural changes. The link between asymmetries and swimming performance is highlighted throughout.

Introduction

To perform at the highest level, swimmers must have both arms and both legs contributing optimally to maximize propulsion and to have body postures that minimise resistive drag (28). However, many swimmers fall short of their potential performance due to asymmetries in strength and/or flexibility. These physical asymmetries can mean that more work is done by arms and/or legs on one side of the body than the other. Asymmetries can also have a resultant effect upon technique and overall body posture increasing resistive drag.

In addition to bilateral asymmetries (left-right), both antero-posterior (front-back) imbalances and deficits in strength or flexibility can limit performance by reducing capacity to produce propulsive force, reducing range of motion or creating postures that do not minimize resistive drag (5). Strength and flexibility imbalances and deficits can also promote the development of injuries, for example, shoulder impingement syndrome, breaststroker's knee, and spinal problems (5, 6). Appropriate interventions may improve swimmer performance and reduce injury risk. The proposed interventions would include physiotherapy, strength and flexibility training programs, and technique corrections.

However, great caution must be exercised when making decisions about whether a swimmer's training program or technique should be modified. Four main questions must be carefully considered:

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 this paper we address the first question as a means of providing the background knowledge to underpin sound decisions with respect to questions 2, 3, and 4. To structure the discussion of the etiology of asymmetries we have developed the model shown in Figure 1.

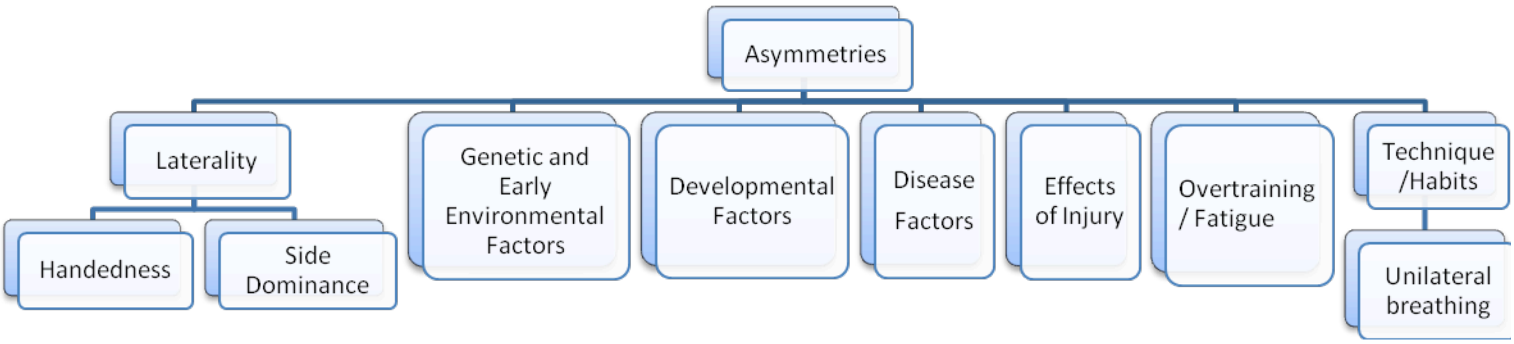

Figure 1: A Model of Factors Associated with Asymmetry in Swimmers

Laterality: Side Dominance and Handedness

The lateralisation of motor functions is a developmental process influenced throughout childhood and the lifespan by several factors including hemispheric specialisation and biomechanical factors (32). The tendency to use one side in preference to another originates from prenatal development of genetic origin and postnatal development. The former is related to the ontogenesis of the brain hemispheres during foetal development (22, 29, 46). Lateralisation in postnatal development becomes apparent prior to the learning of unilaterally oriented activities and sports. Ashton (3) has suggested that postnatal development has a stronger influence on handedness than prenatal development.

Having a preferred side can cause asymmetries both as a primary cause and as a secondary cause emanating from uneven strength and neural development due to favoured use of the dominant side. However, even without uneven use of sides in the sporting activity, asymmetries can exist. For example, although breaststroke does not encourage uneven development in terms of the demands of the activity, side dominance causes asymmetries in the kinematics of the leg kick among most breaststroke swimmers (10, 11). Given the natural tendency towards kinematic asymmetries in breaststroke swimming, Czabański (10, 11) advised coaches not to emphasise symmetry when developing technique in the breaststroke kick.

Other evidence of the influence of lateral preference on symmetry comes from activities and sports in which secondary developmental effects should be equivalent across sides. Carpes (7), in reviewing numerous studies of running and cycling, reported that asymmetries in kinematics and kinetics are very common despite the symmetry of the activity itself. Similarly, Drid (16) found that asymmetries in knee flexor strength were common among wrestlers, judo athletes, and untrained individuals, pointing to a need to introduce new training elements to improve performance and reduce injury risk.

