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ORIGINAL RESEARCH

AQUATIC GAIT MODULATION BY RESISTANCE AND ITS EFFECTS ON MOTOR BEHAVIOR

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Abstract

The aquatic environment causes many modifications in motor gestures, changes directly linked to the characteristics and physical principles that govern this medium. Gait is a functional motor act acquired in childhood, repeated and automated. The objective of this study was to identify how the resistance of the water interferes with the motor behavior in aquatic gait. Methods: a review was carried out using the Bireme database (LILACS, IBECS, MEDLINE, Cochrane Library, SciELO). The articles studied showed that gait could be defined and influenced by its historical evolution, the variables of the water environment (depth, density, flow) and the characteristics of the body being displaced (shape, composition, weight, etc). The findings point to a somatosensory response that is enabled by the action as a function of the composition, shape, weight, etc.

Key words: water; gait; kinematics; motor activity.

INTRODUCTION

Studies involving human movement in an aquatic medium have great relevance on research concerning training and rehabilitation, due to the different physical and mechanical properties that this medium imposes[1]. Of these properties, the resistance of the water stands out, a determinant characteristic when one considers the diverse displacements possible in this medium.

The displacement performance in an aquatic medium can be described by the interaction the body has with the water, aimed at overcoming the resistance offered by the water. One of the most influential negative resistive effects is the hydrodynamic drag, defined by the action of the water in opposing displacement of the immersed body[2]. This drag is enabled by the relationship between the shape or area of frontal contact of the immersed body and by the speed with which the body displaces itself[3,4], a relationship which occurs in quadratic proportions, that is, the resistance increases exponentially with increment in velocity[5].

Another effect to be considered is that of viscosity, which results from the interaction and grouping of the molecules according to their thermal agitation[2], which depends on the temperature of the water, turning into a factor that makes displacement in the medium easier or more difficult[6]. In addition to the factors cited above, turbulent flow, characterized by the disorganized movement of the water, also acts as an element resistive to displacement in this environment, although its action will favor displacement when the direction of flow is equal to that of the movement, and make it more difficult when contrary to the movement[7].

The resistive action of an aquatic medium also provides what is known as active drag - a propulsive movement created by the body itself during displacement due to movement of the limbs. Such a propulsive movement can be explained by the following theories: the first is based on Newton's third law (action and reaction) and establishes propulsion of the bodies due to the reaction of the water to the movement (on pushing the water backwards, this exerts a force of equal magnitude

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to push the bodies forward; the second theory is based on Bernoulli's principle which defines the existence of a sustaining force created by the difference in pressure between the opposite sides of the hands when moved "sweeping" the water: a greater pressure on the palm and lower pressure on the back of the hand (the pressure difference produces a sustaining force perpendicular to the direction of the flow of water over the hands, pushing the body forward), subject to the influence of the angle of action of the hands in movement, this being principal or auxiliary[3].

One of the possible forms of displacement in an aquatic environment, which comes under the action of the properties described above, is gait: a fundamental motor ability and the habitual motor gesture automated, composed of integrated movements of the body and defined by successive disequilibria of the body which determine the movement forward[8]. In normal human beings, the gait pattern is acquired and developed in infancy, such that the sensory motor system becomes highly adapted and automatically generates a repetitive group of motor control commands for the segments, allowing the person to walk without conscious effort[1].

Although this is a complex, automated act of daily life, gait can suffer interference and modification of the patterns of movement according to the type of surface and environment where it is carried out[9]. For the study of gait, the parameters are used from the biomechanical (linear and angular/ articular kinematic variables: speed, displacement, acceleration, etc.), motor behavioral (orientation or postural control, manipulation and locomotion – movement patterns, ability level) viewpoints and by the interaction between them.

Angular displacement, for example, describes the amplitudes of the articular movements during gait. The kinetic variables include the ground reaction force and the moments of force, power and work of the articulations during movement[10]. The kinematic, dynamic or neuromuscular modifications are what determine the interference in the medium in which the movement takes place[10], allowing for conclusions and proposals for the mechanism of this influence.

