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LEARNING OF MOTOR SKILL IN PRETEENS

THESIS

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INTRODUCTION

The research work carried out during my doctorate began with the realization and understanding of the importance rightfully given to the father of modern neurophysiology, Sir Charles Sherrington, who in 1924, during the Linacre Lecture, clearly affirmed that "*...to move things is all that mankind can do ... for such the sole executant is muscle, whether in whispering a syllable or in felling a forest.*"

Learning new movements and motor skills is fundamental for an individual, and the ability to acquire new motor skills and actions is defined as *motor learning*. Some scholars define motor learning as the emergence of a relatively permanent change in performance or potential behavior through direct experience or the observation of others (Adams, 1971).

Therefore, this attitude can be assessed in two ways: measurement of the time required to correctly master a motor skill, or through the observation of the quality of the learned movement based on precision and efficiency (Casolo, 2007).

If we observe an individual who learns a new movement or skill, we also naturally note how the predefined goal is not reached during the first attempts, and the carrying out of these movements is wrong or imprecise.

These descriptions help us explain the foundation behind the principle that the individual does not yet have a model that allows him or her to adequately use the movements required.

Schmidt (1975) underlines how the number of repetitions of the new skill represents a basic element in reinforcing and creating the action model. The carrying out of the these movements is needed in order to store information on initial conditions, the response parameters used, sensory feedback, and results obtained (Schmidt, 1975).

The performance of the skill is slowly perfected through each new movement, until the creation of a relatively stable model with which the movement comes closer to that of the desired performance model.

The effectiveness and efficiency of overall practice, interpreted as the number of repetitions, has been long recognized as the foundation of learning and perfecting movements (Lee and Genovese 1988).

Moreover, we should not forget that the learning phenomenon does not amount to a process that is simply neurophysiological, due to the fact that there are also important psychological consequences to be considered.

As acutely stated by Donal Hebb (1949), the learning process takes place within an "experience-dependent" context – each and every experience can potentially influence, in a significant manner, our neural connections and cerebral structures – a phenomenon defined as *neural plasticity*.

Learning is therefore an active process of acquiring stable behavior aimed at adaptation, which is a change due to the external and internal stimuli. Therefore, we could go so far as to say that learning means *to adapt*.

The start of learning processes in human begins takes place in newborns, subconsciously learning to recognize and use their bodies, embarking on their integration with the outside world.

Following this first step, learning will become intentional – a consequence of growing possibilities that we can use to increase and develop skills for information storage, mnemonic strategies, and finally metaperception, meaning the ability to make considerations on how we think (the perception of perceptions).

Moreover, an important requirement for learning effectiveness and efficiency, in terms of the results, is dictated by our understanding of the subject to be learned, along with the quality and quantity of the stimuli pertaining to this activity.

THE PHYSIOLOGY OF VOLUNTARY MOVEMENT

Part of this research was directed at the execution of motor movements, therefore the learning of what is called *voluntary movement*.

This term indicates an action that is carried out with the intention of reaching a goal: this type of action or movement also represents the only way that we can consciously interact with our environment.

A voluntary movement is the result of a series of nerve activities that are traditionally divided into two phases: the first, in which we identify the goal to reach, is defined as *strategic*, while the second phase, in which we choose the best way to reach that goal, is called *tactic*. We can logically imagine that these different phases, which lead up to the voluntary movement, involve different parts of the brain, in a more or less prevalent manner.

Starting with the groundbreaking studies by Hans Helmut Kornhunber and Lüder Deecke (1965), based on the electrical activation of specific area of the brain before, during, and after a voluntary movement, and moving on to the theoretical model proposed by G.I. Allen and Nakaakira Tsukahara (1974), we reach the conclusion that the parietal lobe starts the movement – a hypothesis the fits well with the observation that this brain region is responsible for somatosensorial, vestibular, hearing and visual information.

In fact, it is evident that for a correct elaboration of a motor strategy, we must know the parameters pertaining to our goal (position, shape, etc.), as well as parameters for the part of our body (geometry, mechanical state) that we want to use (Perciavalle, 2010).

Allen and Tsukahara (1974) postulate that the parietal lobe is not able to exercise direct control on the motor control, and that this control is actually carried out by the cerebellum (specifically the neocerebellum) and the base ganglions.

The role of these two structures is that of identifying the most suitable movement in order to reach the predetermined goal. This *program*, on the level of the motor cortex and subcortical motor structures, translates into a precise motor command (which muscles to use, in what order, how much strength, etc.) that leads up to the activation in stem and/or spinal motor centers.

This is real start of movement, which can also be controlled while it is being carried out. In order to do this, the sensorial image of the movement needs to be used – an image that is reconstructed by cutaneous, muscular, and articular receptors.

According to Allen and Tsukahara (1975), this control is carried out by feedback that acts on the spinal level, as well as that of the paleocerebellum and motor cerebral cortex. The concluding control is then performed based on a comparison of the planned movement and the movement that is actually executed (Perciavalle, 2010).

This may be possible by interaction of important structures that appear to be essential for both motor and psychicological tasks, as the cerebellum (Garifoli et al., 2010; Berretta et al., 1991; Berretta et al., 1993; Giuffrida et al., 1988; Cardile et al., 2001) which plays a strategic role non only in control and learning of movements but also in regulation of several cognitive domains (Perciavalle et al., 1978; Gray et al., 1993; Perciavalle et al., 1998; Perciavalle, 1987; Giuffrida et al., 1992; Perciavalle et al, 1977; Perciavalle et al., 2013).

LEARNING AND MEMORY

The brain, up until a few decades ago, was seen as a biological computer that recorded incoming information, without discerning importance or relevance.

Only recently, thanks to the use new investigative methods, have we begun to understand that the nervous system works as a selector of information, filtering and storing only the information that it considers important and significant.

Learning therefore consists in the increase in the probability that, as a consequence of the experience, there is a precise brain response to the presence of a stimulus.

Repeating a movement that he or she is carrying out for the first time allows a child to have a *memory* of the experience, which clearly induces a series of changes in the neural network. These modifications are mnestic footprints.

Memory represents the psychophysiological process that allows us to acquire and store information that we can then use at a later date.

In other words, we could define memory as the ability of an individual to gain benefit from previous experiences. This highlights the cognitive ability to **acquire**, **store**, and **use**, at a later date, **information** regarding the world around us, as well as our experience within it.

The term "**memory"** refers to the set of internal information based on experience –information that is then able to influence future behavior (i.e. information that we store in our personal database).

The term "**learning**" refers to the processes through which new information is acquired and stored, two actions through which memories are built and created.

Therefore, memory is the ability that allows an individual to gain benefit from previous experiences. Moreover, it represents the cognitive ability that allows us to acquire, store and later use information on the world around us, again paired with personal experience (Anderson 1976).

If we were to close our eyes for an instant and imagine that we wanted to memorize what we are reading, or remember each and every word and note of a song that we are listening to, the information available would, in the first case, reach us through visual channels, and in the latter, through our hearing. However, in order for these sensorial structures to take in this information, which needs to then reach or CNS, they must be converted (i.e. encoded) into a form of energy that the CNS can understand – a form that is the same for all information. In other words, different types of information must be first transformed into a type of signal that allows them to be stored, and then when needed, used.

Therefore, we can summarize the memorization process into three clear moments: Encoding, Storage, and Retrieval.

Encoding incoming information of any nature (electromagnetic waves, physical or mechanical input) is transformed by peripheral sensory receptors (eye, ear, etc.) into electrical signals, called nervous impulses, which through sensory pathways are transferred to the CNS.

The encoded information, once it has reached the CNS, is stored – hence the **Storage** phase. This process is quite delicate, in light of the fact it requires an unambiguous encoded trace (or an **engram**) of the required information, in order to be able to track it down its in "warehouse", and then use it. This is the **Retrieval** stage.

An initial model (Diagriam 1) to explain memory (mnesic) systems was created by Squire, Knowltonand, and Musen (1993), who divided the memory into two large categories: Short-Term Memory (STM) and Long-Term Memory (LTM).

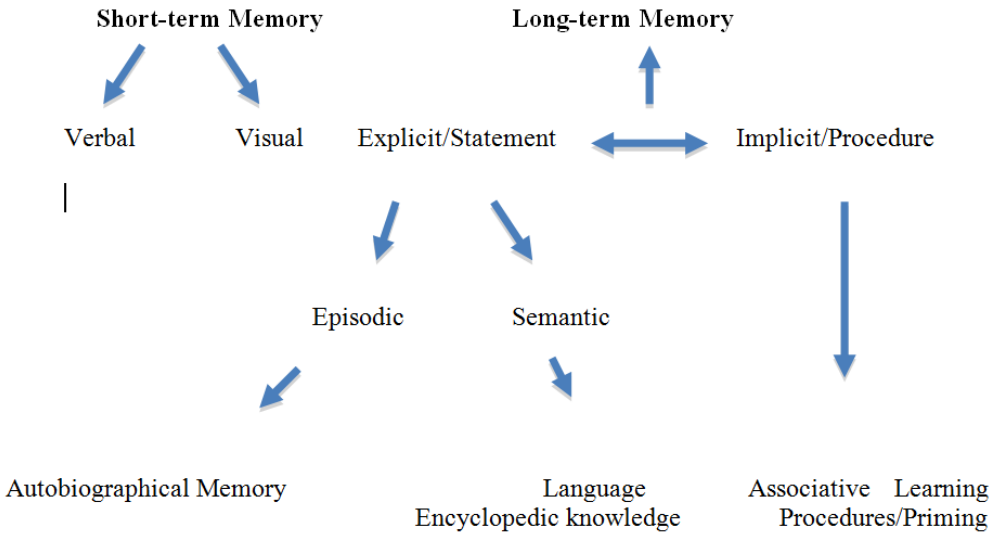

Figure 1: Memory Model

In the proposed model, motor learning is a particular type of long-term memory – implicit and non-verbal – defined as “procedural memory”.

