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PHD THESIS SUMMARY

DIGITAL TECHNOLOGIES FOR THE DEVELOPMENT OF MOTOR COORDINATION THROUGH PERCEPTION-ACTION

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List

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1) **Mancini N**, Mancini S, Grosu E,F. (2023). Effects of integrated training with the use of action perception light sensors on agility, quickness and motor reaction in female volleyball players. Italian Journal of Health Education, Sport and Inclusive Didactis ISSN:2532-3296.V.7,N.2,(2023). https://doi.org/10.32043/gsd.v7i2.846

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3) **Mancini N**, Colella D, Grosu V T. (2022). Relations between agility tests and motor reaction times in young sportsmen. Proceedings of the 10th Edition of International Scientific Conference; "The infinity of human performance"; September 15-16, 2022 Targu – Jiu;Academica Brancusi" Publishing House, 2022, ISSN2344–1003;ISSN–L2344–1003 https://www.utgjiu.ro/fefs/cercetare/2022/MANCINI.pdf

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5) Colella D, Monacis D, d'Arando C, **Mancini** N, Massari F. (2023). The learning of motor competencies through different teaching styles. Analysis of the behavior of the Physical Education teacher in secondary school. XIII National Congress SISMES: Research and Training Applied to Motor Sciences, Milan (Italy) 4-6 November 2022. Sport Sci Health (2023) 19 (Suppl 1):S1–S149. https://doi.org/10.1007/s11332-022-01027-7

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8) Fiorenzo Moscatelli, Giuseppe Cibelli, Anna Valenzano, Vincenzo Monda, Giovanni Messina, Chiara Porro, Gabriella Marsala, **Nicola Mancini**, Maria Antonietta Panaro, Antonietta Messina, Rita Polito. (2023). Dorso lateral prefrontal cortex (DLPFC) stimulation improves reaction time and percentage of errors in volleyball players. ***Under review in Sports - MDPI, ISSN: 2075-4663***

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ABBREVIATIONS

AP = Anti – Phase

BMI = Body Mass Index

bpm = beat per minute

CG = Control Group

CMCT = Central Motor Conduction Time

d= d-Cohen 's effect size

DLPFC = Dorsolateral Prefrontal Cortex

DX = Difference of Means

EF = Executive Functions

EG = Experimental Group

EMG = Electromyography

gl = liberty grade

HAT = Exagon Agility Test

HF = High Frequencies

ICC = Interclass Correlation Coefficient

IP = In – Phase

ip% = increase percent

LED = Light Emitting Diod

M = mean

M1 = Primary Motor Cortex

MEP = Motor Evoked Potential

MT = Motor Threshold

NIBS = Non – Invasive Braian Stimulation

p = significance

PAD = Perception-Action Devices

PCF = Perceptual Cognitive Functions

RA = Reactive Agility

RGB LED = Red Green Blue Light Emitting Diod

RT = Reaction Time

RTc = Complex Reaction Time

rTMS = Repetitive Transcranial Magnetic Stimulation

RTs = Simple Reaction Time

RTsLL = Reaction Time Simple Lower Limb

RTsUL = Reaction Time Simple Upper Limb

SD = Standard Deviation

spTMS = Single-Pulse Transcranial Magnetic Stimulation

S-R = Stimulus – Response

TEC = Theory of Event Coding

TES = Transcranial Electrical Stimulation

TLL = Tapping Lower Limb

TMS = Transcranial Magnetic Stimulation

TUL = Tapping Upper Limb

VTA = Ventral Tegmental Region

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INTRODUCTION

Keywords: coordination, agility, quickness, action perception tools, executive function, perceptive-cognitive functions, cognitive-motor training, neurocognition.

In the last 20 years, research has been increasingly engaged in understanding how the use of technology in the field of motor skills and sports can contribute positively to significantly improve the processes of learning, training methodologies, methods, and tools for assessing and storing data related to physical activity and motor performance. The use of multimedia aids in sports has become indispensable in the modern training process. In the past ten years, the approach to organizing sports training has undergone radical changes, both in amateur and professional contexts, as well as in the training of young athletes in sports clubs and schools. Thanks to the widespread adoption of digitization, numerous devices are now widely used to record and analyze training parameters. In the sports world, studies focused on executive functions (EF) and perceptual-cognitive functions (PCF) are of particular interest. They are useful skills for athletes and have the peculiarity of processing information and at the same time quickly adapting to rapid changes in the environment. In sports, as well as in other contexts such as education, the use of aids for learning and training that enhance sensitivity to perceptual information sources is becoming increasingly common. Coaches and teachers seem to intuitively appreciate this methodology by modifying, limiting, and improving the quality and quantity of perceptual information surrounding the learners. However, the validity of such learning strategies in sports and educational contexts is still underexplored. It is known that EF is represented by a type of top-down mental processes.

This research, as an ecological approach, embraces the idea known as perception-action coupling, in which movement creates information that, in turn, constrains further movements (Kensler & Gibson, 1969), therefore, we need to perceive in order to move, but we also need to move in order to perceive. Perception and action do not work in separate compartments but interact directly and cyclically. In other words, perception represents the initial reason for being able to act while action remains essentially the indispensable component (Gibson, 2014). Executive functions play a significant role in complex motor and sports activities, situations in which motor responses involve reasoning, problem-solving and planning. In game or competition situations, it is crucial to be able to interpret different scenarios and quickly assess a series of internal and external variables related to the moving body in order to select an appropriate motor behavior response, even under conditions of emotional stress (Vestberg et al., 2017). Executive functions are trainable and can be improved through practice and experience. Current methodologies and instrumentation in neuroscience applied to sports can be utilized to improve performance, optimize the energy availability of athletes, for example. Tools such as Perception-Action Devices (PAD) and the use of transcranial magnetic stimulation (TMS) serve as examples in this research. Motor coordination ensures that a motor action is executed in the most appropriate manner to achieve the desired goal. Motor components such as agility and quickness , which require the ability to perceive relevant external information and react quickly and accurately while moving in space, are of great importance in sports performance. According to some authors (W B Young et al., 2002), agility is influenced by perceptual and decision-making factors and the quickness at which movement direction changes occur in space.