In the aquatic environment, as on land, gait is carried out with the individual in the vertical position, with variations in direction and sense[2]. Due to the physical properties of the water described above, the behavior of the gait variables in the water are differentiated from those on land and also between different depths of water[11], determining adjustments that vary according to the characteristics of the individual and his age[12]. Gait can be facilitated if the water temperature is higher, hence decreasing the viscosity; for its part, active drag can determine greater gait efficiency according to the application of the propulsive limb – in this case, with the help of the arms. Thus, be it facilitating or offering resistance to the execution of the movements, the aqueous medium demands that adjustments be made in relation to the terrestrial motor behavior of the individual, such as greater activation of the spinal and femoral rectus erectors[13].

The observable adjustments defined by the aquatic and terrestrial media can be evaluated from the biomechanical and motor behavior viewpoints. To date there has been greater emphasis on studies from the biomechanical perspective, with few studies that argue from the motor behavior viewpoint specifically in the aquatic medium.

Thus the objective of the present study was to verify how aquatic resistance promoted adequacies of motor behavior in aquatic gait.

METHODS

This was a survey of the databases carried out in the period from September 2010 to November 2011 using the Bireme databases (covering the following databases LILACS, IBECS, MEDLINE, Cochrane Library, SciELO), with the objective of finding studies related to gait in aquatic and terrestrial environments. Initially the following keywords, found in the DeCS system, were chosen: flow mechanics, gait, biomechanics, motor behavior and physical aquatic, combined in groups of three words for the survey. This choice of keywords resulted in 68 articles, of which 35 were excluded and the remaining 33 did not cover studies on gait in an aquatic environment, this being the reason for abandoning this survey.

New searches were carried out with the keywords *water, walking and kinematics*, used in a single search. Initially 36 publications were identified, potentially eligible for the present review. The inclusion criteria were: availability of free access online or via the Capes gateway, research carried out with human beings, papers published in the last 10 years, studies published in Portuguese or English and studies carried out in both aquatic and terrestrial media.

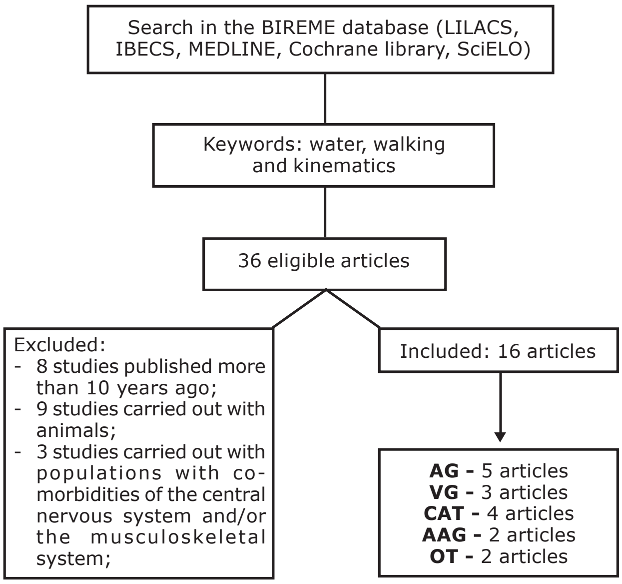
Articles that, from the reading of the titles and summaries, conformed with the exclusion criteria, were then excluded, as follows: studies carried out more than ten years ago (8 articles), those carried out with animals (9 articles), and studies with populations with co-morbidities of the central nervous system and/or musculoskeletal system (3 articles).

The remaining 16 articles were divided at random, in equal numbers between the authors, grouped according to research objective and described in chronological order.

RESULTS

The studies found were grouped according to their research objectives in addition to their chronological sequence: **AG** – aquatic gait, muscular and kinematic activities (5 articles); **VG** – gait on variable terrains with biomechanical differences

(3 articles); **CAT** – comparison of aquatic and terrestrial gait (4 articles); **AAG** – anthropological analysis of human gait (2 articles); **OT** – others (2 articles).



