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**Handout**

# A Biomechanical Analysis: Movement on Land – Movement on Water

***Article by Rich Jemmitt published in CALA Wavelink newsletter Winter 1994***

## LAND BASED TRAINING

On land there are two forces which together produce human movement: the force produced by a muscular contraction and the force of gravity.

Muscular contractions, regardless of where they occur, are either static or dynamic. Static muscular work refers to isometric contractions where no observable shortening of the muscle occurs. In real life these contractions act to stabilize a body part. Dynamic muscular work refers to the concentric: or eccentric: contractions which are seen with movement of a body part.

## WATER BASED TRAINING

The standard definition of concentric and eccentric; work involves the shortening or lengthening of a muscle while it contracts-concentric work referring to contractions where a muscle lengthens while body fat. Archimedes demonstrated contracting. The idea that a muscle can lengthen as it contracts can at first seem oxvmoronish. If we consider concentric: and eccentric: contractions from a gravity perspective then they begin to make more real-life sense.

Gravity is a constant challenge to the muscular system. On land, muscles either try to move a body part against the downward pull of gravity or control the rate at which gravity causes a body part to drop.

Concentric contractions move body parts against the pull of gravity and must therefore generate energy to do so. Eccentric contractions are used to control the rate; at which gravity moves a body part downward. In this ease the energy of movement is `generated' by gravity. If eccentric; activity did not occur an arm lifted to 90° would drop like a stone the instant the deltoid/supraspinatus complex was `turned off'. It is because of our muscle's ability to absorb the energy developed through gravity that we can control our movements as well as we do.

Gravity is not the only force eccentric contractions attempt to control. When a concentric contraction rapidly accelerates the movement of a body part, eccentric contractions in the antagonist muscles must be developed to decelerate or forces act together to produce human movement on land. It is not an overstatement to say that eccentric activity is primarily responsible for the myriad of wonderfully fine and complex movement patterns capably produced by the human body.



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# A Biomechanical Analysis: Movement on Land – Movement on Water

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## WATER BASED TRAINING

A water environment imposes very different challenges to the muscular system than does our more typical terra firma environment due to its unique physical properties. The most notable are buoyancy, drag and hydrostatic pressure.

### Buoyancy

The ancient Greek mathematician Archimedes is credited with discovering buoyancy. Buoyancy provides an upward lift to any submerged or floating object and thus counteracts the force of gravity. The apparent decrease in the force of gravity results in an apparent weight loss for the floating or submerged object. The degree to which a person's body becomes more `weightless' in water due to buoyancy depends on three interactive factors: the degree to which the body is submerged; the amount of body fat relative to total body mass; and the position of the body in the water. If you were to stand in water submerged to the neck, you would experience an apparent weight loss of 90%. A 100 kg. person would only need to support 10 kg. of body weight through muscular effort while buoyancy would support the other 90 kg. This has obvious positive implications for the use of aquatic environments in retraining those with certain gait pathologies or extreme muscular weakness. This apparent weight loss in water has been shown to be directly related to the person's percentage of body fat. Archimedes demonstrated that both the volume and density of an object affect he degree to which buoyancy exerts its upward force on that object. High body volumes are associated with high buoyancy while high body densities are associated with low buoyancy. Thus, if two people having exactly equal volumes were to get into the same pool the person with the lower body density (less lean body mass) would be more buoyant. In other words, fat floats better than muscle. Fatter people will experience a greater apparent weight loss in water than those with leaner physiques. The distribution of body fat may affect a person's performance in certain water activities. In recent years female competitive swimmers have more closely duplicated the best times of male swimmers than have elite female runners duplicated the times of their male counterparts. As well as improved conditioning and training of female swimmers it is thought that as their fat tends to be distributed in the thighs the legs of female swimmers remain more horizontal in the water than the leaner, more `sinkable' legs of male swimmers. This results in a more streamlined, efficient posture in the water and perhaps, faster swim times. Two issues regarding hydrostatic pressure are of interest to aquafitness leaders.
The final factor is the position of the body or body part in the water. When we stand in chest deep water, with our feet generally flat on the bottom of the pool, buoyancy is minimal. If we were to lie horizontally in the same depth of water, however, we would