Problem statement

The use of innovative digital tools has become an increasingly prominent aspect of every human being's life for several years now. Until recently, the development of coordination in sports training did not rely on the support of digital technologies. However, considering that coordinative training requires elements of novelty and unpredictability, which can be easily provided by technological devices, the introduction of lightweight sports systems was predictable. PAD with LED light technology, for example, are now readily available and accessible to everyone. This study aims to examine their applicability and impact on motor and sports performance. From the analysis of scientific literature, it is evident that it is necessary to investigate how the use and integration of such digital tools, from physical education classes at school to training sessions in sports, can improve executive functions, the development of coordinative abilities, quickness of movement, and simple and complex reaction capabilities. The lack of scientific information regarding the effects of using such tools often creates hesitation among teachers and coaches. A systematic review on the use of PAD states that there are still few studies in the literature, and the most tested category is that of young athletes in certain sports (Katanić et al., 2020).

Studies and related evidence regarding significant effects on the development of coordinative abilities through motor protocols that have cross-cutting characteristics in relation to the specialization of specific fundamental skills, and that make use of digital technologies and modern perception-action devices, are rare. For teachers and coaches who venture into this field, the need to have scientific knowledge demonstrating how, when, and in what ways portable technological devices can contribute to improving motor and sports performance in young individuals is increasingly pressing. An essential task in formulating new proposals for the wide application of technological devices in educational and sports contexts is to identify, through scientific literature, the evidence that indicates successful or ineffective initiatives for the acquisition and development of motor skills and abilities (Medeiros et al., 2017). Today, these multimedia support tools for sports allow for the improvement of coordination through the use of gadgets and digital technologies, offering a new dimension to sports training.

Purpose of the study and research questions

In general, this research work aims to demonstrate how the use of methodologies that employ next-generation technological tools can generate innovative solutions to achieve greater effectiveness in training, with positive implications for athletic performance. It is widely recognized that in the sports context, the ability to quickly react to a stimulus, combined with a high level of coordination, agility and quickness, forms a solid foundation for success in competitive situations. During sports performance, athletes have constant access to sensory information sources that they use to guide and adapt their motor behavior. In particular, the aim is to investigate if and how the use of such tools can contribute to improving certain characteristics of PCF and coordination, such as reaction speed, agility and quickness, in individuals engaged in sports activities.

The questions being posed are:

- Are there significant differences in motor performance between tests of motor reaction to visual stimuli and coordinative abilities?
- Can PAD be used as assessment tools?
- Can technological tools improve PAD be integrated into a training program to enhance performance?
- Can the use of PAD improve reaction time and movement to a visual stimulus in advanced athletes?
- Can the use of PAD improve agility and quickness?
- Can the use of non-invasive technological tools that utilize magnetic waves to stimulate areas of the brain have positive effects on tests of motor coordination?

It is important to note that a significant portion of this doctoral journey from 2020 to 2022 was marked by the COVID-19 pandemic, which caused difficulties in accessing subjects and required some initial hypotheses and plans to be adapted. For example, restrictive health regulations in sports and schools prevented the implementation of experimental intervention protocols on the population due to lockdown measures.

PART ONE
THEORETICAL BASES OF THE RESEARCH

CHAPTER I
SENSE PERCEPTION

1.1 Perception-Action

In recent decades, there has been a growing scientific interest in the role of cognitive processes in motor activities and sports. During their performances, players or athletes interact by receiving a constant flow of information from the surrounding environment while executing simple or complex movements. In each individual, this flow is sent from the sensory system to the brain, where the information is processed to construct a representation of reality. This model forms the basis of our perceptual consciousness, and the information it comprises is used to program our actions. In sports, as well as in other domains, the relationship between perception and movement is very close, to the extent that some authors argue that both should be considered as a unified functional system (Arbib, 1987; Kelso et al., 2018; Lee, 1986; Warren, 1988). Perception and action thus constitute an interdependent, almost unified process that functionally integrates the events "to be perceived" and "to be produced." According to this perspective, perception is an actively information-gathering process, also aided by action (e.g., eye movements), while action constantly needs to be guided by sensory information to interact with the environment.

1.2 Attention

Attention can be defined as the ability to focus on a specific stimulus, information, or task while filtering out or ignoring everything else. More precisely, attention can be described as a set of selection processes that the brain engages in with regard to stimuli coming from the external world through the sensory organs (Turatto et al., 2004). It is a fundamental cognitive function that allows us to select, process, and react to relevant information in our environment. Selective attention is an important aspect in sports as it enables athletes to focus on relevant stimuli while filtering out irrelevant ones. During motor and sports practice, athletes must be able to direct their attention to the specific target, such as a moving ball or an opponent. This ability to select relevant information and ignore distractions is critical for achieving optimal performance.

1.3 Motor programs

Motor stimulus-response (S-R) programs are tools used to develop and improve a person's motor skills and coordination. These programs are designed to provide specific stimuli, which can be visual, auditory, or tactile, to participants, who then need to provide an appropriate motor response based on the received stimulus. They can also be used in the context of sports to enhance athletes' performance through specific coordination and movement training.

In models that describe the stages of the information pathway from stimulus to response, three fundamental steps can be distinguished:

- ✓ Stimulus identification (perception)
- ✓ Response selection (cognition)
- ✓ Response execution (action)

Stimulus-response motor programs can be customized based on individual needs and specific goals. They may also include a range of exercises and activities that involve specific movements, such as throwing and catching a ball, following a predetermined path, or responding to visual or auditory signals.

1.4 Human movement

Human movement is explained by various models and functional theories based on different assumptions. One significant model is Schmidt and Wrisberg's (2000), which describes the action process through four systems: the performer, effector, feedback, and comparator. The performer system detects perceptual stimuli, selects the most appropriate response based on the perceived environment, and activates the corresponding motor program. The effector system receives information from the performer and carries out the desired action. The comparator system processes data from the performer and compares it with data from the feedback circuits. If the data does not match adequately, an error message is sent to the performer to correct the action.