Genetic and Early Environmental Factors

Variations from bilateral symmetry in traits that are normally symmetrical, often termed 'fluctuating asymmetry' (53), have been linked to environmental and genetic stresses (35, 36). Bilateral asymmetry in movement patterns can arise from these structural asymmetries emanating from the genetic and early environmental factors (54). Nuysing (31) reported high rates of asymmetry in infants manifest in shape, posture, and movement. One outcome is the development of a 'positional preference' in the first few months of life in which the infant's head is turned preferentially to one side. Consequently, development of active movement on the other side of the body is limited. Parental right handedness can influence this increase in head turning response and a similar increase in favoured leg usage during placement responses in newborns (9).

One of the stresses related to fluctuating asymmetry is growth rate. Wells (55) found that weight gain in the first six months after birth was positively related to fluctuating asymmetry in the traits of finger length, ear height, foot length and foot width. Thus, discrepancies in the size of the propelling surfaces in swimming may exist in some swimmers due to genetic and early environmental factors.

Structural asymmetries can emerge from, or be exacerbated by, asymmetries in mechanical loading (27). Compression, tension, and torsion affect bone growth, dimensions, and shape in addition to the internal structure of the bones. Thus, functional asymmetries in movement can continue to develop through the viscous cycle of cause and effect between structural asymmetry and movement asymmetry. For example, Perttunnen (37) found that bilateral discrepancies in lower limb length resulted in asymmetrical gait patterns manifest in variables including vertical ground reaction forces, phase durations, peak plantar pressures, and isometric torque. The loading was greater on the side with the longer limb and foot loading shifted to the forefoot on the side of the longer limb.

Developmental factors

Bilateral differences in the dimensions of upper and lower limb bones, both in length and diameter, occurs due to differential stresses and strains relating to lateral preference (4, 18, 24). Thus, the long bones of the dominant upper arm tend to be longer and thicker than those of the non-dominant arm. Further a gender effect has been identified (4) in which females tend to have greater asymmetries in length and the males greater asymmetries in diameters.

A tendency towards 'cross symmetry pattern' in which the lower limbs are larger on the opposite side to that of the dominant upper limb was suggested by Kanchan (24) being due to the contra-lateral muscle activity of the lower limbs in support of the actions of the dominant upper limbs. While it might be expected that swimmers who have specialized in swimming from a young age and therefore have quite even stresses on both sides, many swimmers may have a history of participation in sports in which upper and lower limbs may have developed differentially due to favoring one side.

Tourney-Chollet (51) found that the catch and pull phases of the front crawl stroke were longer for the dominant arm than for the non-dominant arm. The discrepancy was greater for sprinters than middle-distance and distance swimmers due to the sprinters seeking to apply larger forces with each stroke.

Psycharakis and Sanders (38) found asymmetries in shoulder roll that reflected breathing preference. Despite the swimmers swimming with no breathing, swimmers rolled more to the side that they prefer to breathe. Thus, side preference for breathing has a persistent effect on asymmetries even when the requirement to breathe is removed.

In addition to side dominance having a direct effect on swimming and the reinforcement of asymmetries through preferential use of dominant limbs, the possibility that swimmers may have uneven muscular development bilaterally due to the influence of other activities should be considered. For example, Rahnama (39) found that soccer players have weaker knee flexors in the preferred kicking leg than the non-preferred leg and muscle imbalance of the flexors and extensors of the preferred kicking leg was common. Thus, there is a possibility that swimmers who played soccer recreationally, or have had a history of playing soccer prior to taking up swimming, would naturally have a bilateral difference in the vigor of the upbeat and downbeats of the kick. Although the opportunity for muscular development on both sides should be equivalent given the symmetrical nature of swimming, the bilateral differences inherited from other activities may be reinforced rather than removed due to unwittingly favoring the stronger muscles. Other examples may include increased strength of rotations about the long axis in a dominant direction arising from sports such as hockey, cricket, and golf; and increased strength in the dominant arm from work activities and sports involving throwing.

Further, Diederichsen (12) raised the possibility that asymmetries in neurophysiology exist across dominant and non-dominant sides. These include faster conduction velocities of the nerve impulse on the dominant side and differences in fibre type due to long term preferential use. This has implications for the fatigue rate characteristics of dominant and non-dominant sides. Thus, asymmetries may emerge with fatigue due to change in the relative contributions of the two sides. EMG data of shoulder muscles during shoulder motion revealed that the dominant arm required less activation to perform a specific task. The implication is that the dominant side is set up in terms of its neurophysiology to perform the same task with less energy expenditure than the non-dominant side.