The articles in group AG showed there was an increase in muscular activation in the aquatic environment due to: movement load and speed[5]; water flow speed and stability[14]; displacement and posture[13]; positioning of the upper limbs, influence of weight, immersion level, body area and speed[11].

With respect to variations in terrain and mechanical differences (VG), the articles showed that the interferences that altered the movement parameters could be: the slope and modification in composition of the surface moved on[15]; the addition of a double task, cognitive and/or concomitantly motor, with or without adjustment by feedback[16]. However, results were also found that showed similarity in behavior for the kinematic factors between irregular and flat surfaces.

When the two types of media in which gait can be carried out, aquatic and terrestrial, were compared (CAT), the articles presented a variation in articular moments according to the difference in body load, influenced by the media[6]; the reduction in the vertical force values[6] and impact of the water[18]; the increase in articular moments and muscle activations as a function of the increase in displacement velocity in the water[19]; the reduction in articular amplitude of the movement in the aquatic environment[19,18] or its maintenance[20]; the difference in articular action of the ankle in aquatic gait – flat support[18] and the increase in plantar flexion in the rest of the phases[19]; the variation between the media of the characteristic of execution speed[18]; the increase in muscle activation to move the body forward in water, against the resistance[6].

Finally, the articles that established an anthropological analysis of human gait (AAG) defended that bipedalism originated in order to improve locomotion: reducing the costs of walking on four supports, such that great distances were covered quickly with less wastage[21]; in the exchange of bipedal locomotion, but with knees and ankles flexed (wasteful in terrestrial gait but facilitating in the aquatic environment), for erect locomotion[22].

Figure 2: studies found, organized by year, type and database

Study	Year	Type of study	Database where found
Miyoshi *et al.* **AG**	2006	experimental	MEDLINE
Roesler *et al.* **AG**	2006	experimental	MEDLINE
Chevutschi *et al.* **AG**	2007	experimental	MEDLINE
Masumoto; Mercer **AG**	2008	review	MEDLINE
Kotani *et al.* **AG**	2009	experimental	MEDLINE
Cham; Redfern **VG**	2002	experimental	MEDLINE
Wade; Redfern **VG**	2007	experimental	MEDLINE
Verhoeff *et al.* **VG**	2009	experimental	MEDLINE
Miyoshi *et al.*; **CAT**	2009	experimental	MEDLINE
Miyoshi *et al.* **CAT**	2005	experimental	MEDLINE
Barela *et al.* **CAT**	2006	experimental	MEDLINE
Barela; Duarte **CAT**	2008	experimental	MEDLINE
Preuschoft **AAG**	2004	review	MEDLINE
Kuliukas *et al.* **AAG**	2009	experimental	MEDLINE
House *et al.* **OT**	2004	experimental	MEDLINE
Prendergast; Lee **OT**	2006	review	MEDLINE

DISCUSSION

For enchainment, the articles were discussed according to the groups based on their research objectives and also the organization of the results.

The first studies described considered the characteristics and behaviors of aquatic gait (AG). Miyoshi *et al.*[5] pointed out there were variations in muscle activation that could be influenced by the weight of the body immersed and by the speed with which it displaced itself. The first influence is described as a reduction in somatosensory input related to the action of pushing, whereas the second is described as an increase in the commands coming

Figure 3: description of the objectives, methods and outcomes for AG articles – aquatic gait, muscle activity and kinematics

