FROM BIOMECHANICS TO MOTOR LEARNING

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ABSTRACT

Introduction: *Human movement develops as the result of numerous variables ranging from neuro-cognitive mechanisms to structural factors of the musculoskeletal system. Greater attention should be directed towards the study of the motor learning mechanisms that have enabled the acquisition and improvement of certain postures and motor acts.*

Aim: *The purpose of this work is to clarify, through a review of the reference scientific literature, the close correlation between the biomechanical aspects of human movement and the mechanisms for acquiring motor models. Biomechanical evaluation does not neglect the mechanisms that have structured and made possible a certain posture or movement over time, i.e. the motor learning phases that follow specific ontogenic phases.*

Materials and methods: *The study was conducted through the treatment of scientific literature.*

Results*: The work was developed through a review of the scientific literature. In the first part, the focus was placed on the definition given to biomechanics as an interdisciplinary science that gives its important contribution to the knowledge of human movement. We then moved on to the discussion of motor learning theories and methodological approaches in the construction of learning programs.*

Conclusion: *The study shows the importance of learning mechanisms in building competent motor skills. The need to move towards the structuring of dynamic ecological teaching methodologies is evident, which, through a heuristic approach, improves learning through trial and error.*

Keywords: *Human movement, motor learning, systems Theory.*

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Introduction

Movement is intended as the precise linking of multiarticular actions that follow a precise order (kinetic chain) based on muscle synergies (Figure 1) which, to be expressed effectively, must be learned through the right methodologies in certain periods of the individual's life. The evaluation of the movement cannot fail to consider the mechanisms that made possible the realization of the motor act itself, from the learning mechanisms to the structural and energy characteristics of the person who performs it[1, 12, 21].

Therefore, in the evaluation of movement, numerous aspects are taken into consideration, ranging from biomechanics to biochemistry, from structural aspects (musculoskeletal, joint, etc.) to cognitive aspects, from aspects related to learning to aspects of a motivational nature, which , all together in the right proportions, allow the realization of a given movement in its entirety[3, 11), 29)].

This work underlines how reductive it is to consider movement only in its purely biomechanical and structural aspects, thus falling into the error of creating technical reference models with respect to a certain motor gesture which, although effective in reference to some subjects with certain characteristics and even if appreciable from a purely aesthetic point of view, it cannot be applied to all subjects as different in both structure and biological nature and, again, in the neural ability to learn and perform the gesture in certain moments of life. Movement, therefore, must be understood as the sum of mechanisms that take place within a complex system in which all its parts interact in a strong and non-linear way[3, 6, 25].

The aim of this work is to clarify, through a review of the reference scientific literature, the close correlation between the biomechanical aspects of human movement and the mechanisms for acquiring motor patterns. In fact, biomechanical evaluation does not disregard the mechanisms that have structured and made possible a certain posture or movement over time, but needs to be truly effective and provide useful and expendable data, data relating to the mechanisms that make it possible to perform a motor gesture.

Figure 1: Muscle synergies (https://www.scienzemotorie.com).

Materials and methods

The methodology used for this treatment is that of the revision of the literature through the consultation of the most recent scientific journals and texts. The main theories concerning motor learning have been treated in order to clarify the training processes for the development and improvement of skills that are effective according to the canons of Biomechanics.

Discussion

Biomechanics

"Biomechanics is the science that applies the acquisitions and laws of mechanics to the study of living organisms", this is one of the definitions that is given to biomechanics[18, 19, 20]. It is an interdisciplinary science that contributes significantly to the study of the knowledge of human movement.

The fields of application of biomechanics are manifold: from bioengineering, to orthopedic medicine, from the sciences that are interested in training methodology to clothing.

Classical mechanics, which deals with inert bodies and tendentially stable models, are not always applicable to the study of biological phenomena such as human movement.

Classical mechanics deals with stable systems and, once the initial conditions are decided, everything else follows in a deterministic way. The bodies of the living are not invariant systems.