be more likely to float, depending on our overall body composition and fat distribution (remember, these factors are interactive: not isolated). The buoyant force acts straight upwards as if striking any horizontal surface in or on the water at right angles. The greater the horizontal surface area of a person's body or body part, the greater the real effect of the buoyant force acting upon it. If we position our body or some part of our body as horizontally as possible, the lift or buoyant force is greater. Consider again the previous vertical versus horizontal posture example. When standing only our feet are horizontal and thus the total horizontal surface area with that posture is small. When lying on the surface the horizontal surface area is great and the buoyant force is experienced more fully. A person will therefore weigh more standing up than lying horizontally in the same depth.

## Drag

When an object moves through almost any medium it experiences a resistive force caused by contact with the particles that make up the medium. A runner is slowed down somewhat because she is constantly `hitting' molecules of oxygen, nitrogen and carbon dioxide. Similarly, a swimmer is slowed down by contact with water molecules. Generally, drag increases as the density of the medium increases. In a vacuum, drag would be non-existent while in a solid it would be maximal (and painful). Drag also increases as velocity increases because the moving object contacts more particles in a given amount of time. Similarly, if the frontal surface area of the object is increased the object contacts more particles per unit time and drag is again increased. In the water a twofold increase in velocity results in a fourfold increase in the resistive force of drag. The faster we move, the harder it is to do so. If we were to slice the water with our hands, there would be less drag encountered than if we pushed the water with flat palms. This of course explains why the use of webbed gloves or hand paddles increases the muscular work of movement in water. As mentioned earlier, the buoyant force acts directly upwards at right angles to the water's surface. It resists any movement acting directly downwards. When we move a body part directly downwards in the pool, the combining resistive forces of drag and buoyancy create more resistance to movement than would he experienced by movement at the same speed in some other direction. Buoyancy assists movement toward the surface and resists movement toward the bottom. Drag resists movement regardless of the direction of that movement.

## Hydrostatic Pressure

Conceptually, hydrostatic pressure can be thought of as a construct similar to that which produces drag. It is a function of the number of particles of the medium per unit volume. Unlike drag, it is also a function of the depth of the medium. In a vacuum there are no particles; thus, there is no pressure regardless of the depth of the vacuum. For a given depth, say 100m., pressure will increase as the medium changes from gas to liquid to solid with maximal pressure exerted by a solid. When discussing the pressure exerted by a liquid those in the scientific; community speak of hydrostatic pressure, but the concept is really no different from air pressure. Hydrostatic: pressure increases as one moves into deeper water. Two issues regarding hydrostatic pressure are of interest to aquafitness leaders. If you are working with a client who requires therapy for some condition involving swelling, optimal results will be obtained at deeper depths. Remember, as depth increases so does the `inward' force of hydrostatic pressure - it is this force which helps resolve swelling. Secondly, if a client suffers from severe respiratory muscle impairment, these muscles may not be strong enough to expand the chest if the person is standing in water deep enough to submerge the thorax. This is obviously a contraindication to deep water therapy but not to writer exercise which takes place in hip deep water. Of course, if the person is challenged from a respiratory standpoint, the intensity of the program must be altered accordingly.

**When we move into and in the water, the interaction between muscular and gravitational force changes significantly.**

## MOVEMENT ON LAND - MOVEMENT IN WATER

The downward pull of gravity is markedly reduced because of the buoyant force upwards and subsequently, so is the need for eccentric work. It is as if the buoyant upward force takes over some of the work formerly done by eccentric muscular effort. In the water, concentric; contractions become much more predominant than on land.

### *Example 1: walking slowly in chest deep water*

As I walk in water submerged to the chest buoyancy acts upwards to reduce the pull of gravity. I need less eccentric quadriceps control to lower my leg to the bottom and to accept weight onto the leg without the knee buckling. My velocity is slow thus drag is minimal and does not add too much to my work in getting my foot to the bottom. The majority of my muscular work remains eccentric quads in terms of lowering the foot to the bottom.