Study	Year	Objective	Method	Outcome
Miyoshi *et al.* **AG**	2006	Investigate the activations related to the synergetic muscles of ankle plantar flexion when subjected to walking in water.	10 healthy volunteers walking in water with 3 different loads and 4 different speeds; water level up to the armpits. EMG of the gastrocnemius and soleus muscles.	The results showed that the EMG activation of the soleus muscle depended more on the load for walking than on the speed in the water; activation of the gastrocnemius muscle depended more on speed.
Roesler *et al.* **AG**	2006	Analyze the components V and AP of the ground reaction force (GRF) during aquatic gait and compare the influence of speed and position of the upper limbs (UL) on the GRF components.	28 men and 32 women, height 1.6-1.85m, divided into 3 groups according to immersion level. Gait on a platform (at a depth of 1.3m) with 2 load cells attached, in 4 different positions: speed (slow/ fast) and UL position (under/out of the water). Analysis of the vertical and anterior-posterior components of GRF.	Comparing the values for gait with the UL under and out of the water, the results were significant for UL out of the water. The vertical component of GRF varied from 20 to 30%. The component AP of GRF varied from 8 to 20% considering the three immersion levels.
Chevutschi *et al.* **AG**	2007	Define the muscle activation degree during gait, so as to help in the choice of exercises for the clinical practice of hydro-therapy.	7 healthy women; comparison of the EMG of the femoral rectus, soleus (right leg) and the lumbar contra lateral spinal erector.	No differences were found between the two situations neither for the amplitudinal peaks nor in the shape of the patterns. The speed of the gait cycle was reduced in the water, walking in the water increases the activity of the spinal erectors and activates the femoral rectus to levels close to or greater than those found for walking on land.
Masumoto; Mercer **AG**	2008	Systematic review – EMG activity in the methodologies for measuring muscle activity during aquatic locomotion, summary of the findings for muscle activity during aquatic locomotion.	Systematic review – EMG activity in the water.	Methodological considerations: use of impermeable material for making measurements in the water.
Kotani *et al.* **AG**	2009	Measure muscle activity during gait so as to estimate the distance for safe evacuation when there is a flow effect and changes in speed.	8 healthy men; walking against the flow of the water at 4 different speeds (0, 0.47, 0.76, and 1.12 m/s); walking on dry land. EMG: femoral rectus, lateral vastus, femoral biceps, gastrocnemius, anterior tibial, gluteus medius.	Activation of the gluteus medius increased with flow speed, suggesting that the objective tends to be to stabilize the pelvic area to avoid falls; the anterior tibial showed greater muscle activation with increase in flow speed.

Figure 4: description of objectives, methods and outcomes for VG articles – gait on variable terrains with biomechanical differences

Study	Year	Objective	Method	Outcome
Cham, Redfern **VG**	2002	Quantify if individuals modify their gait biomechanics on slippery terrains.	8 men and 8 women. Ramp with inbuilt power platform for different slopes (0, 5, 10°) and extensions (1.8m long, 1m wide, 1.4 ext), covered with a thin wood layer. LEDs were attached to the: acromion, greater trochanter, femoral condyle, lateral maleolus and foot. 3 experiments: base reference (they knew the surface was dry), expectation (they did not know) and recovery (they knew why they were told).	For the "base reference" the kinetic variables were affected by the slope of the ramp. An increase in angle increased GRF. In the kinematic evaluation, the heel support decelerated at the end of the balance phase. In the "expectation": GRF 16-33% smaller as compared to that of the reference, with a greater decrease with increase in the angle of the ramp. Postural and temporal gait adaptations that affected GRF were used to reduce the GRF peak. Gait adaptations included reductions in duration of the support. A decrease in pace length decreased the foot angle and the angular speed on heel contact. The adaptations carried out to walk on the slippery surface led todid not affect the capacity of the platform to.
Wade; Redfern **VG**	2007	Determine the feasibility of using power platforms to measure GRF during gait on gravel surfaces (specifically the feasibility and precision of power platforms on gravel to measure the GRF of gait).	5 individuals; 5x8.5m catwalk, vinyl covering on floor and platform, covered with gravel (heights: 31, 63, 101mm); static test to check GRF according to location and height of covering; gait tests with self-selected speed and with/without covering – support at center of platform.	The gravel covering a change in the angular moment of the joints precisely measure GRF; During gait, the GRF curves demonstrated the similarities between the surface conditions; The values for GRF were the same for gait on all the surfaces.
Verhoeff et al. **VG**	2009	Investigate the effect of a biofeedback (BF) system on trunk oscillation (TO) when walking, with application of a double task (DT).	13 healthy elderly individuals and 16 healthy youngsters; carry out gait with body gyroscopes (L1-3) to measure oscillation; the gait tasks: walk normally, walk with decreasing count (-7), walk carrying a tray with glasses of water.	The body oscillation angle did not alter significantly after adding the cognitive DT; the motor task involved a significant reduction in TO; the youngsters reacted to the BF on walking and carrying out the DT at the same time; the elderly individuals reduced their trunk action (with BF) during normal walking, smaller capacity to react to the BF and reduce the TO when the cognitive or motor task was added (the increase may have exceeded the available processing capacity); the TO did not decrease in the elderly, but performance in the cognitive task improved with BF.