The term “**Procedural Learning”** (Bullemer et al., 1989) indicates the acquisition process of almost all of our motor skills and capacities, learned through a process call “trial and error”. This special type of learning is the only way emotional involvement can play a negative role in the learning process, due to the fact that if we are excited, performance is undermined. Scientific studies have proved that the structures involved in procedure learning processes include the supplementary motor cortex (SMA) of the cerebellum and the putamen (Sakai et al., 1999).

The process is defined as non-verbal and implicit, seeing that it is very difficult, if not impossible, to verbally explain a motor skill or learn it through verbal explanation. It turns out that the best solution for correct learning is to *try and try again*, meaning *trial and error*. Just imagine the first time you tried to tie your shoes or the first time you drove a car – you paid attention to each phase or step in the sequence, and after many attempts and repetition, both of these skills became automatic (Perciavalle, 2010).

The classic distinction between STM (or primary) and LTM (or secondary) highlights how information to be remembered initially passes through a limited capacity stage, with a short duration, and then later enters a stage that is more stable, capacious, and enduring. Passing from STM to LTM is the goal of the learning process called **consolidation**.

Through studies on aplysia californica (the California sea slug), Nobel Prize winner Eric Kandel (1994) succeeded in explaining some mechanisms implied in the memory and learning circuit.

Everything, in fact, appears to depend on precise modifications in the synaptic transmission (*sensitization, desensitization, habit, conditioning*) at crucial points in the neural systems. The set of modifications falls under the term *synaptic plasticity*.

Thanks to the phenomenon of synaptic plasticity, we can continue to modify the content of our minds (Paller, 2002).

In our brain, learning can take place either through reiteration or emotional involvement, be it positive or negative.

The structures involved in almost all of these learning processes are the *amygdala* and the *hippocampus*. The amygdala is responsible for learning emotions, while the hippocampus handles verbal learning.

Information can quickly pass into long-term memory even with few repetitions (or, in certain cases, none) when the learning takes place within a context defined by strong emotions (Fell, 2001; Fernandez, 1999).

More specifically, emotions (which from a physiological point of view are the effects of positive or negative reinforcement) are a tool that helps foster learning in almost every shape and form of long-term memory, however not in procedural learning. The more emotional we are, the faster we can consolidate information, as in the case of certain episodes in our lives or the effects of Pavlovian, or classical, conditioning (associative memory). With regard to consolidation of procedural memory, on the other hand, emotions play a negative role. The more emotional we are, the less we learn.

Emotional involvement is correlated to adaptive behavior, and aside from our cognitive choice, it subconsciously pushes us to take on behavior that helps our survival, such as *fight and flee* when we are afraid (Bear et al., 2003; Reichert, 1993; Carlson 2002).

Aerobic physical activity is capable to induce improvements in the cardiovascular and respiratory systems, unlike a type work anaerobic where a significant increase of blood lactate is observed (Woods and Cray, 2013). This is important to assess because recent data (Coco et al., 2010) show that high concentrations of blood lactate influence positively the excitability of primary motor cortex and negatively attentional processes involving the prefrontal cortex (Alagona et al., 2009; Fagone et al., 2012; Coco et al., 2013; Mijatovic et al., 2010; Fagone et al., 2013; Donia et al., 2012). Therefore, the choice of a proper sport in terms of intensity (aerobic or anaerobic) is important, because it affects differently the frontal lobe, with different effect on cognitive domains (Coco et al., 2009; Perciavalle et al., 2010; Coco et al., 2011).

MOTOR LEARNING: NEUROPHYSIOLOGICAL ASPECTS

Motor learning is the cornerstone of this research work. The learning process begins with our first cry and will continue for the rest of our lives.

This fact helps us understand how motor development cannot and must not be treated in a way that is detached from the personality traits of an individual, such as intelligence, social interaction, and how we show our emotions.

Fostering the growth of motor skills and capabilities, in the right way and with the right methods, means acting directly – and effectively – on the willingness of others to learn, on the ability to make intelligent choices, and on an understanding of ourselves that leads to healthy self-awareness and self-control (Casolo, 2007).

A number of authors have tried to give a thorough definition to the term *motor learning* (cfr. Shadmehr e Wise 2005); the majority states that this term means a relatively permanent change in performance of behavioral potential, carried out through direct experience or by observing others.

Motor learning therefore takes place in stages that include the gradual passing from a learning phase to that of raw coordination (verbal-cognitive stage or raw coordination development), then moving on to a step of in-depth understanding (motor stage and refined coordination development) and the development of executive automatisms (autonomous stage or variable resource development).

Martens and his team (1976) highlight how, at the beginning of the learning process, visual information is favored, allowing the learner to understand the movement in its entirety – it may be useful to help the subjects focus their attention on important elements or parts of this skill.

In the initial phase of learning a motor skill, it is important that the subject understands the task that he or she is about to carry out, while also gaining an idea – a mental image of the movement – in order to build a primary correct point of reference that will become more and more accurate through practice. This model is used as guide for the movement or skill, and also as a point of reference for verifying errors and correcting them.

Paul M. Fitts (1954) underlined the important role of the mental image of the movement, stating that this created a model for "adjusting" the movement, used as a "training" function, and therefore able to determine faster learning.

According to **Functional Psychology of the Self** (Rispoli 1993), human beings are born with a psychosomatic unit that leads to an inseparable connection between psyche and body. Therefore, movement is perceived not as the mere execution of a certain gesture, but rather as a channel of expression through which we can express ourselves as well as our relationships with reality. This theory highlights the reciprocal exchange between mankind and the environment – the first influences the latter, but at the same time the feedback received is stored on a body-experience level as a trace or footprint. Given the complexity of the psychosomatic framework, the movement – motor learning – like any activity, arises from individual development, i.e. a set of cognitive, emotions, relational, and physiological aspects.

In order to better understand the mechanisms at the foundation of the learning process and motor skills, we must understand the scientific pathway and research that has led us to our current knowledge.

Numerous theories have come forth over the years. The first theories regarding motor learning were elaborated based on studies on motor behavior in the first years of life, carried out by developmental psychologists.

One of the greatest contributions was offered by Jerome S. Bruner (1968, 1971, 1973), who observed the first attempts of a child to grasp and handle objects, hypothesizing that he/she went from a chaotic movement that was not aimed at the acquisition of a skill or ability, to the execution of a voluntary movement.

Bruner considered motor development as an analogy of the language development model: the child possesses an "inborn predisposition to create plans of action", generalizing and transferring rules of action from parameters abstracted in specific movements with timing and kinematic depictions of the movement, in relation with specific environmental needs.

Therefore, the development of this *plan of action* becomes a flexible and modulated construction that is continuously adapted to the child's relationship with his or her environment.

Based on this perspective, learning assumes that the child is active and proactive, interacting with his or her environment and formulating ideas and intentions based on understanding and communication.

In following, actual theories on the role and mechanisms regarding motor learning arose. The three most important theories, based on current studies, will be discussed below.

1) The theory of the stages of motor learning

Two psychologists, Fitts and Posner (1967), focused their attention on the learning of a basic technical skill, highlighting the path by starting from the simplest part and moving to the most complex, which is achieved through several stages.

Specifically speaking, according to Fitts (1964), we can define three stages:

a) The cognitive stage: in this stage, we make decisions that allow the first attempts at performing of the movement. These decisions are accompanied and facilitated by the verbalization of the movement and the strategies adopted to accomplish it. Therefore, it is important to give a practical demonstration of the movement, by imitating or miming it, due to the fact that, according to the authors, it would be difficult, if not impossible, to verbally teach a movement.

Therefore, the motion must be received and stored, while also isolating its key attributes. In the early stages of motor learning, movements still require the use of attention-based resources and therefore should be isolated and stored individually.

b) The associative stage: various movements that make up the action will be conveyed into a single action. It is evident that the resulting motor activity will be different from the sum of the various movements performed individually.

In order to "condense" and increase the speed of two or more movements, transfer of some variables of the first task (already learned) must be transferred to the second or others. The transfer must, however, regard the general model of motor control, which provides that units of lower level contain the values of specific variables such as the muscles involved in the movement, while the higher levels of the hierarchy are based on a general representation of the movement that is independent of the specific limb or particular groups of muscles used.

In the description of this motor action, or skill, we can also recognize a higher and more general level in which the purpose of the action is represented (stoppage/brake), which is centralized and therefore common to both the limbs, and another level, the lowest, which concerns the values of the variables of each muscle and muscle groups (such as the force exerted), which is specific and cannot be transferred entirely from one limb to the other. In this last level, we find all those variables that have not yet taken part in the movement and are not yet included in the learning process.