CHAPTER II
COORDINATION ABILITIES

2.1 Motor coordination

The term "coordination abilities" in the field of motor sciences or physical education still allows for a variety of opinions, perspectives or interpretations. From a neurophysiological perspective, coordination is the activity aimed at regulating the synchronization and magnitude of muscle contractions and relaxations in order to achieve more or less complex movements, pursuing predetermined objective. Coordination abilities depend on the intellectual, cognitive, and emotional dimensions of an individual and are responsible for controlling, adapting, and transforming motor behaviors. Humans are capable of recognizing, acquiring and discriminating information from external sources (surrounding environment) or from within their own bodies, becoming aware (perception) through sensory-perceptual functions. Often in daily life, work, and especially in motor-sport activities, we see individuals effortlessly performing coordinated actions while others struggle more. In the field of motor and sports activities, the issue becomes even more complex as there is often a need to move rapidly to resolve simple and sometimes complex situations that require speed of action in a purposeful, efficient and safe manner. When attempting to complete motor tasks faster than usual, motor control diminishes, leading to greater errors in precision and, in extreme cases, an increased risk of injury. The success of a motor action, when it is goal-oriented, requires a balance between execution speed and accuracy (Fitts, 1964). Coordination abilities allow athletes to harmonize motor actions safely and efficiently in various situations, whether they are stereotypical, unpredictable, or require the acquisition of rapid sports gestures (Tudor & Popovici, 1999). There is a significant relationship between motor coordination and motor skills. As some authors note (Gierczuk & Sadowski, 2015), close and reciprocal relationships among motor abilities, skills and coordination capacities depict a complex functional activity of motor coordination. In particular, these relationships include general mechanisms of information reception and processing, accumulation and realization of motor experience, programming elements and correction mechanisms, as well as general components of the coordination process (Boichuk et al., 2017).

Although the phenomenon is of a complex nature, it is evident that individuals with high levels of coordination abilities have a series of advantages in the field of sports sciences:

- ✓ they move with greater control, precision, and lower energy expenditure.
- ✓ they learn new movements or complex technical skills more quickly.
- ✓ they possess a broader repertoire of motor skills and can utilize them in various contexts, for example, they excel in different sports disciplines (multi-sport development).

2.2 Classification of coordination abilities

In the field of physical education and sports, the classification of coordination abilities has undergone numerous modifications and updates in the past forty years, in line with the evolution of new discoveries and knowledge in the sciences (psychology, physiology, neuroscience).
The main distinction among coordination abilities lies in their division into general and specific categories. Schnaibel (1976) identifies three fundamental capacities:

- ✓ motor learning capacity
- ✓ adaptation and transformation capacity
- ✓ movment command and control capacity

and 11 special coordination abilities.

General coordination abilities result from a teaching and learning process based on multilateralism, involving the assimilation and acquisition of even new movements (motor learning capacity), a refinement phase where movements are controlled to achieve predetermined goals (motor control capacity), and a phase where individuals can change, transform, and adapt motor programs based on sudden changes in situations or external conditions different from those in which the movement was learned (adaptation and transformation of movements capacity) (Meinel et al., 1984). Special coordination abilities are related to various motor activities or specific contexts within each sports discipline, and they assume particular technical-executive characteristics based on the sport or discipline. Over the years, attempts have been made to create a unique classification of coordination abilities for identification purposes. The questions lies in the inability to separate individual coordination abilities since they are simultaneously involved in movements, albeit with different degrees of prevalence that are difficult to quantify.
Based on the intervention of analyzers during movement, Blume D. (Blume, 1986), proposed a further classification of coordination abilities, distinguished as follows:

- ✓ combination and coupling of movements
- ✓ spatial-temporal orientation
- ✓ differentiation capacity

- ✓ static-dynamic balance
- ✓ motor reaction capacity
- ✓ movement transformation capacity
- ✓ rhythmization capacity

It is evident how the differentiated involvement of the various analyzers varies from sport to sport, therefore, an athlete's level of motor coordination, as well as the degree of readiness, adequacy and accuracy of motor responses, depends on how they perceive movement and the environmental context in which they perform.

The most significant components of coordination abilities for sports performance are as follows (Weineck, 2009):

- ✓ balance capacity
- ✓ orientation capacity
- ✓ differentiation capacity
- ✓ rhythm capacity
- ✓ reaction capacity
- ✓ transformation capacity
- ✓ segmental coordination capacity.

CHAPTER III
AGILITY AND QUICKNESS

3.1 Premise

In most sports, athletes frequently need to swiftly accelerate, decelerate, and change direction in response to game situations, involving movements that engage their entire body. Interestingly, the capacity to rapidly change direction is often considered more crucial than simply running in a straight line at high speed. As a result, numerous coaches and athletes are actively seeking effective approaches to enhance agility and quickness. A portion of ongoing research endeavors to explore novel methodologies that leverage technological tools to aid sports coaches, athletes, as well as fitness and conditioning professionals in achieving this objective..

According to some authors, the most significant factors influencing agility performance include the speed with which individuals change direction in space and cognitive factors such as perceptual and decision-making abilities. Within these two major components, there are various sub-components that play an important role, as shown in Figure 3-1.

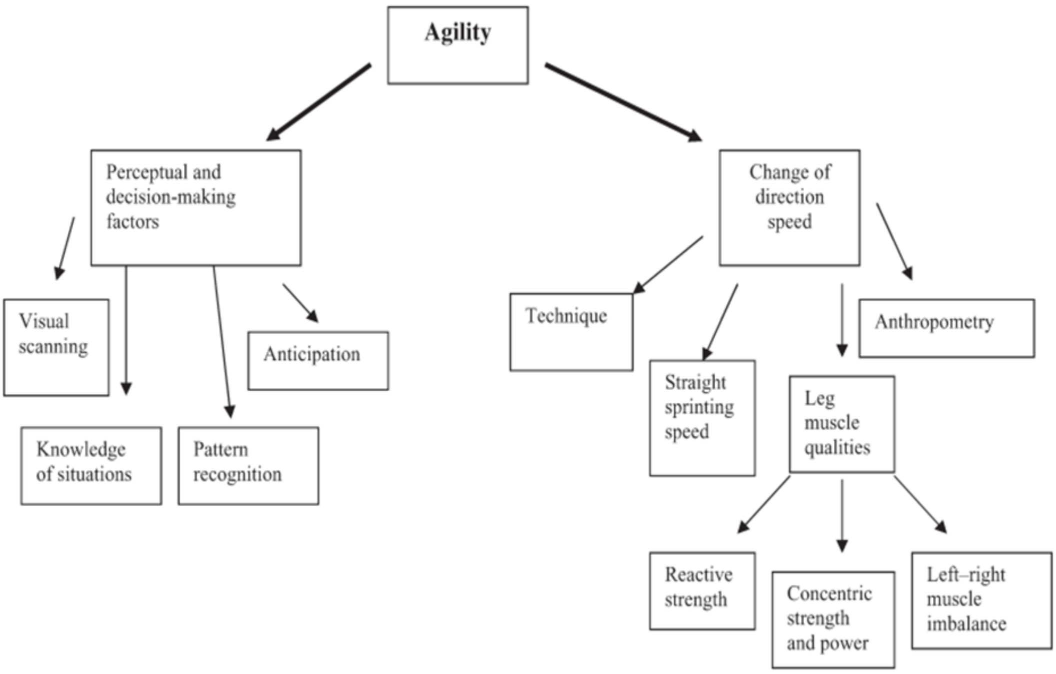

Figure 3-1 Universal agility components (modified from Young et al, 2002)