The human body is a complex system and in continuous relationship with non-linear variables and, as such, must continually face a succession of events[14, 17, 26].

The theory of dynamic systems (Smith, 2006) began to develop around the mid-twentieth century, a period in which the canons of (post-positivist) classical science-typically reductionist, deterministic and mechanistic - began to be questioned in favor. a vision more oriented towards complexity and therefore characterized, on the contrary, by a holistic, probabilistic and organicistic approach.

Born from the integration of different disciplines including cybernetics and information theory, philosophy of science, physics, biology, psychology and sociology, the theory of dynamic systems claims that:

- The world, at each of its levels (subatomic, physical-chemical, biological, psychological, social, cultural, etc.) is organized in terms of the system, that is, of a set of elements in mutual interaction in non-linear and circular ways;
- There are general principles, referable to the key concepts of self-organization and emergency, capable of explaining the change of these systems regardless of their nature (biological, psychological, social, etc.).

The theory of dynamic systems has so far shown that it can legitimately be considered a unitary and coherent frame of reference for the study of numerous disciplines, including the study of human movement[5, 14]. On the basis of what has been said, it is clear that the acquisitions of biomechanics can make an important contribution in the evaluation and management of problems affecting human movement, but, in an integrated way, they need other knowledge and interventions in order to be truly effective in their application.

In fact, a certain movement pattern cannot be standardized to all human beings. The numerous variables to consider in evaluating a certain motor gesture are not always easy to understand[24]. Among them it is appropriate to include anthropometric measurements, muscle morphology, the number of muscle fibers and the type, arrangement and quantity of elastic elements in series and in parallel, etc. to which must be added the cognitive mechanisms that always intervene in the planning, execution and correction of motor gestures.

Movement, therefore, must be understood as the sum of mechanisms that take place within a complex system in which all its parts interact in a strong and non-linear way. The motor activity of living organisms is the manifestation of integrations of the organism itself with the environment that surrounds it and the motor control is distributed between different systems that interact with each other, cooperating to achieve behaviour appropriate to the required circumstances: nervous system, muscle and skeletal, external forces, gravity and inertia.

We must consider the characteristics of the system that is moving, the internal and external forces acting on the body, and the variations with respect to the initial conditions. Motor synergies are therefore at the basis of the generation of movements and the flexibility of neural systems allows to manipulate these synergies to constitute motor strategies and, that is, the selection of a particularly suitable synergy to achieve a certain purpose.

The body is considered as a mechanical system that has many degrees of freedom, which must be constrained in order to work together as a functional unit. The degrees of freedom are the number of independent directions of movement allowed for a joint. A joint can have up to three degrees of angular freedom, corresponding to the three cardinal planes. From a strictly engineering point of view, however, degrees of freedom apply to both translational and angular movements.

The "degree of freedom problem" introduced by Nicolaj Bernstein refers to the fact that the motor system has too many independent parts to move and therefore a level of conscious control is not possible. A solution accepted by various scholars is that it is the actions that are controlled and not the individual degrees of freedom: when performing a movement you are aware of the overall action, but you are hardly aware of the muscles involved and never of the motor units involved[25, 26]. There would be structures, subordinate to the management, which would be able to manage the degrees of freedom. Such structures, capable of influencing the activity of the various degrees of freedom, independent of each other, so as to make them work as a single unit, are called motor programs (Brooks, 1979, 1986, Henry & Rogers, 1960, Keele, 1968, Keele, Cohen & Ivry, 1990, Lashley, 1917, Schmidt, 1975, 1988).

Bernstein's thought contrasts with that of another scholar who, at the same time, dominated the field of physiology in Russia. This scholar was Ivan Pavlov who was decisively supported by the Russian government, which soon led Bernstein to lose his job due to criticism of Pavlov's research.

For Pavlov, movement was made possible by passive forces that triggered conditional reflexes; for Bernstein the movement was caused by active and targeted forces. Pavlov's research was aimed at isolated movements, Bernstein considered movement in its complexity.