We can therefore conclude that the associative phase is characterized by a process of “compression" of the motor activity, a process that takes place through the transfer of skills found in the movements that we have already learnt, and which belong to more general classes of common actions.

c) The autonomous stage: lastly, automation of cognitive processes in the underlying motor activity takes place, and the control system then operates in a more reduced way. In order to understand the process we need to remember the distinction between open and closed movement – a movement is open during its execution if you are not able to predict the performance and the value of the variables in the environment, while a movement is closed when the person carrying out the movement (following a period of practice) is able to maintain it within an environment that has become now completely predictable and controllable. Therefore, the transition from an open to closed movement represents the process of automation, meaning the possibility of this being done in an automatic (autonomous) way – moving resources to other processes of elaboration that take place in parallel with the autonomous motor activity.

Therefore, the learning process is a consequence of the acquisition of a more accurate representation of the action. The internal representation of motor activity may, however, refer to the specific movement we have learned, or to a more general class of actions to which the movement belongs.

In the first case, the relationship between representation and action is based on a one-to-one-theory (Adams) while in the latter case the same relationship is defined as one-to-many (theory of Schmidt).

2) Meinel's theory on the evolution of learning: moving from "raw" to the "refined"

According to the theory of Kurt Meinel (2000), just a few attempts of a motor task are enough for the student to acquire an early form of movement, rough and inaccurate, but which already contains the fundamental building blocks. This can take place provided that there are no perturbing factors and that the required task is not too difficult. So after a short time, the person reaches what Meinel defines as the *rough coordination stage*, characterized by a pattern of movement that is still *raw*, yet complete as far as the basics/fundamentals are concerned.

Therefore, the mastery of gesture is slowly gained in a proximal-distal sense (first movements of the large joints, then those of the extremities).

The movement will be regulated predominantly "from the outside", using visual inspection and the teacher's help (explanations and demonstrations), through the "external regulatory circuit". The contribution of "internal regulatory circuit", based on kinesthetic information (poorly perceived at this stage of learning), will be minimal, and the "sense of movement", on the other hand, will still be underdeveloped.

Mental representation (the program of movement) is imperfect, and control and regulation are affected by flaws and inadequate kinesthetic reaffirmation. However, after a given number of repetitions, an initial shape of the movement will be automated (global image formation).

The birth of this general scheme allows the gesture to be performed, in its entirety, without the intervention of consciousness, which can be directed in detail.

Therefore, it then becomes important to quickly achieve this automatism as "free" consciousness, allowing the student to direct attention to the more detailed aspects.

According to this author, the achievement of raw coordination concludes the first phase of learning, ranging from the understanding of the task up to early complete executions that are also structurally correct.

This stage of coordination is characterized by a coarse, or rough, form of the movement, and frequent failures are characteristic of the initial executions.

The cause of this can be attributed to insufficient processing of information (in terms of quality and quantity), a flaw in the program or method of movement, and poor regulation, due to unclear design, as well as feedback that is confusing.

At this stage, clear demonstrations, with just a few explanations, are fundamental in order to achieve the goal – additional indications are unnecessary, perhaps even harmful, because they confuse the students and, especially with beginners, should be eliminated or at least reduced to a minimum.

Verbal information may increase and refer to the more detailed aspects of the movement only when the student is able to *connect* to the motor experience after a number of attempts.

The student, now free from the control of the global movement, begins to perceive – through feedback – kinesthetic information that is essential for improvement of the program/method of action and the fine-tuning of the gesture.

In order to increase the likelihood and speed of success, the student will need to facilitate performance conditions. Therefore, the emotional climate in which the exercise is carried out is of paramount importance, and the right conditions can be extremely beneficial.

Through repetition, we can quickly reach solid results, and an initial automated general pattern of movement is created, allowing the student to perform the act in its entirety without having to pay a great deal of attention. The first form of automatism, which is a characteristic of raw coordination, however, represents a milestone for the subsequent completion of the gesture, as the student – freed from the consciousness control of the global movement – can focus on details. Therefore, while the general control scheme (initial autonomy) is used in the form of a mechanical guide, and the student can refine the more subtle elements. Therefore, he or she will be able to process a larger amount of kinesthetic information, eventually becoming more aware of the details that can be corrected or refined.

Motor execution, under favorable conditions, will then be almost error-free, with harmonized strength, accuracy, speed and consistency of the movement, as the external image of the gesture (the form) will be characterized by a fluid and harmonious course.

The characteristics of the second stage of learning are defined by Meinel as phase of the *fine coordination*.

Transfer of motor skill control, down to the smallest details, to automatic circuits determines the improvement of all parameters of the movement, which then appears more fluid, profitable and effective; this represents a fundamental step in learning and is reached through repetition.

c) **Schema Theory**

The basic concept of this theory is that of a schema, borrowed from psychology (Bartlett 1932), in which the term denotes an abstract representation stored in our memory based on a set of general rules, which characterize classes of objects, functions, and behavior.

Richard A. Schmidt (1982), advocate of this theory, tried to apply this concept to motor learning, in an attempt to explain how a motor program/method can be learnt.

In schema theory, two elements are essential: the generalized motor program and the motor schema.

The generalized motor program is seen as a mnemonic representation of a class of action (i.e. a group of responses that possess the same general structural features).

This is an elaboration of the concept, already used by several authors, of motor skills and programs, perceived as an abstract structure in memory that precedes actions and contains the spatial-temporal patterns of muscle contraction and relaxation which define the movement (Adams, 1987).

The motor program that starts the movement does not need the feedback produced by the response, due to the fact that it contains the centrally stored pre-structured set of muscle controls capable of initiating the action, determining which muscles to contract, in what order, strength, and duration (Schmidt, 1976).

Schmidt (1975, 1982) elaborates and enriches the concept of a motor program by introducing that of "Generalized Motor Program", in order to solve the problem of storage of massive amounts of information, which would occur by postulating a specific program for each action, and to explain the possibility to realize movements never performed before.

Therefore, the brain appears to find a solution to these problems by generating a general program (an operation performed by changing the existing patterns of movement) while also making it adaptable to new situations, the variability of the environment, and the different possibilities – or combinations – of movement.

A type of schema created in this way, therefore, is not developed in a static pattern, but rather within a "dynamic stereotype", or an "internal model that guides the movement" that is extremely flexible and which the student reshapes continuously, adapting the movement to the external and internal environment.

Confirmation of this is supported by the fact that a gesture learned with the dominant limb/hand can be replicated, although more coarsely, with the other limb, and this is possible despite the use of nerve impulses that originate from different areas of the brain and that excite different muscle groups (in this case, bilateral transfer).

The movement of the limb with the "weak" limb or hand, in general, is less effective because the subject, while using the same general program of movement, sends pulses of adjustment that are less precise, due to an insufficient specific practice (i.e. related to that movement) and the lower overall efficiency of the limb less used. With a symmetric workout, these differences can be reduced significantly.

Refined technical skill is therefore based on the action of actuating (regulatory) impulses, either implicit and explicit (conscious or unconscious), from the subcortical areas of the brain and which direct the muscles that allow you to adapt the general programs to environmental conditions in which the movement takes place, offering accuracy, effectiveness and proper use of strength (minimal effort).

Therefore, the motor program is not in a rigid sequence of instructions defined in every detail, and in each and every case, leading to the production of the same movement, but rather a general guide, which is quite schematic. It is, every time we carry it out, adapted to environment through appropriate actuating pulses (hence the name: dynamic stereotype).

Based on the aforesaid, the generalized motor program has invariant features that remain the same from one response to another, determining the essential elements of the class of actions that are under the control of the program and which define the basic shape of the movement. They are represented by:

a) Order of the elements, i.e. the sequence of muscle contractions involved in a movement or skill;

b) Temporal structure (phasing), or the proportion of time for each segment of motion, which remains constant even if the total time of movement changes (Schmidt and Young , 1987);

c) Relative strength, i.e. the constant relationship between the forces expressed by the various muscles involved in the action, regardless of the degree of overall strength.

Invariants characteristics define a generalized motor program, relative to a whole category of movements with a certain identity of the structure and a global resemblance or similarity.

According to Shapiro and Schmidt (1982), invariant features are the factors that allow us to identify the movements that belong to the same class – when, for example, two movements have an identical structure regarding time, they can be considered to be governed by the same generalized motor program.

The same motor program should be adapted to the specific requirements of a situation, and the necessary changes in the movements of the same class should also be produced by changing only a few parameters.

These response specifications modify the existing motor program we have stored in order to adapt to the real situation, that which changes are not the invariant features, but rather the surface characteristics of the response (Shapiro and Schmidt 1982).

The motor pattern can hence be considered a prototype – an abstract rule to specific information about the members of a class (Posner, Keele 1968) and a generalization of concepts and relationships derived from experience – allowing you to identify the specifications required to carry out a particular version of a program of movement.

The generalized motor programs are therefore the starting point for the development of motor patterns based on the settings of the feedback. The execution of any movement, and therefore also in technical sport, is never repeated exactly the same way. Adjustments and changes to the motor program must be constantly made in order to meet the demands within the environment, while in the open-skill branches of knowledge or skills, processes regarding adaptation to constantly changing situations are of particular relevance to the achievement of objectives, in closed-skill areas the adjustments required are minimal since the execution environment can be considered relatively stable.