Agility and quickness are complex athletic skills that encompass both physical and cognitive components. For example, we can imagine a soccer player who, upon receiving a pass in the opponent's penalty area, must quickly make a decision on which direction to go in order to surpass a defending player and shoot at the goal. The evolution of the game in modern sports is increasingly focused on speed of action, therefore athletes must also think, decide, and act swiftly to achieve exceptional quickness on the field. In order to optimize sports performance, current training programs must consider both physical and cognitive aspects related to agility and speed of movement. Only through this integration will athletes be able to effectively bridge the gap between training and actual competition.

3.2 Agility Factors

A rapid movement that involves the entire body thus determining a change in speed and direction, all in response to a stimulus is a recent definition of agility (Sheppard & Young, 2006).

According to some authors, this definition takes into account the cognitive components of visual scanning and also the ability to make quick decisions that contribute to agility performance in sport (Abernethy & Russell, 1987; Chelladurai, 1976; W B Young et al., 2002). In this way, from a practical point of view, the physical performances involved in acceleration, deceleration and changes of direction are respected, such as in those situations in which a player has to avoid an opponent, or when performing sprints with changes of direction to dribble with a ball or disengaging from a defender or initiating whole body movement in response to a stimulus. Agility is an important quality that significantly contributes to success in sports outcomes (Sekulic et al., 2017; Warren B Young et al., 2015). In open skill sports, the continuous dynamic environmental changes (for example the changes in the positions on the playing field of teammates or opponents) induce players to act with previously programmed motor responses, coordinated movements of body segments and anticipated responses based on complexity and rapid evolution of sensory information (Lage et al., 2011).

3.3 Reactive agility

Reactive agility differs from general agility in that, in a highly dynamic context such as game actions in sports, an athlete will need specific abilities to adapt quickly and effectively to sudden and unpredictable changes in the game scenario. Reactive agility can be defined as a combination of agility, responsiveness, and decision-making skills.

3.4 Factors of Quickness

Quickness is defined as the ability to reach, under specific conditions, the maximum reaction and movement speed possible, based on cognitive processes, maximal efforts, and the functionality of the neuro-muscular system (Grosser & Renner, 2007). Quickness is defined as a motor ability that is expressed in three-dimensional space on multiple planes and multiple directions by mixing the subject's ability to accelerate and execute movements explosively and reactively. (Moreno, 1995). Some authors have demonstrated the existence of significant correlations between motor quickness and mechanical muscle factors such as strength, power, and execution technique, while also considering cognitive motor factors such as technique, visual scanning speed, and anticipation ability. (Sheppard & Young, 2006). It is evident that the quickness of an individual, whether young or adult, is certainly a complex quality composed of multiple psychophysical abilities: speed of perception, speed of anticipation, speed in decision-making, reaction speed, cyclic and acyclic movement quickness, simple action reaction, and general action quickness (Weineck, 2009, 437).

In team sports with teammates and opponents, such as badminton, martial arts, combat sports, soccer, or basketball, motor reaction quickness is essential in various diversified situations because athletes must make quick decisions to have a greater likelihood of success in their actions (Mudric et al., 2015; Ruschel et al., 2011; van de Water et al., 2017).

3.5 Motor Reaction Time (RT)

Reaction time (or premotor time) is the central processing time between a stimulus and the initiation of a response (Donders, 1969; Sternberg, 1969). In other words, The motor reaction time (RT) is represented by the time interval in milliseconds that passes from when a stimulus occurs until the start of the consequent motor response, it is therefore considered an excellent indicator of the efficiency of the cognitive system in perceiving and processing the information. (Jensen, 2006; Kuang, 2017). RT depends on the speed of the sensorimotor cycle, which consists of the arrival of excitation (signal) to a receptor, information transfer through afferent nerves, generation of response by the central nervous system, and final mechanical response (Adleman et al., 2016; Greenhouse et al., 2017). It has been highlighted that physical activity and sports can be related to improved RT (Jain et al., 2015; Okubo et al., 2017; van de Water et al., 2017; Walton et al., 2018). RT can be classified as simple reaction time (RTs) and complex reaction time (RTc), which includes recognition and choice RT (Boisgontier et al., 2014). RTs is defined as the time interval between the appearance of a stimulus, its detection, and the given response (Jayaswal, 2016) and this time interval is typically over 120 milliseconds.

The factors influencing reaction times are:

- ✓ Attention capacity
- ✓ Number of stimulus-response alternatives
- ✓ Stimulus-response compatibility
- ✓ Exercise quantity
- ✓ Exercise nature

Training through physical activity and sport can improve RT thanks to a wide variety of motor actions. (H. Kirk et al., 2017; Lynall et al., 2018; Rabiner et al., 2010; Walton et al., 2018).

3.6 Measurement of reaction time: issues

There is a certain degree of confusion in measuring reaction time. Some authors consider the onset of the reaction as the moment when an electromyographic signal reaches the muscle, activating it. Others, on the other hand, consider the visual onset of movement, such as when pressing a button or when there is a change in force intensity. It is clear that the latter methods may be more approximate in measuring reaction time because they include delays. Although these measurements estimate reaction time, they actually include delays of electromechanical nature as well, related to the time required to generate the force to press on a surface. In the context of sports, reaction time is often recognized as a total time required to perceive, identify, process an external stimulus, and respond with motor actions, and it has two partial components: reaction time and movement time.

In this research, reaction time is considered as the time elapsed from the presentation of a visual stimulus to reaching it through a rapid movement of the upper (hand) or lower (foot) limbs:

RTs = Reaction time + Movement time.