Motor learning theories

In addition to the elements of a structural and cognitive nature, the level of ability achieved by the subject through learning in specific phases of the individual's life should be considered[4, 8, 9, 10, 23, 24].

The learning ability consists in the assimilation and acquisition of movements or parts of them, previously not possessed, which must then be stabilized[1, 9, 27, 28].

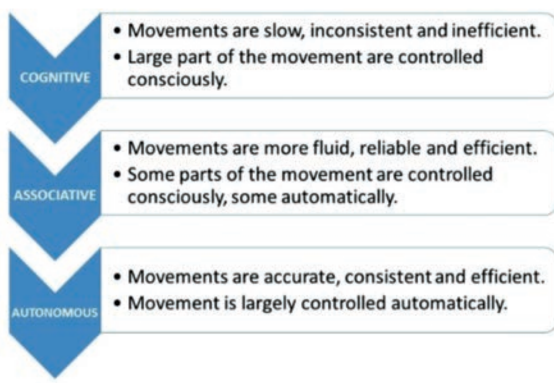

Table 1: Motor learning.

These learned and consolidated movements are called Skills. They take place automatically when needed. Motor learning (Table 1), according to numerous authors (Adams 1971; Fitts and Posner 1967, Meinel and Schnabel 1977, Glencross 1993, Magill 2001, Mannino and Robbazza 1990) takes the form of the succession of three stages which include a gradual passage from a phase of understanding of the task and rough coordination, to a phase of in-depth understanding and development of variable automatisms.

Another factor to consider in the qualitative and quantitative evaluation of the motor gesture, which travels hand in hand with motor learning and which is fundamental for its realization, is the maturation of the nervous system[16, 22, 25].

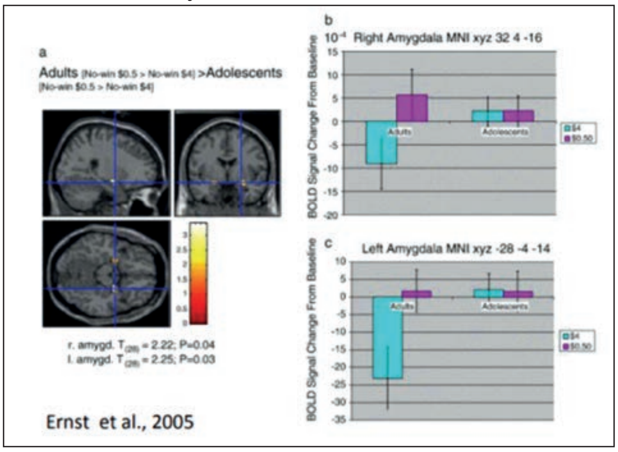

Figure 2: Difference in reaction of the amygdala to stimuli between adolescents and adults (Ernst et al., 2005).

The maturation of the nervous system (Figure 2) is a process that affects specific phases of human life, from before birth and in a non-linear way[7, 15]. It is clear that adolescents show less reactivity of the amygdala and frontal cortex, compared to adults, when faced with exposure to adverse stimuli, dangers or punishments[7].

This could explain the different approach of the teenager compared to the adult when faced with the request to make a motor gesture for the first time.

Three different approaches (Table 2) emerge in the study of the mechanisms that allow motor learning:

- Cognitive approach;
- Ecological approach;
- Dynamic approach.

The cognitive approach believes that the relationships between perception and action are mediated by prescriptive structures developed on the spot and/or stored centrally.

The motor programs[25, 26] are control structures that allow the start of a movement according to specific sequences. These motor programs would be able to influence the activity of the different degrees of freedom (Bernstein's degree of freedom problem), independent of each other, so that they can work as a single unit. The motor program "... defines a movement pattern rather than a specific movement; this flexibility allows it to be adapted so as to produce variations of the motor pattern adapted to modified demands of the environment ".