Figure 5: description of objectives, methods and outcomes for CAT articles – comparison of aquatic and terrestrial gaits

Study	Year	Objective	Method	Outcome
Miyoshi *et al.* **CAT**	2004	Compare the GRF, articular displacements, articular moments and EMG activity occurring during gait at different speeds on land and in the water.	50 healthy men. In the water the depth was adjusted until the body weight was reduced by 80%. The analysis was carried out by video with the help of a power platform for the kinetic and kinematic variables of the hip, knee and ankle. EMG.	The AP component differed between water and soil; the median-lateral was similar. The angular displacements of the hip and ankle articulations were similar in the water and the soil. The amplitude (ADM) of the knee movement was smaller in water than on land. The articular moment of the three joints was smaller in water than on land during the support, the hip extension moment and the EMG activity of the hip extensors increased, as also the speed of gait in water.
Miyoshi *et al.* **CAT**	2005	Explain the role of the articular moment of the lower limb, and its contribution in sustaining tasks and gait propulsion in both aquatic and terrestrial environments.	The kinematics, EMG of the femoral biceps and gluteus maximus and GRF were measured under the following conditions: walking on land and in water with a self-determined rhythm, walking slowly on land, walking quickly in water with/without an additional load (8 kg).	The ankle plantar flexion moment was highly sensitive to weight and less sensitive to gait speed; the main function of this moment is to maintain the stability against gravity. The force of impact under both conditions increased with the weight of the loads and/or gait speed; the main function of the knee articular moment is to absorb the force of impact during gait. Walking in the water reduced the load and increased the force to move the body forward (act of pushing and resistance) – strong propulsion is necessary for displacement; the moment of hip articulation is for extension (support phase) and increased as the speed increased (water); the main function of this moment was to project the body forward against the resistance of the water.
Barela *et al.* **CAT**	2006	Qualitatively and quantitatively characterize a complete gait cycle in adults in shallow water and compare with terrestrial gait.	10 adults (6 men and 4 women). Analysis of bidimensional gait in the water on the xyphoid process in each individual. Use of reflexive markers: head of the 5th metatarsal, lateral maleolus, lateral epichondyle of the femur, trochanter and 5cm below and to the side of the xyphoid process. EMG: TA, VL, BF, tensor fasciae latae (TFL), gluteus (G) and spinal erector (SE). Power platform for the components V and AP of GRF.	Qualitatively all the joints obtained similar patterns in the cycles in both environments. The ankle pattern in the water was that of plantar flexion for the support and balance phases. The knee showed a reduction in flexion during the first 15% of the cycle (water) and was more extended in the support phase in water than on land. The pattern of the hip was similar in both cases. Qualitatively the segments presented a neutral posture in the water at the start and end of the phases. The amplitudes of movement of the ankle, knee and trunk were the same in water and on land; there were differences between the environments for the segments of the foot, leg and trunk. The components V and AP of the GRF were different under the two conditions. EMG: G presented a smilar pattern in both environments. TA and TFL were activated in the balance phase, BF and VL in the support phase and ES at the end of this phase and throughout balance. RA in the contact phase.