Visual-motor response time can be classified as recognition response time and is defined as the time from the appearance of a visual stimulus to its detection and the execution of a multi-segmental movement response (Bigsby et al., 2014)

CHAPTER IV
TRANSCRANIAL MAGNETIC STIMULATION

4.1 Non-Invasive Brain Stimulation (NIBS-TES)

Transcranial magnetic stimulation (TMS) is a non-invasive technique widely used to study neuronal activity in the human cerebral cortex (Missitzi et al., 2011). It is a relatively recent technique, introduced approximately 30 years ago (Brasil-Neto et al., 1992), and has often been employed, along with other neuroscientific modulation methods, to investigate intra-cortical, cortico-cortical, and cortico-subcortical interactions (Petersen et al., 2003). Transcranial methods for brain stimulation are able to deliver such stimuli through high-resistance barriers, including the layers of the brain, such as the scalp, skull, meninges, and cerebrospinal flui (Capotosto et al., 2012). TMS generates a rapidly changing magnetic field through a coil positioned over the scalp, which induces weak electrical currents that excite the underlying neural tissue. To appreciate the potential of TMS, it is necessary to evaluate the neuromuscular responses elicited by cortical stimulation. Since stimulating neurons that innervate muscles in different regions of the body generates a response, it is possible to assess the underlying neural network. These neurons have specific locations on the motor cortex (Candidi et al., 2010), and TMS enables the delivery of magnetic stimuli to clusters of neurons associated with specific muscle groups. In classic TMS experiments, pulses are delivered to the primary motor cortex (M1), and motor evoked potentials (MEP) of a muscle or group of muscles are recorded using surface electromyography (EMG) electrodes. The intensity of TMS is typically expressed as a multiple or percentage of the threshold intensity required to evoke MEP of a specified amplitude in a specified number of consecutive trials in a hand muscle. Since TMS thresholds vary significantly in the population, it is crucial to use intensity measures that account for the biological effectiveness of the stimulus in the individual subject, rather than relying on the output of the stimulation device. Therefore, the multiple of the threshold to evoke MEP in a low-threshold muscle is commonly used as the unit of stimulus intensity (Ricci et al., 2012).

4.2 MEP (motor evoked potential)

The MEP, or motor evoked potential, is a potential that can be generated through TMS stimulation in a specific area of the motor cortex (Hallett, 2000). For example, if a TMS pulse is applied to the hand representation in the motor cortex, it can induce a contraction of the contralateral hand muscle, and an MEP can be recorded. The neural conduction time of a motor signal can be calculated by subtracting the latency of the evoked potential through direct muscle stimulation from the latency of the motor evoked potential in the muscle stimulated by stimulating the spinal cord nerve roots.

4.3 Motor Threshold (MT)

MT is defined as the lowest intensity of TMS required to evoke an MEP in the chosen muscle of the motor cortex in at least 50% of subsequent stimulations (e.g., 5 out of 10) (Boroojerdi et al., 2001). The MT provides crucial information about the excitability of the specific muscle in the motor cortex and is believed to reflect the excitability of corticospinal neurons as well as motor neurons in the spinal cord, neuromuscular junctions, and the muscles themselves.

4.4 Repetitive Transcranial Magnetic Stimulation (rTMS)

rTMS involves applying a series of pulses with the same intensity to a specific brain area at a specific frequency and intensity. In general, the higher the frequency and intensity of the stimulation, the greater the impact on cortical functions during pulse application. However, apart from immediate effects, a series of rTMS pulses can induce a prolonged modulation of cortical excitability that may persist even after the series is completed, and this is its distinctive characteristic. The modulation effect can be inhibitory or facilitatory depending on the stimulation parameters used (Nowak et al., 2010). For example, lower frequencies such as 1 Hz applied to the motor cortex can decrease excitability, while series of stimulation at higher frequencies around 20 Hz increase cortical excitability. These effects can vary among individuals and depending on the characteristics of the pulse series. In the use of rTMS, therefore, frequency appears to be the key parameter determining the direction of the effects, although other variables need to be taken into consideration when planning an experiment with this method.

CHAPTER V
LED PERCEPTION-ACTION DEVICES

5.1 Perception-action systems in sports

In recent years, we have witnessed the growing adoption of technological tools consisting of wireless devices that emit LED light signals and/or visual cues (letters, numbers, or symbols) to train and test reaction times or fast movement times (Appelbaum & Erickson, 2018). LED perception-action devices are employed in scientific research to study human perception, action, and cognition, by utilizing these devices, researchers can investigate the relationships between visual stimuli, motor action, and cognitive processes. In summary, LED perception-action devices are tools that combine visual feedback and bodily interaction to facilitate specific activities, games, rehabilitative therapies, or scientific research. These devices utilize LED lights to provide real-time visual feedback, thereby enhancing the user's perception, interaction, and learning. A systematic review investigated the application of the Fitlight Trainer system (Fitlight System, 2022) in sports, using the following electronic databases: Google Scholar, PubMed, Medline, and Mendeley, covering the period from 2014 to 2020 (Katanić et al., 2020). The authors found that these new technological tools are generally used in sports as training aids and for assessment purposes. They can be employed in both individual and team sports and can be utilized to study sensory and cognitive skills, as well as various motor abilities such as reaction speed, individual movement quickness, running speed and agility (Katanić et al., 2020).

5.2 Operation

The use of these systems is quite simple, and some of them have highly flexible control software that allows the system to be adapted and configured for any exercise, game situation or sports discipline. The operation is more or less the same for all systems. A set of wireless LED lights (from 1 to 8 discs) that can be controlled remotely up to a distance of 30-40 meters is used. These lights can be randomly turned on or arranged in a specific pre-set order by the control device (tablet or smartphone). The task for the athlete is to try to turn off the lights by touching or getting as close as possible to the sensor as quickly as possible. It is possible to determine in advance whether the LED should be turned off by touching the disc or by passing any part of the body or an object through it. Each disc can emit lights of the same color or different colors, allowing the exercise to be shaped. For example, if a specific motor task is assigned to each color in advance. It is also possible to determine the duration of the lights' activation and deactivation (from 0.1 to 10 seconds) as well as the interstimulus duration, which is the minimum time between one activation and the next. The ability to control the timing allows the coach to speed up or slow down the exercise according to the predefined objectives, making it more or less intense. These systems also have pre-set programs to train movement speed, simple or complex reaction capabilities, memory and visual scanning. This is done using sequences of lights of different colors presented in sequential, random, or simultaneous order.