Even the motor schema, much like the motor program, is generalized: variable parameters determine, in turn, the result of each new movement of the same class.

Schmidt (1975) believes that after the execution of a movement with a generalized motor program, the subject storea basically four types of information relating to:

1. **Initial conditions** (information on the status of the muscular system and the environment before the response. For example: the position of the limbs and body, environmental conditions, etc.);

2. **Specifications in response to the motor program** (parameters of strength, direction, speed, etc., which are appropriate in this situation);

3. **Sensory consequences of the response produced** (information based on sensory feedback during and after the completion of the movement);

4. **Results of the movement** (information on the result).

As a general rule, with each subsequent movement of the same class, the schema (scheme or model) is updated and strengthened, also in relation with increasing the accuracy of the feedback response, while at the same time specific information is eliminated, solving the problem of the amount of data to be stored (Schmidt, 1982).

Through the execution of multiple actions or movements from the same class, the method (schema) becomes progressively richer, clearer and more precise. On the basis of this schema more specific movements, which have never been made before, can be generated. Schmidt highlights, in this regard, two states of memory that are based on the relations established among the four sources of information we have, specifying two aspects of a more general concept of *schema*: recall schema and recognition schema.

The recall schema allows us to determine a new response by selecting and providing generalized motor program parameters necessary for the execution of the movement that is suitable to the demands of the task.

MOTOR LEARNING: PSYCHOBIOLOGICAL FACTORS

The subject of motor learning has been the subject of studies from many different branches of science – however, psychology, since its beginnings, has practically made this subject its own. The result has been the creation of two main theories that try to explain learning: behaviorism and cognitivism.

Behaviorism and *connectionism* (see Rumelhart and McClelland, 1991) consider learning as the consequence of the association between a stimulus and a response, in which the subject is passive, and everything that he or she learns is a *copy of the experience.*

According to this theory, learning is found in overt behavior and expresses itself through habit and the ability to carry out certain tasks. The greatest exponent of this view is Ivan Petrovich Pavlov (1849 -1936) who, with his reflexology conditioning (Pavlov, 1927), asserts that one can speak of learning only in the event that he/she establishes new relationships between *stimulus and response*, as a result of a procedure defined today by the term *classical conditioning*.

Pavlov noted this fact in a completely random manner, during an experiment with Siberian dogs that was aimed at investigating the relationship between the composition of the food and the saliva of the animals. These dogs initially produced saliva only when actually given food, but later salivation occurred even the mere sight of food or the person who usually fed them.

This observation led him to the understanding that this reaction could not be a simple reflection of innate biological reflex, but rather a learned phenomenon. He decided to submit his dogs to further experiments: first, he exposed them to a neutral stimulus, for example, the sound of a bell (i.e. unable by itself to cause salivation), but which after a short interval the ringing was paired with the provision of food, and salivation followed, as we can rightly imagine (unconditioned reflex). This was then repeated several times as a combination of the two stimuli in succession (sound and food) and at the end he noticed that the dogs began to salivate at the mere sound of the bell, therefore highlighting this as an involuntary response that was not present before the experiment began (conditioned reflex).

Moreover, Pavlov noted that if you continued to ring the bell for the animals, but then not bring the food, salivation tended to disappear (the phenomenon of *extinction*); he also observed that, once the experiment was interrupted, if the ringing was subsequently made, the sound of the bell was still able to induce salivation (phenomenon of *spontaneous recovery* of the previous response).

Moreover, Pavlov saw that salivation occurred even if you used a sound that was more or less similar in volume (the phenomenon of *generalization*), while no salivation was obtained if the food was associated with a sound that was much louder than the original (the phenomenon of *discrimination*).

Another theory was subsequently developed by Edward Lee Thorndike (1874 - 1949). Based on his work, the concept of *learning by trial and error* emerges as a result of experiments on cats deprived of food and locked in a cage equipped with a closure (Thorndike, 1911).

The cat had the opportunity to exit only if it was able to remove the closure of the door.

The study showed that the animal adopted a series of behaviors: initially, it performed several attempts (biting, scratching, pushing, etc.) and then began to gradually eliminate the errors, until it reached the goal of "getting out".

The cat, in doing so, had learned by "*trial and error*".

This form of learning is based on *Reward or Punishment* and takes the name of "*instrumental learning*", due to the fact that the functional behavior is aimed at obtaining certain consequences (reward, if successful), or to avoid others (Punishment in the event of failure).

Based on this theory, those actions that produce satisfactory effects are more likely to be repeated and then learned. Otherwise, actions that lead to unpleasant or inconsequential effects are less likely to be repeated.

The result of the aforesaid is that the repetition of valid actions (practice) contributes to learning. Therefore, success is a powerful reinforcement – more relevant than punishment and therefore more influential on motivation.

Ensuing experiments soon came forth through the work of Burrhus Frederic Skinner (1904 -1990), who introduced the concept of *operant conditioning* (Skinner, 1938).

The experiment devised by Skinner, consisted of placing a mouse in a cage (a Skinner box) in which there was a lever (or button), which, once pressed, put food in the cage.

A few days before the experiment, the animal was put on a minimal diet in order to induce a greater motivation to search for food. When the animal was introduced into the cage, it accidentally pressed the lever and received food. After a few more random "pushes", the mouse would then press the lever more frequently. The action of the animal is therefore instrumental in the successful achievement of a rewarding goal.

The test showed that once the task has been learned, the action occurs whenever the animal is introduced into the cage. With the food as a positive reinforcement, conditioning is called "operant".

“Operant" responses are defined as finalized behavior.

A similar experimental technique is that of *shaping*, which rewards all responses that come close to that which is desired, increasing the reward every time you get closer and closer to the correct response. Shaping was inspired by the experiential theory of John Broadus Watson (1878 -1958), who believed that man is a product of his experience, taking a central role in learning (i.e. the way in which mankind learns, through experience) motor behavior, verbal behavior, etc., which will be essential in building his or her personality (Watson 1928).

Straddling the two major theories, we find Gestalt psychology, which focuses on learning through *insight* (intuition), of which Wolfgang Köhler (1887-1941) is one of the greatest exponents.

In order to formulate his theory, he began with the observation of the behavior of a chimpanzee placed in front of a problematic situation. The animal was put in a cage and was able to reach the food placed outside of his cell only with the aid of a tool. The monkey, in this case, Kohler noted, did not act by trial and error. Instead, the animal suddenly used restructuring of the perceptual field, using two sticks to bring food closed, therefore resorting to a strategy rather than a random action (Köhler , 1947).

The Gestalt theory, unlike behaviorism, takes the learner 's creativity into consideration – a capacity that allows him or her to capture the key aspects of a situation that has never been faced before.

Cognitivism, however, when applied to studying the mental processes that occur in cognitive activities, puts design and processing of information at the foundation of the learning process. Therefore, learning is considered an active process in which the stimuli are processed, transformed, and integrated. This process allows us to remember a large amount of information, while also making inferences through manipulation.

The theme of the processes at the foundation of motor learning has influenced almost every author, each of whom has left his or her contribution. Among these, we should highlight the work of David Everett Rumelhart (1980), who introduced the schema theory (or scheme theory, i.e. "abstract structures of knowledge"), stating that information is organized and placed based on relationships and inter-relationships.

In this regard, Jean Piaget (1896 -1980) had long before placed schemas at the center of intelligence development patterns and cognitive activities of children (Piaget, 1969).

However, these schemas, according to the cognitive psychologists, have more complex functions. Thanks our knowledge schemas, we can understand the information coming in, activating patterns suitable to interpret them and learn them, while also integrating them into the schemes we have available, or by creating new ones. In this way, new knowledge that fits into a pattern constitutes a learning experience, which has as a consequence a change in the schema itself.

On the other hand, according to Rumelhart and Norman (1981), a schema, or scheme, can be changed in three ways, therefore corresponding to three different types of learning. The simplest is the extension of the scheme through the addition of new information. In the event, however, that the nature of the new information is likely to change the associative links of content already owned, there will be a restructuring of the scheme, with the coexistence of old and new information. On the other hand, when the new stimuli do not require a real restructuring because such they are added to recently-formed patterns, and therefore more flexible, then a partial adaptation of the relationships between the existing information is created, in a process defined as "tuning". Therefore, the flow and the acquisition of new information, especially in complex tasks, may require modifications of all three types of learning at a later time, thus determining the increase, restructuring and adaptation of knowledge.

While it is true that animal experiments by leading scientists such as Pavlov, Skinner and others helped allow for further clarification on the basic processes of elementary motor learning, as highlighted by classical conditioning and operant conditioning.

That said, it important that we consider the fact that there is complex motor learning that fall under the direct influence of higher cognitive processes.

For this reason, in the case of highly complex motor skills with rhythmic structures in uniform, we find ourselves in front of sequences of predefined movements that are sometimes too fast to be explained on the basis of the temporal relationship between the conditioned stimulus and the conditioned response.

In contrast to what happens in the case of conditioning, awareness is present and even necessary in the early stages of learning a complex motor skill.

In the later stages of learning, awareness retracts, having lost its initial function, and is replaced by automatisms that are increasingly perfected. Not only that, but its rather random reappearance in the later stages of learning can seriously hinder or damage results.