The laterality research literature suggests that the developmental influence of motor asymmetries may differ in fine motor skills when compared to physically demanding gross motor skills (49). However, the relative volume of research relating to gross motor skill asymmetries is much less than that investigating fine motor skills. Furthermore, analysis of coordination and control behaviour is typically absent from the fine motor skill literature. The notion of 'modulation of lateral preference' through targeted interventions in high performance sports such as swimming, where bilateral skill intervention may influence performance behaviour, has been suggested by Teixeira (50). Therefore, investigations into laterality status, gross motor skill asymmetries, and resulting coordination response in swimming, could provide an insight into the developmental and adaptive status of lateralized functions and resulting motor asymmetries.

Disease Factors

Disease factors can induce asymmetries in various ways including postural asymmetries, muscle imbalances and bilateral deficits, and flexibility limitations. These can influence the ability to generate propulsion, the ability to streamline, as well as the physiological capacity. Additionally, interactive effects are common. For example, despite similar peak knee extensor torque and dorsiflexor torque relative to matched controls, bilateral asymmetries in power output created more postural variability and fatigue when walking among those with multiple sclerosis (8).

In swimming, compensations by unaffected or less affected limbs for those with lower ability to contribute leads to asymmetries in technique and effects on the posture and alignment of other body parts through the 'kinetic chain effect'. This effect in swimming is particularly detrimental due to the effects of misalignment of body parts on resistive drag. Structural and functional asymmetries increase the difficulty of balancing torques about the three principal axes causing body parts to move out of alignment.

Children with cerebral palsy (CP) have muscle spasticity that increases stiffness and reduces mobility. Bilateral differences in stiffness have a strong effect, particularly among those with hemiplegic CP. Fonseca (20) showed that the propelling limbs adopt different movement patterns and strategies in walking. From our observations of Paralympic swimmers with CP, the bilateral differences affect the capacity to balance propulsive efforts and to correct for unbalanced rotational effects.

Spinal asymmetries in the frontal plane such as scoliosis of the spine, and in the sagittal plane such as kyphosis of the spine, have an affect on performance via several mechanisms including muscular function, technique, and postural alignment. Scoliosis can result from neuromuscular diseases, congenital deformities and, more frequently, may develop independently of other disease mechanisms (17).

Osborough (33) found that single arm amputees developed asymmetrical strategies of coordination, in terms of the timing of the phases of the stroke cycle, to optimize performance. The strategy was thought to involve maximizing the propulsion gained from the unaffected arm while the affected arm adopted the role of maintaining 'stable repetition of the overall arm stroke cycle'. Similarly, Satkunskiene (42) reported that many swimmers with a range of loco-motor disabilities developed extreme timing patterns to optimize performance in front crawl. Among veteran swimmers with Parkinson's disease, the increasing unilaterality of symptoms with progression of the disease creates increasing asymmetry in the motor patterns (14, 43).

Effect of Injuries

Asymmetries can develop as a consequence of injury. Furthermore, the effects of the injury on symmetry can persist following recovery. This finding is supported by studies in which no initial asymmetry exists. For example, Schiltz (44) found that professional basketball players with a history of lower limb injuries had asymmetrical knee extensor strength whereas those without a history of lower limb injuries had no dominant side effect. Hunt (23) showed that rehabilitation of an injured joint, in this case, a knee joint following injury to the anterior cruciate ligament, is hampered by reduced activation and compensation by the unaffected limb.

Injuries in swimming can develop or exacerbate asymmetries. Swimmer's shoulder, for example, inevitably reduces the forces applied by the affected shoulder leading to asymmetries in technique as well as favored development of muscles strength on the unaffected side and loss of strength on the affected side. Further, Swaine (48) found that the deficiency in muscle function due to 3.7 weeks of inactivity of a dominant arm following soft tissue injury persists for at least eight weeks after resumption of swimming training. Given the evidence cited, the concern with swimmers returning from injury is that the compensation by the uninjured limb could persist and lead to development of technical asymmetries and inequitable contributions of limbs that are sustained and reinforced to become habit.

Overtraining and Fatigue

Overtraining is a general term that covers situations in which the training load does not allow sufficient time for the body to recover and repair itself for continued activity (21, 25). From a physiological perspective it incorporates aspects relating to too high intensity and/or volume of training, inadequate recovery time, and increasing training load too rapidly. From a physical perspective it incorporates the inability for tissues such as muscles, cartilage, tendons, and protective sheaths to recover from the micro-trauma caused by training. This results in inflammation and release of enzymes that cause structural damage to the tissue and precipitates overuse injuries (13, 25). Additionally the soreness and loss of function reduces output of affected muscles and associated joints and limbs leading to asymmetries in performance and compensation by less affected parts.

While fatigue is a symptom of overtraining, some fatigue is normal and necessary to stimulate adaptive responses to training (28). Therefore, there are periods of swimming training sessions in which the swimmer's technique is affected by fatigue. These effects are considerable and are reflected in changes in many technique variables (1, 2, 34, 47, 52). The problem for the swimmer and coach is to ensure that the changes when fatigued do not become habit and a long term part of the technique. It is also essential that a swimmer avoids development of asymmetries during periods of fatigue that might become habit.