Among the most common programs, we find:

- ✓ Turning off the light as quickly as possible;
- ✓ Turning off a sequence of lights as quickly as possible;
- ✓ Turning off the correct color, which is declared in advance, among multiple colors (true/false task);
- ✓ Turning off multiple correct colors, declared in advance, among multiple colors (true/false task and memory);
- ✓ Turning off the LEDs with different colors in a series based on logical difference;
- ✓ Comparison exercises/games between two or more players, such as "the slowest one loses";
- ✓ Comparison exercises/games between two or more players, turning off the lights of their assigned color;
- ✓ Visual memory exercises/games, memorizing the colors that turn on and repeating them after they turn off;
- ✓ Visual memory exercises/games, memorizing the chronological sequence of activation and repeating it;
- ✓ Training sessions using special occlusion glasses that interface with the software.

5.3 Considerations

LED light PAD systems are becoming increasingly popular in the market for sports training support products, thanks to their availability and ease of use. However, the manuals for these light sports training systems provide usage instructions but do not provide details on the distinctive technical specifications of the devices. There are few studies in the literature regarding their use and the implications in sports practice or physical education hours at school.

PART TWO
EXPERIMENTAL

CHAPTER VI
PILOT STUDY

RELATIONS BETWEEN AGILITY TESTS AND MOTOR REACTION TIMES IN YOUNG SPORTSMEN.

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"The infinity of human performance"
September 15-16, 2022 Targu – Jiu
Academica Brancusi" Publishing House, ISSN 2344 – 1003; ISSN–L 2344 – 1003
https://www.utgjiu.ro/fefs/cercetare/2022/MANCINI.pdf

6.1 Premise

As stated in the introduction of this research thesis, the COVID-19 emergency has significantly modified the originally planned course of this doctoral study. Therefore, the initial hypothesis has been readjusted based on the evolving and real restrictive health situations. In fact, for a large part of the emergency period, Italian students of all levels were prohibited from engaging in practical physical education activities both in gymnasiums and classrooms. This restriction has prevented the availability of human resources and consequently hindered the execution of the experimental study as initially planned, which involved intervention protocols spanning multiple weeks with test administration and retesting. To overcome this limitation, it was decided to proceed with an adapted pilot study in an extracurricular context during a summer camp. During this period, the restrictive anti-COVID measures allowed physical activities with social distancing, and the participants primarily engaged in outdoor activities while having access to a gym and classrooms, with the subjects being organized into small groups for testing purposes. The main objective of the adapted pilot study, conducted on a numerically limited sample, was to verify the statistical validity of the research project's study model, assess its feasibility, or gather information to determine the type and size of the sample for subsequent studies. Additionally, an effort was made to familiarize ourselves with the methods and means of experimentation, aiming to eliminate various issues, including those associated with chance factors.

6.2 Aim of the study pilot

The pilot project consists of two experiments. The first experiment aims to determine if there are significant performance differences between simple reaction time and agility tests within a sample of young individuals (N=44) aged between 11 and 12 years, comprising males (N=23) and females (N=21). The second experiment aims to analyze the reliability and validity of the HAT (Exagon Agility Test, specific test acronym), comparing the performance of the HAT test and simple reaction time (RTs) for upper and lower limbs among students regularly engaged in diverse sports activities (N=44). Additionally, statistical procedures were employed to investigate the existing relationships between simple reaction time and agility. The coefficient of determination was defined to indicate the extent to which the total variation in one test variable is explained by another.

6.3 Materials and methods

6.3.1 Subjects

During a summer camp in a southern Italian city, which had approximately 200 students in attendance, a utility sampling method was used to recruit 44 students, including 21 girls and 23 boys (age: 11.50 ± .50 years; height: 147.5 ± 6.0 cm; body mass: 41.11 ± 4.35 kg; BMI: 18.87 ± 1.27). All procedures adhered to the guidelines outlined in the Declaration of Helsinki.

Inclusion criteria were considered through the administration of a questionnaire, including:

- ✓ Age between 11 and 12 years.
- ✓ Participation in competitive sports or organized extracurricular sports activities.
- ✓ Knowledge and practice of at least three different sports disciplines.
- ✓ Regular participation in physical education classes at school (2 hours per week).

Exclusion criteria were as follows:

- ✓ Recent injuries requiring medical treatment.
- ✓ Adverse neurological events such as epileptic seizures.
- ✓ Contracting a COVID-19 infection.

6.4 Methodology

The motor reaction time estimation tests using Fitlight TrainerTM (*Fitlight System*, 2022) with the use of LED lights were conducted in a quiet room with low light exposure, while the HAT was conducted in an air-conditioned gymnasium with a parquet sports floor.

6.4.1 Motor test: Hexagon Agility Test (HAT)

The HAT is described as "a measure of foot agility and quickness that involves balance and coordination abilities" (Baechle et al., 1994; Roetert et al., 1992). The test involves the subject facing forward, standing at the center of a hexagon drawn on the ground with adhesive tape.
Procedure:

They perform 6 consecutive jumps, going back and forth to the center, crossing each side. The first jump is towards the front line, then the side line, and so on.The stopwatch is automatically stopped when the participant completes the entire circuit and returns to the center on the contact platform.

6.4.2 Cognitive-Motor Tests

The FitLight Trainer (*Fitlight System*, 2022) is a portable equipment that provides versatile options for measuring reaction times (RTs) and can be easily configured for applications involving both upper and lower limbs. The FitLight Trainer consists of a control tablet and mobile discs with wireless connectivity, and it can be used as a cognitive-motor training and assessment system, for example, for measuring simple and complex reaction times. Each disc (diameter: 10 cm) emits light signals through LED lights or sound signals depending on the program used, and it is equipped with proximity sensors as well. The system operates by deactivating the lights (yellow, green, red, dark blue, light blue, purple) either through proximity sensors (by passing over the sensor) or by direct contact of the hands or feet. The system allows for measuring and recording the times in milliseconds with each contact.

6.4.2.1 *Reaction Time simple upper limb dominant (RTs UL)*

RTs UL (Wilke et al., 2020) is a test that assesses simple reaction times (ICC/Rho: 0.81* (95% CI: 0.48-0.94), $p < .001$) of the upper limbs and requires a high level of attention and extremely fast reaction to visual stimuli. The participant, in an upright position, placed the palm of their dominant hand (defined as the hand intuitively used for sports activities, e.g., throwing, pushing) on a table adjusted to elbow height. On the same table, a sensor was placed at a distance from the participant equal to the length of the forearm. The task was to deactivate the sensor as quickly as possible by passing over it as soon as it illuminated without making contact with the sensor. The response time in seconds and milliseconds was measured for each repetition.