The learning of complex motor skills, in general, is divided into three stages: initially the subject differentiates the main components of the motor skill, and subsequently learns to perform with efficiency increasing minor movements belonging to each of these components, and finally he or she learns to effectively coordinate the increasing number of main components.

Generally speaking, the learning of complex motor skills follows a characteristic pattern: the main components are differentiated and quickly learned; the difficulties begin when it comes to coordinating these main components. At this point, there is a setback in the learning process, called " plateau", during which practice, if with its intense and tenacious nature, fails to show improvements in individual performance. It is as if the body is in need of a "pause for recovery", leading to insensitivity – a lack of response – to external influence or stress.

In following, this stalemate is suddenly unraveled. The process continues in the same discontinuous manner, up to a maximum efficiency and level of performance, which varies from individual to individual.

Furthermore, we can observe that the visual and auditory inputs and perceptions, with the progress of learning the complex motor skill, tend to be more and more replaced by proprioception, which is transmitted from the muscles and joints of the body.

In addition to this step, further clarification and distinction in terms of learning can be made between what we can call Inattentive Learning and Unintentional Attention (also called non-attentive and non-intentional learning).

Inattentive Learning: psychophysiological reflexes, spontaneous responses, and physiological (organic) functions correspond to biological memory.

Unintentional Learning: unintentional stimuli are voluntarily processed, stored in the memory, remembered and reused, through subliminal perception and incidental learning.

Controlled processes, unlike an automatic process, show an intense frequency of monitoring, frequent memory access, compatibility of orderly sequences, and a great deal of limitation regarding the capacity of the system.

Each of us has a set (i.e. a schema that offers to a predetermined cognitive, emotional, behavioral pathway), which, if functional, allows for training and automation, leading to a reduction in the time and mental effort necessary during the learning process.

For example, imagine automation and autonomous behavior. This allows the well-trained athlete to perform without any conscious and voluntary intervention. This means that he or she is not thinking about the motor action itself.

Execution can be considered perfect when it is closest to the ideal model that the athlete has internalized, and this happens by continuously refining the motor skill through long workouts (Cox, 2002).

In this regard, it is not uncommon to hear professional sportsmen claim that they have achieved their best performance in an automatic way – they found themselves in a situation with high performance focus, yet without having experienced the physical and mental perception of the effort put forth to do what they were doing (Williams and Werner, 1993).

In fact, expert athletes are able to greatly develop their anticipatory capacity, successfully recognizing and encoding complex structures and quickly extracting the correct information during execution.

Awareness, time and time again, plays an important role in moving voluntary attention-based focus and the acquisition of new aspects, even if they conflict with their own schemas and methods, which were previously learnt.

The role of metacognition is therefore very important, as self-consciousness and self-awareness in the active role with the reality, as well as cognitive, emotional, and motor processes, clearly paired with choices (in an automatic/controlled relationship).

Robert Nideffer (1976) was the first author who, in the field of sports psychology, used the concept of *attentional style* to highlight the importance of the athlete's personal cognitive style and how it is possible to pass from the assessment of attentional style to the formulation of systems for psychological training.

The Nideffer's model describes attentional processes in a system in two dimensions: width and direction.

Width is expressed as the amount of information to which a person can pay attention, which can be either wide or narrow.

Direction, however, depends on the object of our attention, which may be internal with regard to the individual (thoughts, physical or emotional states) or external (environmental stimuli).

The intersection, or the meeting place, of these features gives rise to four dimensions of attentional styles.

It is therefore essential for the athlete to know his or her emotional style in order to control the negative effects, while also making best use of the emotional activation.

By starting from automatic patterns or models, through control and intentional movement, we can learn new schemas and new models.

RESEARCH SCOPE

The scientific community unanimously agrees that regular practice of motor activity, above all when started at a very young age, has overall effects that are truly beneficial (Boreham and Riddoch, 2001; Cale, 2004; McMurray, 2003).

In fact, motor activity represents an important tool for the physical and psychological development of a child, due to the fact that it influences muscles, bones, circulation, breathing, and coordination, in addition to having a positive impact on social behavior and recreational activities.

Recently, Boreham and Riddoch (2001), along with other scholars, have observed how sports practiced by young people have an ever-decreasing role, a fact that is directly related to the onset of the Playstation, Wii-Fit, and other video consoles (Sirard and Pate, 2001).

There is little doubt that a key role for promoting physical activity in young age groups is that of the school and public institutions (Cavill et al., 2001).

Physical education in the school environment and during early growth, in fact, is the central nucleus of scientifically correct training in the field of motor skills and development (Cavill et al., 2001).

Getting young children started with sports should therefore be a fundamental part of school programs and after-school activities.

However, the choice to practice a sport is not always simple. Families and schools generally have doubts about whether or not a sport offers a complete and correct activity for the physical development of a child (Marchi, 2000).

Sports not only contribute to physical-structural development and improved coordination, but they also play a fundamental role in social skills and games (Giovannini e Savoia, 2002).

Respecting and supporting the choice of the children is therefore paramount. Therefore, a child’s passion for physical activity, experienced as a game, helps foster his or her level of dedication, concentration, and motivation – aspects that contribute not only to physical growth, but also positive emotional development (Allen, 2003).

The understanding of the important role played by physical activity in the development of a child pushed the author of this study to embark on a doctorial research project that focuses on motor activity and skills in children, placing a great deal of attention on the responsibility of schools and educational centers in a child’s choice of sports, as well as the best training methods for the acquisition of new motor skills based on how practice or training is organized.

By teaching a child the basics, a skill or a notion becomes much more effective and useful for his or her growth when we work with methods that favor the learning process.

In fact, children are able to elaborate varying and great quantities of information without particular difficulty. However, success will take place only if the offered stimuli are suitable to the age group.

The learning process in children develops in a way that is quite different from that of adults. We can rapidly add a set of new elements only if they are the result of the child's direct experience. If this occurs independently, the learning process is further enhanced.

Each and every new skill is learnt through later steps that differ based on the age of the child.

The age group of this study, ranging from 7 to 10, represents a stage that is defined by the development of coordination in movements, and therefore motor skills that lead to learning.

During the initial learning phase of a motor skill, the subject, a preteen in this case, must understand that he or she is trying to carry out and gain an idea – a mental image of the movement – in order to build a correct point of reference, which grows more and more accurate during practice. This model is used as a guide for the execution of the skill and also as a reference of performance and how to correct mistakes.

We must also underline the importance of repetition in a successful learning process – the quantity of repetitions is the foundation for strengthening and reinforcing learning.

These repetitions, or reiteration, are necessary in order to store information on initial conditions, the parameters used for response, sensorial feedback, and the results reached.

The performance of the skill, each time, is enhanced by doing it again and again, leading up to the creation of a stable model that is the means by which the movement gets closer and closer to the desired model.

The real effectiveness of total practice (the number of repetitions) is commonly accepted with regard to the learning process and the perfection of the movements, either new or technical.

During my research with elementary school children, I assessed if – and to what degree – different timings of the trainings were able to affect the learning of a new motor skill.

I decided to use time distribution of training/practice as an optimizing parameter to be studied and analyzed. The results obtained were designed to clarify a debate that has been running for more than a century: many authors support the idea that concentrating practice over a short time is more successful, while others state the opposite. Tangible, unequivocal results that show the best learning methods would allow us to define training programs that are more effective and efficient.

In order to reach this goal, the selected subjects were initially given a new motor skill to be learned.

Sixty children participated in the study. They ranged in age from seven to ten, 30 boys and 30 girls, all elementary school students in the city of Catania, Italy.

The children who took part in the research were selected in a random manner within the school. No participants showed motor or cognitive deficits. None of the young students had ever carried out the activity that is the subject of this study. The school's principal and parents of the children gave their consent before any research was carried out.

Experimental protocol defined the preteen's learning of an ocular-manual skill, which was completely new to him or her. Moreover, half of the children had to learn this skill using their dominant hand, while the other half with their weaker hand.

MATERIALS AND METHODS

Participants

Sixty children who were healthy and developing typically (30 male, 30 female; mean age 8.5 years, SD 0.89, range 7–10) voluntarily participated in the study. Table 1 summarizes gender and age of the 60 children.

Subject	Dominant		Non Dominant	
	gender	Age (yr)	gender	Age (yr)
1	girl	7	boy	7.2
2	boy	7.1	girl	7.3
3	girl	7.1	boy	7.3
4	girl	7.3	girl	7.4
5	boy	7.5	girl	7.5
6	boy	7	boy	7.5
7	boy	7.6	girl	7.6
8	girl	7.7	boy	7.6
9	boy	7.8	girl	7.7
10	girl	7.9	boy	7.8
11	girl	8	boy	8
12	boy	8.1	girl	8.1
13	girl	8.1	girl	8.3
14	girl	8.8	boy	8.4
15	boy	8.5	girl	8.4
16	girl	8.5	boy	8.5
17	boy	8.6	girl	8.6
18	girl	8.7	boy	8.7
19	boy	8.8	girl	8.8
20	boy	8.9	boy	8.9
21	girl	9	boy	9
22	boy	9.2	girl	9.2
23	girl	9.5	boy	9.3
24	girl	9.6	girl	9.3
25	boy	9.8	girl	9.5
26	girl	9.2	boy	9.5
27	boy	9.2	boy	9.6
28	boy	9.5	girl	9.8
29	boy	9.9	girl	9.8
30	girl	10	boy	10
Mean		**8.46**		**8.49**
S.D.		**0.93**		**0.87**

Prior to participating in the experiment, parental consent and child assent were obtained for the children who participated. Inclusion criteria were children who were developing typically and performing at grade level in school. Exclusion criteria were any orthopedic or neurological problems that would interfere with the ability to perform a coordinated arm movement. Half of the participants (15 boys and 15 girls) have used their dominant arm while the other half (15 boys and 15 girls) has instead utilized the non-dominant arm. The Table 1 shows the age and gender of the group of children who used the dominant arm and the group who used the non-dominant one; as can be seen, the mean age of the children of the two groups was similar and did not differ statistically (P > 0.05) .