For other authors, supporters of the ecological and dynamic approach, the use of prescriptive mental structures is not necessary at all because they consider movement a process of self-organization tending to effective execution while respecting the structural characteristics of the subject in relation to the external environment.

	Assumptions	Clinical Implications	Limitations
Adams Closed Loop Theory	- Closed Loop - Sensory feedback is used for the ongoing production of skilled movement - Slow movements - Relies on sensory feedback (Sherrington) - Blocked Practice - Errors = Bad! Needs to be accurate! - Memory trace - initiation of movement - Perceptual trace - built up over a period of practice & is the reference of correctness. - Improvements = Increased capability of performer to use the reference in closed loop	- Perform same exact movement repeatedly to one accurate end point - Increase practice → Increase learning - Errors produced during learning→increase strength of incorrect perceptual trace	- Can't explain accurate performance of open loop movements made in absence of sensory feedback - May be impossible to store separate perceptual trace for every single movement - Variability of movement → may improve motor performance of task
Schmidt's Schema Theory	- Open Loop - Schema - Abstract memory representation for events → RULE - Generalized Motor Program - Rules that allow for the generation of novel movements - Rapid, ballistic movements = recall memory w/ motor programs and parameters to carry out movement w/o peripheral feedback - Variability of practice → Improve motor learning	- Optimal learning → task practiced under many different conditions - Positive benefits for error production (learn from own mistakes) - Schema has rules for all stored elements, not just correct elements	- Differences b/w children & adults w/ variable forms of practice. - Lack of specificity of interaction w/ other systems during motor learning. - Can't account for immediate acquisition of new types of coordination.
Ecological Theory	- Karl Newel, 1991 - Systems & Ecological MC theories - ML = increases coordination b/w perception and action thru task & environmental constraints. - Perceptual-motor workspace - identifies movements and perceptual cues (reg. cond.) most relevant to performance of task - Optimal task-relevant mapping of perception & action → NO Rules!	- Pt. learns to distinguish relevant perceptual cues important to action.	- Very new theory - Not applied to specific examples of motor skill acquisition in any systematic way. - Stages of Learning Motor Skills

Table 2: Theories of motor learning.

Complex systems can be highly organized and adaptive even without any means of central control. Dynamic interactions between all parties cause the system to become attracted, statistically or probabilistically, to certain states which are advantageous under certain conditions. Therefore, the system shows intelligent and adaptive behaviour even without a single part of the system that really "knows" what it is doing.

Coaches and teachers should remember that athletes are self-organizing systems, that good movement will tend to emerge in the right conditions and that athletes will be attracted to the right movement patterns if they have the right type of practice, as the regularity of the Movement patterns are not represented in motor programs, but rather emerge naturally as the result of complex interactions between numerous connected elements[2, 21].

They don't need specific information on how to move exactly, just the right conditions for learning. The teacher takes the background and organizes the optimal environmental conditions for the self-organization of the learner.

Newell (1978) identifies three basic constraints around which complex adaptive systems, such as training, self-organize:

• The task (for example the squat);

• The current state of the body (for example the length of the femur, the health and condition of the knees, quadriceps and buttocks);

• The environment.

A coach could change one of these constraints to change the model: the task, for example, holding a kettlebell in hand while performing the squat; the environment, lowering or raising the box, or crouching on an unstable surface; changing the body, through hypertrophy training, weight loss or pain reduction.

A change in one of these constraints would cause the system to be automatically reorganized, without any specific instruction from the coach on how to perform the task (squats).

Conclusion

Considering the human movement in its entirety, therefore not focusing only on isolated aspects that determine it, is the essential requirement towards a complete study of an extremely complex phenomenon: this allows teachers, trainers and movement specialists a more effective approach to teaching sports.

From what has been described, in fact, it is clear the need to move towards the structuring of dynamic ecological teaching methodologies which, through a heuristic approach, enhances learning by trial and error.

The student must be assisted in the search for the best solutions for carrying out the task: this will allow him to improve his ability to "read" environmental situations and automatically associate effective motor responses in variable situations.

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