6.4.2.2 Reaction Time simple lower limb dominant (RTs LL)

RTs LL (Wilke et al., 2020) evaluates the simple reaction times of the lower limbs (ICC/Rho: 0.89* (95% CI: 0.67-0.97), $p < .001$) and is designed for a task almost identical to that of the upper limb. The participant is in an upright position with feet parallel (feet distance equal to shoulder width), and a sensor is placed in front of the participant's feet. The task for the participant is to deactivate the sensor as quickly as possible by passing over it as soon as it illuminates without making contact with the sensor using the dominant foot (defined as the foot that would intuitively be used for sports activities, e.g., kicking a ball, jumping over an obstacle with the leading leg). The response time in seconds and milliseconds is measured for each repetition.

6.4.3 Statistical Analysis

The independent samples t-test was used to determine if there is a statistically significant difference between the means of two independent groups (male and female) in each administered test. Pearson's correlation coefficient (r), linear regression analysis, and coefficient of determination (r^2: used to interpret the significance of the relationship) were used to examine the relationships between the tests: RTs UL vs HAT and RTs LL vs HAT. The significance level was set at 5% ($p \leq 0.05$).

6.5 Result and Discussion

The aim of this pilot study was to investigate the relationship between a field agility test, the Hexagon test (HAT), and two tests measuring simple reaction times to visual stimuli with rapid movements for the upper limbs (RTs UL) and lower limbs (RTs LL), using a portable wireless measurement system (Fitlight Trainer™ Sports Corp, Canada) to assess their validity. In the analyzed sample, there are no significant gender differences in both simple reaction times to visual stimuli and agility tests. This implies that for the 11-12-year-old age group, both reaction times and agility do not depend on gender.The relationships between the tests, RTs UL vs. HAT and RTs LL vs. HAT, were examined using Pearson correlation (r), linear regression analysis, and coefficient of determination (r^2: used to interpret the significance of the relationship). The analyzed results demonstrate that in the considered sample (N=44), there are positive correlations between RTs UL vs. HAT ($p<.05$) and RTs LL vs. HAT ($p<.05$), regardless of gender distinctions .

The results allow us to say that, as demonstrated in other similar studies, there are significant relationships between agility and reaction time tests to visual stimuli for both upper and lower limbs. Authors have shown that activities that stimulate motor reaction typical in defense and attack phases during competitions and training sessions improve reaction capabilities to visual stimuli, with positive effects also on agility characteristics (Kucukipekci & Taskin, 2011).

6.6 Conclusions and limitations

The significant relationships observed between HAT and RT provide evidence supporting the hypothesis that reaction times influence motor agility in young athletes. Although limited in sample size, this pilot study has demonstrated that tests utilizing perception-action devices like Fitlight for measuring reaction times can be statistically significant predictors of performance in field tests such as the Hexagon agility test. The reliability and accuracy of perception-action devices for reaction time measurement are of great importance to coaches, teachers, and professionals.

CHAPTER VII
EXPERIMENT 1

REACTION TIMES, AGILITY AND BODY MASS INDEX: DIFFERENCES BETWEEN BOYS AND GIRLS IN MULTISPORT.

Proceedings of the 8th International Conference "Education for health and performance," organized by the Universitaria Consortium
in Cluj-Napoca, Romania, on October 21-22, 2022.

7.1 Introduction

Premature sports specialization is defined as mono-disciplinary sports practice carried out from childhood through many hours of deliberate practice with the aim of improving sports performance (CôTé et al., 2009), this anticipated start towards a single sporting discipline consequently involves an early involvement in high intensity sports training and a premature start to agonistic competition (Baker et al., 2009). In children, interventions focused on multi-sport lead to improved motor skills and perceptions of motor skills, which are essential for regular participation in health-related physical activity (D. Kirk, 2005). Children who practice multisport activities have higher levels of motor coordination than children who practice monodisciplinary activities (Sekulic et al., 2017). Some authors have highlighted the lack of literature examining the development of agility during childhood and adolescence and have pointed out the current lack of understanding of the effects of maturation on its performance (Lloyd et al., 2013).

In the present study, the RTs is considered as the time required from the presentation of the visual stimulus (LED light on) to its achievement (LED light off) through a rapid movement of the upper (hand) or lower (foot) limbs:

RTs = Reaction time + Movement time.

It should also be emphasized that the relationship between agility and reaction times has not been extensively studied in the literature, especially in the gender differences in young athletes. Many authors have conducted studies on children, from infancy to adolescence, in which they show that due to the increase in the capacity and speed of information processing that the central nervous system is able to manage, the motor reaction times tend gradually to diminish (Nicolson, 1982; Sugden, 1980). Generally women have longer reaction times than male peers (Henry & Rogers, 1960). However, one study (Silverman, 2006) in which a 72-dimensional meta-analysis of the effect from 21 studies (n = 15,003) was published over a 73-year period, the author reported that male advantage in visually stimulated RTs are decreasing (especially outside the United States), likely because more women are involved in driving and fast-acting sports. In this study we want to examine whether the multi-sport activity carried out for several years may have created significant differences between males and females aged 11-12 years in agility, simple reaction times to visual stimuli and BMI. It has been hypothesized that giving children multidisciplinary sports opportunities would optimize the development of agility and motor reaction times without distinction of gender, also considering the possibility of variation in individual development typical of the age group considered.

7.2 Materials and methods

7.2.1 Participants

In the present study 96 children participated, of which 49 girls (age: 11.6 ±.61 years) and 47 boys (age: 11.7 ±.55 years) practicing different sports disciplines (football, athletics, basketball, volleyball) in different sports clubs in the city of Foggia (Italy).

7.2.2 Measures and Instruments

7.2.2.1 Anthropometry and Body Composition

The height (cm) and the mass (kg) was measured of the subjects. The BMI for each subject was calculated using a spreadsheet set on Excel (office 2007) according to the summary report (Barlow & Committee, 2007).

7.2.2.2 Test

Three tests were administered:

- Hexagon Agility Test (HAT) for movement agility
- Simple dominant hand reaction time (RTs UL) for upper limb reaction ability
- Simple dominant foot reaction time (RTs LL) for lower limb reaction capacity

The tests are described in the previous chapter

7.2.3 Procedures

The data was collected on the occasion of a summer sports meeting in Italy in which young athletes who had been participating for 2 years in a national project called "Educamp - Multidisciplinary Sports Centers" by Italian National Olympic Committee (CONI), a project that favors the practice of multisport. Through the proposal of a cognitive questionnaire, the inclusion criteria were considered: (i) aged between 11 and 12, (ii) adherence to the "Multidisciplinary Sports Centers - CONI" project for 2 years, (iii) knowledge and practice of at least 3 sports disciplines, (iiii) regular participation in physical education classes at school (2 hours per week); and the exclusion criteria: (i) any recent injury requiring medical attention, (ii) neurological adverse events for example seizures, (iii) having had Covid 19 infection.