Figure 2: Wireless device used in the present study (FreeSense, Sensorize s.r.l., Rome)

Measurement Settings.

During the test, subjects wore an elastic belt with a WISD (FreeSense, Sensorize s.r.l., Rome; sampling frequency = 200 Hz) placed with a band on the wrist of the arm they would use to throw the ball (Figure 2).

This device is lightweight (93 g) and contains a triaxial accelerometer to measure accelerations along the three body axes (antero-posterior, AP; latero-lateral, LL; and cranio-caudal, CC) and gyroscopes to measure angular velocities around the above axes (± 6 g and ± 500° s-1 of full range, respectively). Data capture was managed using a Bluetooth protocol and directly loaded into a database. Matlab (The MathWorks Inc., Natick, MA) scripts have been implemented to calculate and analyze the WISD measures.

Task

The task for the children was to throw a tennis ball to hit a target (a 1.5 liter green bottle full of water) placed in front of him/her at a distance of 3 m. Thirty children had to perform in each session 20 throws with the dominant arm and another group of 30 children with the non-dominant one for 5 consecutive days (Monday to Friday). After 7 days, on the Friday of the following week, all the children had to perform a session of 20 throws to verify the amount of learning (control sessione).

Figure 2 displays the recording of 7 consecutive hits recorded from one child. In a single hit it is possible to identify the onset of movement (O), its end (E) and the perk of acceleration. Evaluated parameters were the number of successes (goals), the duration of gesture (time from O to E), the duration of acceleration from 0 to the maximum value (time to peak, Time from O to P) and the maximum value of acceleration (peak acceleration). Routines were developed with MATLAB software (The MathWorks Inc., Natick, MA) to calculate these parameters.

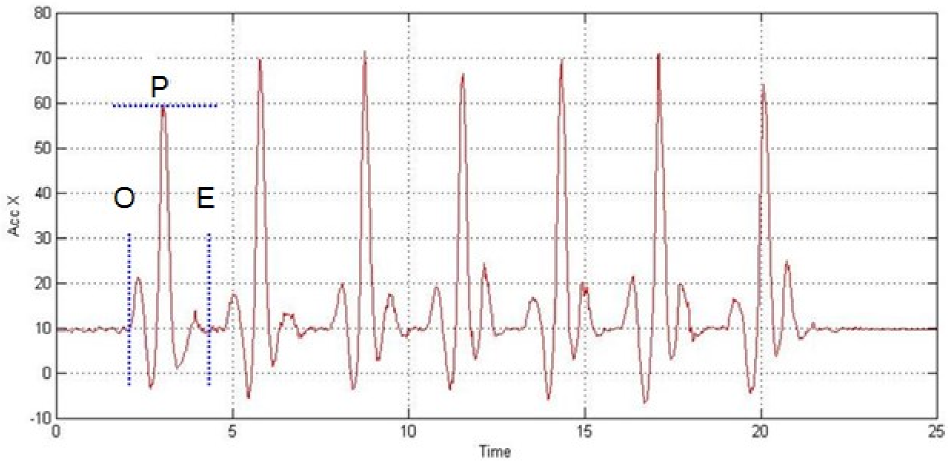

Figure 3: Acceleration in function of time of 7 consecutive hits performed by one child. Evaluated parameters were the number of successes (goals), the duration of gesture (time from O to E), the duration of acceleration from 0 to the maximum value (time to peak, Time from O to P) and the maximum value of acceleration (peak acceleration)

Data analysis

All behavioral measures were averaged across blocks of trials and days of practice. Data was collected and averaged, and then compared by using Data analyzed with the unpaired t test (two-tailed) or one-way repeated measures analysis of variance (ANOVA; Friedman test), followed by Dunn's Multiple Comparison Test. Significance was set at $p < 0.05$ and all data is reported as mean ± standard deviation. All analyses were performed by means of Systat software package version 11 (Systat Inc., Evanston, IL, USA).

RESULTS

Figures 4-7 summarize the whole results obtained in the present study. As can be seen, children using the dominant arm (D group) had a number of successes (goals) significantly higher ($p<0.01$) than that of the children using the non dominant arm (ND group).

During the 5 days of training, a small increase of goals in D groups of children was observed only in day 3. No significant differences were observed for the other evaluated parameters, i.e. duration of performance, time to peak and peak acceleration.

Concerning the influences of age, it can be seen that children having an age between 9 and 10 years displayed better results with respect younger subjects, in both D and ND groups. Finally, no gender difference was observed both for the D and ND groups.

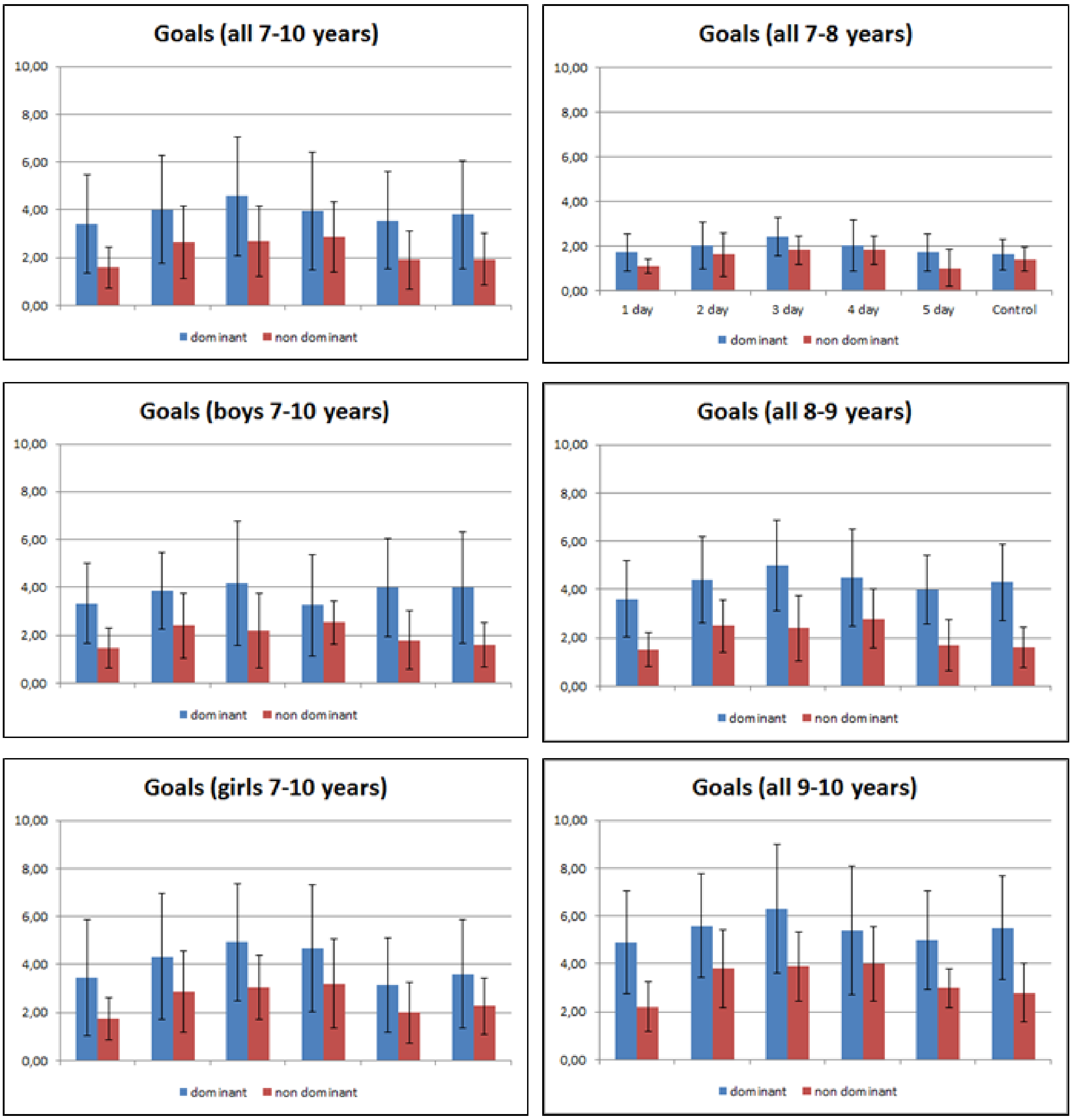

Figure 4: Number of successes obtained in the present study.