### *Example 2: walking rapidly in chest deep water*

As the depth of the water is still the same, buoyancy provides the same amount of assistance against gravity and my need for eccentric; control is therefore unchanged.

My rapid pace has increased the amount of drag working against me as I move my leg toward the bottom of the pool. Remember that drag increases dramatically as speed increases and that against downward movement, buoyancy and drag combine to resist movement even more strongly. In this case I may actually need to work concentrically with my hamstrings & glutes to get my foot to the bottom primarily duo to the increase in drag brought about by my increased speed of movement. (If we compare rapid walking on land to rapid walking in chest deep water, it remains primarily an eccentric quadriceps activity on land and becomes primarily a concentric hamstring & gluteal activity in the water.)

## *Example 3: lateral shoulder raises in neck deep water, moderate speed, no hand paddles*

This movement begins with the arms at the sides and the elbows extended. As we lift the arms toward the surface at a moderate speed, gravity pulls downward but the buoyant force acting upward assists our deltoid/supraspinatus complex in concentrically performing the task. In fact, as the arms move from their vertical starting position to their horizontal ending position, buoyancy acts more strongly because the horizontal surface area of the arm increases as it approaches shoulder height. The speed is moderate so drag will cause the muscles to work somewhat harder than if the speed were slow. In returning the arms to the starting position or lowering them, gravity still pulls downward but now both buoyancy and drag act upwards. The shoulder adductors must now work concentrically against this upward force to bring the arms down again.

## *Example 4: lateral shoulder raises in neck deep water, moderate speed, with hand paddles*

The only variable changed is the frontal surface area of the hand. Only the degree of resistance to both the upward & downward movement will change. Recall that drag works against movement regardless of the movement's direction. By increasing the amount of drag we force the muscles to work harder. The same muscles will be active at each phase but they will be required to work harder if the same speed is to be maintained. (i.e., If we compare lateral shoulder raises on land to those in neck deep water, we find the following: In land the deltoid/supraspinatus complex works concentrically to generate energy against the pull of gravity to lift the arms to a horizontal position. The same muscles act eccentrically to absorb the energy of gravitational pull as the arms are lowered. In neck deep water at a moderate speed, the deltoid/supraspinatus complex again works concentrically, generating energy during the up phase, to draw the arms down against both drag and buoyancy, the shoulder adductors, pec major & lat dorsi, must work concentrically during the down phase.)

On land, the same muscle which lifts a body part concentrically against gravity will lower that body part eccentrically, offsetting the downward pull of gravity to produce a controlled movement. If an agonist muscle rapidly accelerates a body segment via concentric work, the antagonist muscle will often be used eccentrically to decelerate or control that movement.

In the water these relationships are often altered. An agonist muscle which produces upward concentric movement assisted by buoyancy but resisted by both gravity and drag will not always be active eccentrically during the opposite movement. Often the antagonist muscle will need to become active to generate energy against the additive forces of buoyancy and drag to produce the desired movement. If this antagonist accelerates a body part rapidly the agonist may need to do some eccentric work, as on land, to decelerate the segment. The necessary deceleration is partially assisted by drag and possibly buoyancy thereby decreasing the amount of eccentric force required from the agonist muscle.

## Weight versus Mass

I have used the term `weight' often in this article and the difference between weight & mass should be discussed as it applies to water-based exercise. Weight is a variable entity as we have seen earlier. A per son's weight will vary depending on the strength of the gravitational pull. Mass however is a constant and never changes. Even if a hand weight used for strengthening in an underwater environment is somewhat `weightless' due to buoyancy, it still requires increased muscular force to move that extra mass. This is most important in working with clients who might have pathologically challenged muscular systems remember that it still requires x amount of force to move a 10 kg. mass regardless of whether that mass is under water, on land or on the moon.