Figure 6: description of objectives, methods and outcomes for CAT articles – comparison of aquatic and terrestrial gait; AAG – anthropological analysis of gait; OT - others

Study	Year	Objective	Method	Outcome
Barela; Duarte **CAT**	2008	Compare the gait of healthy elderly individuals in water and on land qualitatively and quantitatively. Compare the gait of the elderly in water and on land with a previous study (Barela; Stolf; Duarte, 2005) carried out with young adults.	10 elderly individuals (6 men and 4 women). Analysis of bidimensional gait in water on the xyphoid process of each individual. Arms on the surface of the water. Use of reflexive markers: head of the 5th metatarsus, lateral maleolus, lateral epichondyle of the femur, trochanter and 5 cm below and to the side of the xyphoid. EMG: TA, VL, BF, TFL, G and ES. Power platform for the components V and AP of the GRF.	There was no difference between the groups in the duration of the pace on land, but in water the duration was shorter for the elderly. On land the gait speed of the elderly was less than that of the young adults, but in water, it was the same. Qualitatively all the joints obtained similar patterns for gait (two environments). Ankle pattern: plantar flexion in the water for the support and end of the balance; tap on the land carried out by the leveled foot, not with the heel. The knee showed the greatest flexion at the start and end of the cycle (water and land). Hip pattern: flexion for the whole cycle on land and in the water. The ADM of the ankle (elderly) was smaller than that of the young adults. The ADM of the knee was smaller in the water than on land (both groups). The elderly have greater knee flexion in the support phase in the water, compared to young adults. For balance, the elderly showed less dorsiflexion in the water than young adults. Young adults carried out greater knee flexion (land) and the elderly greater hip flexion (water). GRF: the first peak of component V was smaller in the elderly and in the water; the second was smaller in the water for both groups. The horizontal impulse was smaller on land and in water for the elderly. EMG: The peak activity of G in water was smaller than on land. The TFL were activated in the balance phase in the water, BF and VL during support in the water, TA in both phases, ES at the end of support and during the whole balance. RA in points in the contact phase.
Preuschoft **AAG**	2004	Discuss the general morphological characteristics of the majority of species (theoretical and descriptive mechanics of the skeleton and proportions – chimpanzees, orangutangs, gorillas, gibbons, siamangs, modern humans)	Not described	The bipedality of modern man has various sources of explanation, by references to the upper limbs or simply in terms of improvements that reduce the costs of walking low, such that great distances can be covered at considerable speed for a minimum energy consumption.
Kuliukas *et al.* **AAG**	2009	Analyze the two possible forms of locomotion of australopitecos, which show a pattern of greater energy expenditure.	30 volunteers; the individuals were submitted to tests in the water with different degrees of knee flexion in the vertical position.	In deep water it can be seen that the energy expenditure for locomotion with the knees flexed was not as big as perceived in locomotion on land
House *et al.* **OT**	2004	Test the efficiency of insoles for the training of military personnel, checking the decrease in liquid retention.	The military personnel used the insoles from weeks 12 to 30 of training, analysis of the biomechanical aspects of the pressure on the tip of the foot and the heel.	The insoles were sufficiently durable for the military personnel; water retention was reduced, decreasing the injuries resulting from the non-freezing of the feet.
Prendergast; Lee **OT**	2006	Analyze the contributions of the author to biomechanics: emphasis on the theory of the hydrodynamics of lubricating the joints.	Analysis of the books and publications by MacConaill	The author played a great scientific role in the area of studies on knee joints. After 1930, MacConaill applied a mathematical approach to combating each problem.

from higher centers, making it possible to transport the body forward against the resistance of the water.

The author also explored another question, stating that the commands coming from the higher centers, related to a greater propulsive force, appear to selectively activate the motor neuron of the muscle responsible for the action; that is, the request was direct and selective, it being conceivable to relate it directly to the effort or role of this motoneuron in overcoming the resistance to movement in the water. According to Kotani *et al.*[14] this activation depended on the association between the type of muscle requested (monoarticular/ biarticular) and its function. The authors also established that the variation in time of this activation was related to the existence of a flow of water encountering the body being displaced, and would increase according to the increase in this flow.