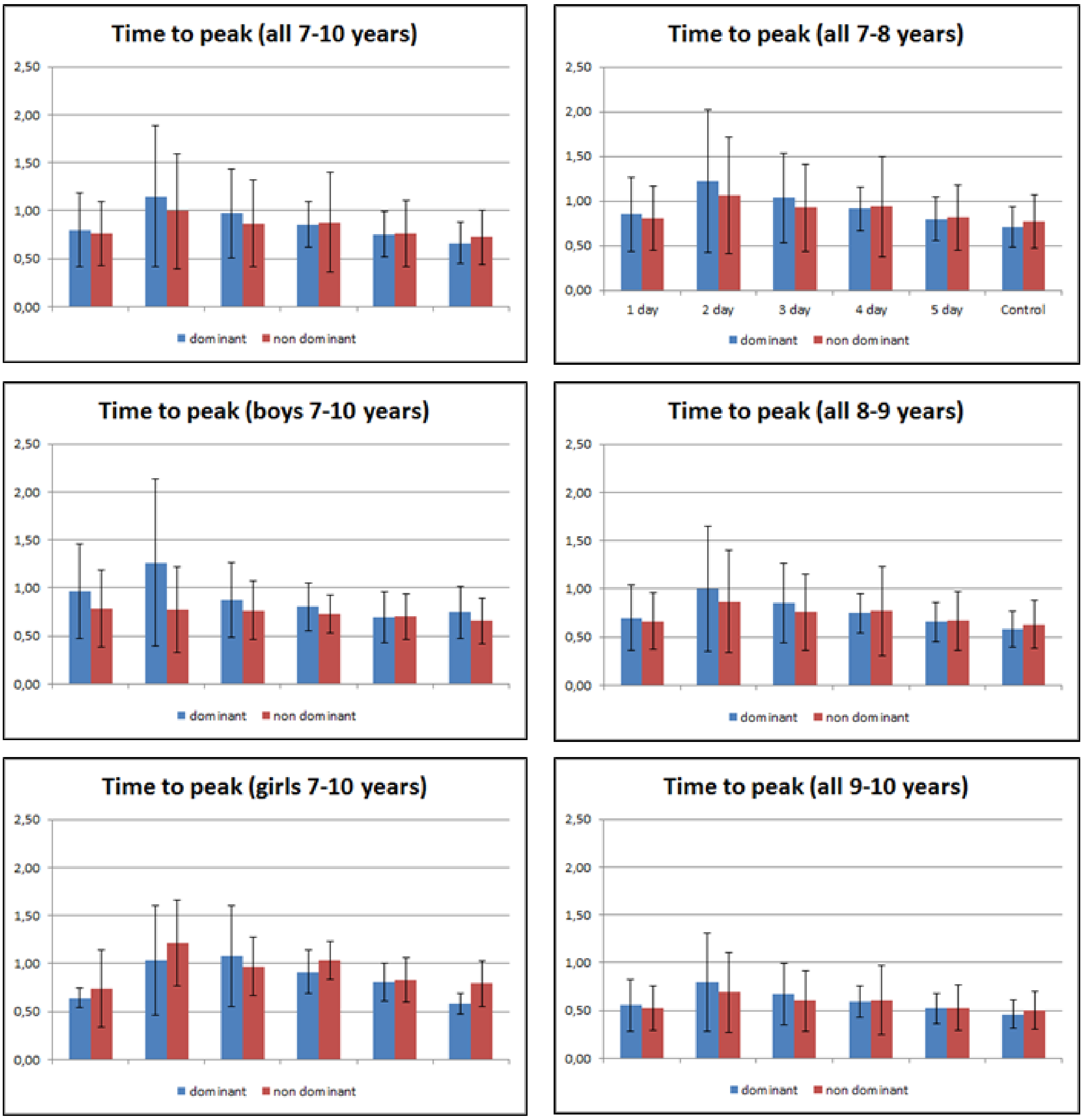

Figure 5: Time to peak measured in the present study.

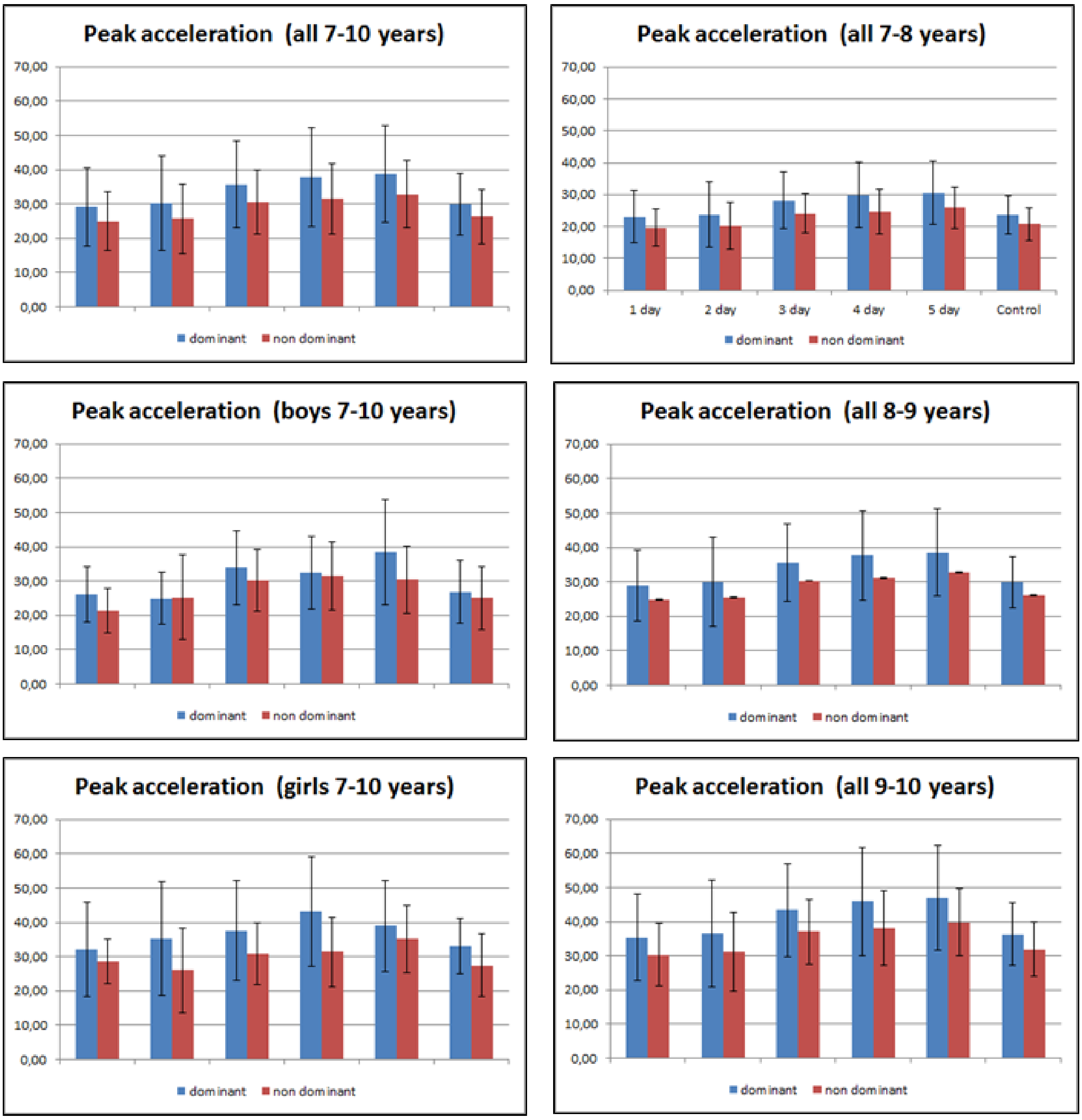

Figure 6: Peak acceleration measured in the present study.