One goal of training for swimmers and coaches is to maintain good technical form, posture and alignment during periods of fatigue so that performance isn't adversely affected in the closing stages of a race. This is likely to require attention to dry land training to correct imbalances in muscle strength and propensity to fatigue. Differences in fatigability are common between dominant and non-dominant sides. For example, spectral analysis of EMG signals has indicated that the upper trapezius, important for maintaining good posture, fatigues more readily on the non-dominant side (19).

Technique/Habits

Muscle function changes in response to the demands of the activity. In many sports there are considerable differences in the demands across sides of the body and between agonists and antagonists involved in the actions. This is most obvious in sports in which there are specific and different roles for different limbs and muscles. For example, long jumpers develop asymmetries in the joint torques of the takeoff and non-takeoff lower limbs (26). Professional baseball pitchers have differing ranges of motion between the elbows of the dominant (pitching arm) and non-dominant arm (56). The activity of pitching reduces the range of motion of the elbow. However, there was no evidence that the reduction in range of motion reduces performance in baseball pitching. A separate study of shoulder mobility of baseball players also revealed adaptive changes resulting in differences between the pitching/throwing shoulder and the non-pitching/throwing shoulder (15). Scapular upward rotation and glenohumeral external rotation were greater in the pitching/throwing shoulder while glenohumeral internal rotation was less than in the non-pitching/throwing shoulder.

In sports in which the shoulders are used forcefully through a large range of motion, such as swimming and kayaking, with no deliberate side bias, adaptive changes could be expected to occur evenly to both sides. However, the adaptive changes may not necessarily be entirely beneficial. McKean and Burkett (30) found that kayak paddlers had reduced internal and external range of motion compared to other populations and the pull/push strength ratio differed from that of the normal population. In swimming, swimmers and coaches are very aware of the need to maintain shoulder joint flexibility to maintain performance and minimize injury risk (5). Thus, among serious competitive swimmers, the tendency to develop adverse adaptive responses to training may be largely offset by the emphasis on dry land training with appropriate strength and flexibility exercises.

However, in general, the maintenance of muscle balance may be achieved less well than the maintenance of shoulder joint range of motion. The technique in all swimming strokes involves pushing forcefully against the water with internal rotation of the shoulder. Conversely there is little use of external rotation against resistance. Consequently, swimming tends to strengthen the muscles involved in internal rotation without equivalent strengthening of the external rotators (28, 40, 41). There is a tendency towards development of the pectorals, particularly in breaststroke swimming, leading to kyphosis (43). These muscle imbalances produce postural changes that may affect performance as well as predisposing the swimmers to shoulder injuries. Rupp (41) found a significantly lower external/internal rotation ratio of peak torque among swimmers than among non-swimmers matched with the swimmers according to age, gender, and side dominance. Further, Ramsi (40) revealed a worsening of the ratio over a training season. Therefore coaches and swimmers must ensure that muscle balance is maintained by emphasizing training of the muscles that externally rotate the shoulder.

It may be difficult to assess whether asymmetries in stroke technique are the effect of development asymmetries due to laterality or due to high training volume. In any case, asymmetrical characteristics of technique are likely to reinforce or perpetuate the observed asymmetry and related outcomes including muscle imbalance. Large volumes of training may also exacerbate the asymmetry. The possible corrective influence of targeted interventions requires further investigation (49).

One of the major asymmetries in front crawl technique arises from the natural tendency, related to side dominance, to favor one side when breathing (38, 45). In the

Seifert (45) study, asymmetries in phase times of the stroke were most apparent when breathing on one side and increased when swimmers were required to breathe on their non-preferred side. Conversely, when swimmers swam with bilateral breathing, without breathing, or breathing with a snorkel, asymmetries were reduced. Thus, the authors recommended training using symmetrical breathing patterns to reduce the tendency towards asymmetrical patterns that arises from unilateral breathing patterns. This is supported by the findings of Tourny-Chollet (51) that the asymmetry related to side dominance was less among swimmers who breathed bilaterally.

Therefore, in light of the literature, targeted technique interventions may reduce asymmetry effects. However, the evidence for positive influence of interventions is sparse. To date, many questions remain unanswered with respect to how asymmetries affect performance and injury risk and how amelioration of asymmetries can be achieved optimally.

Conclusion

This paper has provided an insight into the many etiologies of asymmetries among swimmers. This insight provides a background for further reviews to address the remaining questions and major categories of questions identified in the introduction - how can asymmetries be identified and measured? Do the observed asymmetries affect performance? What interventions can be administered to correct the asymmetries?

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