With respect to the influence of the weight of the immersed body, which is determined from its characteristics and from the pushing action, Roesler *et al.*[11] confirmed that the immersion level and position of the upper limbs (variation in weight) determined greater responses for the ground reaction force (GRF) during gait. This idea was corroborated by Masumoto & Mercer[2], who stated that muscle activation occurred due to the somatosensory input of the weight – a relation characteristic of the body and its consequent pushing action. The authors explained that pushing modified the gravitational action in the aquatic medium, decreasing the ground reactions, and for its part the related somatosensory input. This reduction determines less muscle activation, as well as modifying the influence of the hydrostatic pressure, altering the muscular action mediated by body pressure receptors.

The displacement speed of a body in the water behaves according to the interaction of some factors: the influence of the area of the submersed body and the imposed aquatic resistance, since the relationship of this resistance with the speed is in a quadratic proportion[5]; and the viscosity of the medium[2]. This interaction is enabled by the vertical position of the body during gait, since with the increase in frontal area, in resistance and with the interaction between the body and the medium (viscosity), there is a reduction in speed in relation to that in the terrestrial medium[2]. If the speed is the result of motoneuron activation for a movement[23], be it angular or linear, there will be great activation in order to overcome the resistance of the water, which is greater than that of the air[2]. Some motor and functional adjustments are carried out to increase the speed such as: alteration in posture maintenance by the erector muscles, which stabilize in the frontal plane for low speeds and alternate in the sagittal plane for higher speeds; and a reduction in pace frequency in relation to movement on land, as a consequence of the pushing action and the hydrodynamic drag[13].

With respect to variations in the surface (VG), the studies found reported that when a body finds an environment that is different from that in which it developed its gait routine, it needs to carry out potential adaptations, resulting in significant differences in the gait biomechanics[15,16]. Cham & Redfern[15] commented that adaptations carried out to walk on a slippery floor altered the angular moment of the joints, which is associated with the concept of equilibrium in biomechanics. This equilibrium is where the joints assume a stable posture, which, according to Caromano[24], is where various forces act on a body in opposite directions and hence annul themselves. This equilibrium is also observed in studies where the people have to carry out two tasks simultaneously[16]: in the tests applied, the participants had to carry out a task involving reasoning together with a motor action, making adaptations to their posture in the search for equilibrium in order to attain the determined objective.

The comparison of gait in different media and people is a focus of research in human beings, considering the diverse phases of evolution: Preuschoft[21] showed an interest in studying the differences in gait in the australopitecos and how this form influenced locomotion in modern times. He showed that in deep waters the energy expenditure in locomotion with the knees flexed, the form of locomotion of the australopitecos, is less than that seen in locomotion in the terrestrial environment. The author attributed this difference to less activity of the gastocnemius and soleus muscles in the aquatic exercise, justified by the absence of contact and consequent vertical forces with the bottom of the swimming pool, during walking in this medium[25].

The studies related to the comparison of aquatic and terrestrial gait (CAT) justified the results by relating them to the properties of pushing and hydrodynamic dragging and the viscosity of the water.

Miyoshi *et al.*[19] and Barela *et al.*[20] reported that a decrease in the vertical component of GRF was related to the pushing action, which influences the reduction in the force of impact in the initial support phase in the water. This supports the study of Masumoto & Mercer[2] which reported a 71% reduction in body weight when the water was level with the xyphoid process, which could be related to the decrease in the vertical component of GRF. Barela *et al.*[20] added that the decrease in the vertical component of GRF was related to a decrease in gait speed in water as compared to on land. Considering that the characteristics of area and viscosity contribute to such alterations[2], this corroborates the idea that aquatic gait speed is half of that on land[26].