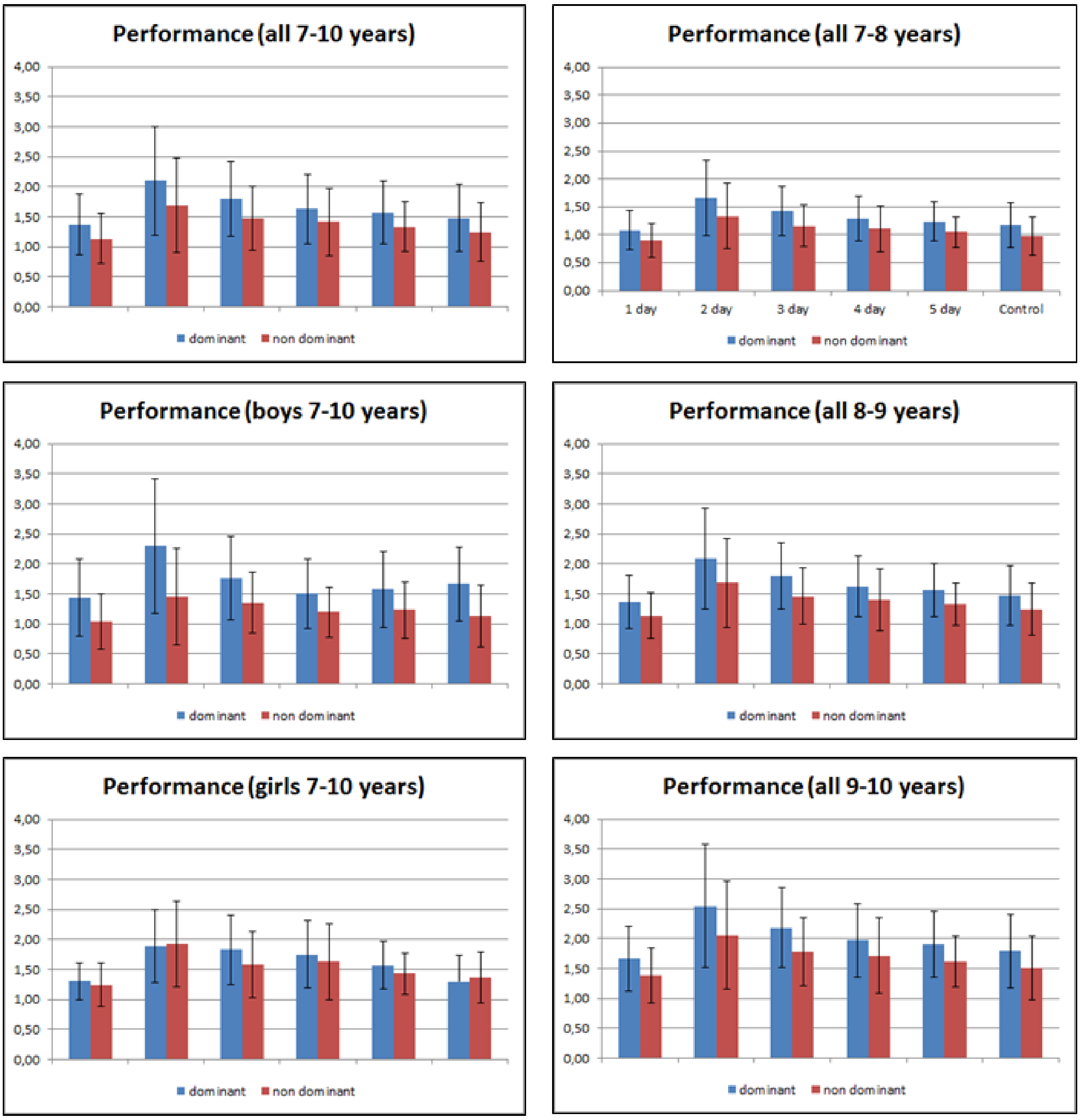

Figure 7: Performance measured in the present study.

However, as the lack of statistically significant differences may be due to the considerable inter-individual variation, I have analyzed the data as a percentage change compared to the value measured on the first day.

As can be seen in Figure 8, where the present results are summarized, children using the dominant arm (D group) had a number of successes (goals) progressively and significantly ($p<0.01$) increasing during the 5 days of training.

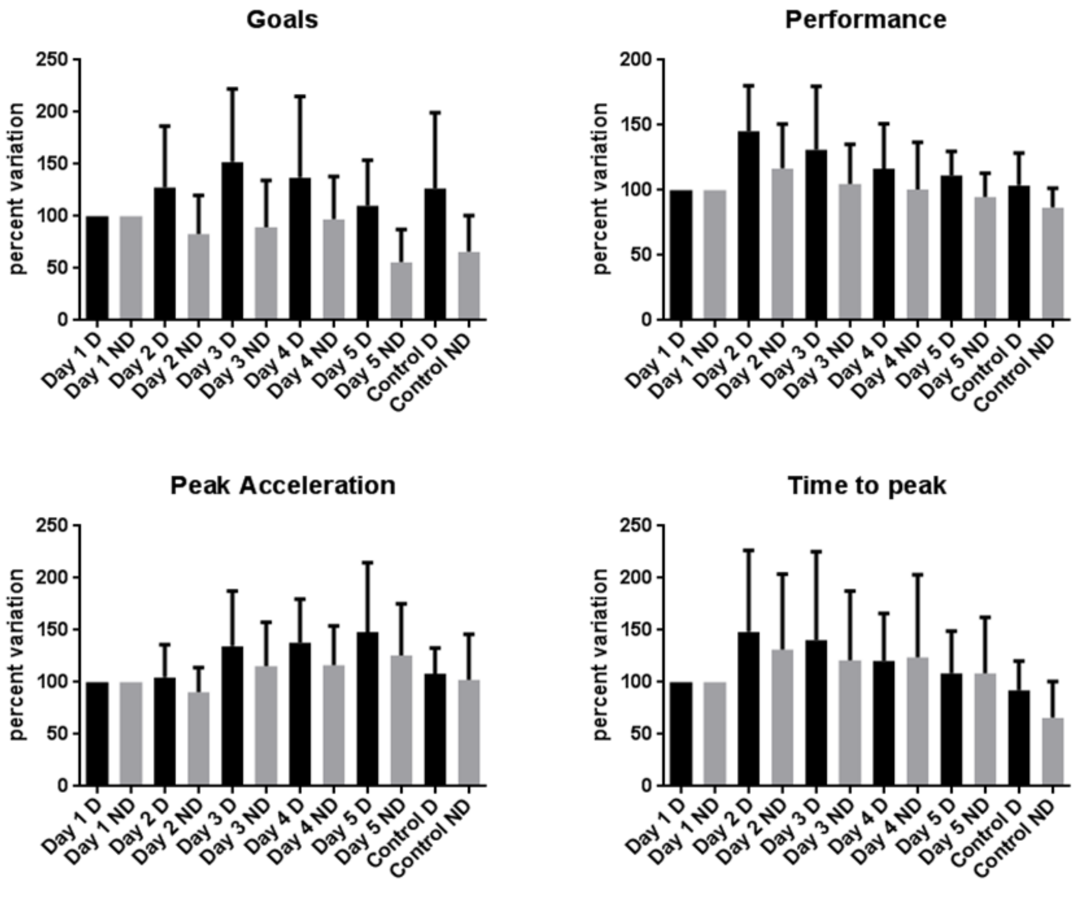

Figure8: Results obtained in the present study expressed as percent variation (black= D group; gray = ND group).

On the other hand, children using the non-dominant arm (ND group) did not exhibit any increase of goals during the training. Moreover, children D group had a significant improvement in performance, perk acceleration and time to peak, while the children of the ND group showed no significant changes in these parameters.

A final observation was that, after a week, the improvements were observed in group D during the training was no more present. In fact, both in D and ND group the values of the four parameters measured at control did not differ statistically from those observed in the first day.

DISCUSSION

The present results, obtained using a sample of 60 children with an age between 7 and 10 years (30 boys and 30 girls, with a mean age of 8.5 years), allow us to draw some conclusions.

First, as expected, the use of the dominant arm results in a greater number of successes, regardless of age and gender.

Moreover, the probability of success increases with the age of the children, independently of they were using the dominant or the non-dominant arm. The observed improvement is associated to significant changes of some kinematic parameters of the gesture, as duration of performance, time to peak and peak acceleration.

Furthermore, a training session of only 5 days was sufficient to achieve significant improvements in the success probability of a simple but not usual gesture, as the launch of a tennis ball to hit a target, but only when the children were using the dominant hand. It is therefore reasonable to conclude that, at this age, motor learning is already concentrated on the dominant side

However, the improvement observed after 5 days of training was no longer present to a control performed after one week. It can be, therefore, concluded that, in order to learn a new gesture in a stable manner, training must be continued for a greater period of time.

Finally, the present study underlies the efficiency and reliability of a WISD (FreeSense, Sensorize s.r.l., Rome) for the analysis of the kinematics of an arm movement, which resulted a device easy, economical and feasible in the field. This device, positioned around the participants' waist, has been successfully used for estimating traversed distance in level walking (Kose et al., 2011) and for assessing locomotor skills development in childhood (Masci et al., 2013), To our knowledge, this is the first time it is used for measuring kinematics of arm's movement.

FINAL REMARKS AND CONCLUSIONS

Maximization and optimization of the learning process are issues that interest almost everyone, whether we are dealing with cognitive or motor learning.

The possibility of creating conditions, which greatly improve and foster how an individual takes advantage of the time and effort dedicated to learning, takes on a fundamental role in various sectors of life: school, training, rehabilitation, physical therapy, and sports.

Successfully highlighting the differences that we find during the learning process – using various methods – can help us understand not only what is the best way to learn, but also *how* we learn.

With reference to the role of practice scheduling and distribution in the effective and consolidated learning of a motor skill, based on the results obtained from this research, we can deduce that a reliable quantification of the learning stages is based on the careful analysis of time distribution of practice with the aim of obtaining precision and high levels of performance stability.

In line with data found in current studies, repetition was found to have a decisive role in reaching learning goals and skills. As a matter of fact, this concept of skill assumes that automation of a movement takes place after, or through, a period of practice.

Schimdt himself underlined that *in structuring practice session, the number of practice attempts should be maximized,* reaffirming that *the decisive factor that* *contributes to motor learning is the repeated execution of the exact movement* (Schmidt and Wrisberg, 2000).

Therefore, it is clear that there is a necessity to *practice*, giving time to repeat that which is needed during the motor learning stage, which Fitts and Posner (1967) called the *associative stage* – the time in which the student gains orientation towards the association and *setting* of each element needed to refine and perfect the skill.

As Bortoli (2003) wonderfully highlighted: *the effectiveness of teaching must be founded on two aspects that the teacher must know how to manage in way that is increasingly precise: the time needed to ensure that the students carry out a task in a significant manner, and the chance or opportunity for all students to successfully practice the defined task.*

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