However, Barela *et al.*[18] and Barela *et al.*[20] explained that the difference found between aquatic and terrestrial gaits was not only due to the influence of the medium, but also due to the

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different speeds used during displacement, the decrease in body weight in water on account of the act of pushing and the changes required to overcome the hydrodynamic drag. According to the principles of hydrodynamics, the movements of segments in water are influenced by the dragging force and by the act of pushing[28], differentiating them from movement in the terrestrial environment.

Electromyographic findings define the low speed developed during aquatic gait as a fundamental element to overcome the hydrodynamic drag, and in addition consider that the decrease in weight generates a smaller propulsive impulse for displacement in the water[18,20].

According to this reasoning, the decrease in muscular activity during aquatic gait as compared to terrestrial gait is related to changes in the gait: in their study Masumoto *et al.*[27] showed a decrease in pace frequency (approximately 57% in relation to on land) and a decrease in pace length in water in relation to on land. The decrease in muscular activity in water could be related to the act of pushing and to decreases in the force of gravity and hydrostatic pressure which act on the neuromuscular system[2].

Barela *et al.* [18] and Barela *et al.* [20] found no differences in the amplitude of movement (ADM) of the joints during gait on land and in water, but when considering the segments (feet, legs and trunk) separately, there was a difference, due to maintenance of the limb in a neutral position during displacement in the water in order to overcome the force of drag, corroborating with the study of Ribas *et al.*[1].

Miyoshi *et al.*[19] suggested that the decreases in ankle plantar flexion and knee extension were due to the act of pushing, and that in their study, the knee joint did not show the role of absorbing the impact of the water. In their study Ribas *et al.* [1] stated that in the initial support phase and final oscillation, knee joint extension was greater on land than in the aquatic environment, and that in the balance phase, knee flexion was greater in the aquatic environment due to the attempt to decrease the frontal resistance of the water.

Miyoshi *et al.* [19] and Miyoshi *et al.*[6] justified the reduction in body weight of the individual on walking in water, and the increase in force required to move the body in this environment, as being due to, respectively, the act of pushing and the aquatic resistance, specifically the viscosity. They also argued that the increase in angular moment of the hip in the extension during the support phase was due to the impulsive force required to displace the body in the water. Similar responses for the activation of propulsive muscles for walking were found in investigations with fixed speeds (same physiological intensity for the exercise)[23,26] in the muscles responsible for the propulsive movement.

When carried out at the same intensity of physiological effort in the two media, the terrestrial gait speed has to be twice the aquatic gait speed[23]. In the same way, the increase in activity of muscles such as the gastrocnemius, anterior tibial, vastus medius, rectus femoris and biceps femoris in an aquatic medium is due to the increase in resistance imposed to the movement on account of the need to overcome the greater density of the liquid, as compared to that of the air at the same exercise speed on land[23,28].

Miyoshi *et al.*[6] focused on the fact that ankle plantar flexion increased when body instability, body weight and speed increased, indicating that greater changes in articular moment are required to maintain the stability against gravity. Miyoshi *et al.*[19] reported increases in articular moments and muscular activations as a function of an increase in displacement speed in the water. These observations suggest that muscular activities can be activated by small changes in the displacement speed in water in relation to that on land, since this could be due to the exponential increase in hydrodynamic drag, which influences the speed of movement during locomotion in water, since the relationship between the force of dragging and the speed of movement is not linear, such that drag increases as a function of the square of the speed[28].

The alterations suffered by the body start on its first contact with the medium, but the effects of resistance are only experimented by way of displacement. The articles described in this study established that alterations in motor behavior were based on synesthetic reflexes (vision, touch etc. receptors), movement and load reflexes in the corresponding sensory-motor activations, in the consequent muscle actions and, finally, in changes that could be observed: kinematic (linear, angular), etc. Some limitations were identified in this study: the keywords chosen and used were far from being able to cover the studies corresponding to the areas responsible for producing this knowledge; and only one database was used to survey the articles, thus reducing the number of studies passive to analysis under the conditions specified here. The authors suggest a widening of this research with a greater number of keywords and databases, such that the subject can be discussed at greater depth.

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