7.2.4 Statistical analysis

Data are reported as mean ± standard deviation (SD). Before using the parametric tests, the hypothesis of normality was tested using the Shapiro-Wilk test. The Student's t test for independent samples was used to determine if there is a statistically significant difference between the means of the two groups (boys and girls) independent of each other in each test administered. Statistical analyzes were performed using IBM SPSS vers. 25 for Windows.

7.3 Result and Discussion

There are many studies that have shown the existence of significant relationships between agility and reaction tests to visual stimuli both for the use of the upper and lower limbs (Fiorilli et al., 2017; Homoud, 2015; Horicka et al., 2018; Moradi & Esmaeilzadeh, 2015), but few that show gender differences in pre-pubertal age. Physical exercise and motor and sports practice have positive effects on the reaction times of the upper and lower limbs (Akarsu et al., 2009). The objective of the present study is to verify whether there are differences in performance on simple motor reaction times to visual stimuli, agility and BMI, between boys (N = 47) and girls (N = 49) aged 11-12. years, practicing multi-sport activities. Adult men generally have shorter and less variable motor reaction times than women. One hypothesis could be that gender differences in the variability of motor reaction times may originate from the effects of sex hormones on the central nervous system and therefore can consequently be predicted in adults but not in pre-adolescents (Der & Deary, 2006). In the present study in the analyzed sample (boys; N = 47 and girls; N = 49) the t-test for the equality of means shows that there are no significant differences between gender and in UL dominant RTs (mean difference of times = -.011 s; p = .416) that RTs LL dominant (mean difference of times = -.007 s; p = .919), this is equivalent to saying that the reaction times for this age group 11-12 years do not depend on the gender; a probable explanation could be that the rates of reaction times are determined by predominantly cognitive processes in which there are no sex differences. Conditions similar to the results of the tests described above were also found in HAT, i.e. that statistically there are no significant differences between boys and girls (mean difference of times =-.208 s; p =.435), therefore similarly to what was stated for the tests of motor reaction, agility performances for this 11-12 year age group do not depend on gender.

The values of the anthropometric factors (weight, height) in this study were used to determine the BMI of boys and girls, assuming that theoretically, factors such as body fat and lengths of body segments can particularly affect performance of agility. The data show that 94% of the boys (N = 47) and 96% of the girls (N = 49) examined fall within normal BMI values therefore, given the low number of the sample analyzed (N = 96), there are no particular differences between the two groups. The estimated BMI was however taken into consideration to verify the homogeneity of the reference sample in each group.

7.4 Conclusions and recommendations

Boys and girls between the ages of 11 and 12 who regularly practice multisport have high levels of motor performance and good physical fitness. A hypothesis to be confirmed for coaches or teachers is whether specific motor exercises or tasks on the development of agility and motor reaction times in pre-pubertal children should be differentiated by gender. The present study, within its limits, confirms how in children who practice multisport, reacting to visual stimuli in the shortest possible time and being more agile, does not seem to depend on gender.

7.5 Limit

Numerically reduced sample. The pandemic situation has influenced the duration and complexity of administering the tests, which required participants to touch the LED light devices with their hands. Special attention was required to thoroughly disinfect the testing station after each trial in order to reduce the risk of contagion. This resulted in increased time needed to complete each testing session. Many children wore protective masks during the tests, and the effects on performance are not known.

CHAPTER VIII
EXPERIMENT II

EFFECTS OF INTEGRATED TRAINING WITH THE USE OF ACTION PERCEPTION LIGHT SENSORS ON AGILITY, QUICKNESS AND MOTOR REACTION IN FEMALE VOLLEYBALL PLAYERS.

Original works published on

Italian Journal of Health Education, Sport and Inclusive Didactis ISSN:2532-3296.V.7,N.2,(2023) https://doi.org/10.32043/gsd.v7i2.846

8.1 Introduction

In this study we wanted to investigate the effects of the training method enriched with specific exercises that make use of action perception technological tools (PAD) to improve reaction times, quickness and agility in a sample of young volleyball players, compared to a training program with traditional methodology. Volleyball is an open skill situation sport in which the physical performance of the players together with the technical and tactical factors determine the success in competitions (Lidor & Ziv, 2010a). Volleyball players must have medium to high levels of sensory skills and cognitive functions as essential prerequisites, as well as physical and motor skills. Short reaction times (Nuri et al., 2013), quickness and agility of movement (Gabbett & Georgieff, 2007) are important qualities for success. In sport, the ability to react, quickness and agility of human movement are closely related to each other as they interact continuously for the realization of the motor act. In addition to jumping, volleyball is characterized by movements with changes of direction that occur in various parts of the playing field, therefore the ability to change direction as needed quickly and precisely is considered by many to be an integral part of motor and sports performance (Docherty et al., 1988; Keogh et al., 2003; Meir et al., 2001; Reilly et al., 2000).

8.2 Materials and methods

8.2.1 Participants

In this randomized controlled study 24 female volleyball players participating in the national championship took part voluntarily. The sample was divided into a control group (CG) of 12 female players (X ± SD: age 20.3 ± 1.1 years) and an experimental group (EG) of 12 female players (X ±SD: age 20.4 ± 1 years).

8.2.2 Research design and procedure

On August 20, 2022, the initial tests (pre-tests) were administered to all participants using the Fitlight Trainer technological system (Fitlight System, 2022). From August 22 to October 3, 2022, a 6-week training program was implemented, with the experimental group (EG) using a technological system (ReactionX, 2022) consisting of lighted disks, while the control group (CG) underwent traditional training without the use of any modern technology. In the morning of October 10, 2022, one week after the completion of the intervention, both groups underwent the final tests (post-tests).

8.2.2.1 Circuit Training Method

For the purpose of the experiment, training sessions for movement reaction speed, quickness, and agility were organized using the circuit training method. The main motivation behind this choice was to make the workload between the two groups as uniform as possible by adjusting the parameters of the motor load in terms of volume, intensity, and density.

8.2.3 Measures and instruments

The following tests were used in this study:

Cognitive-Motor Tests

- Simple upper limbs reaction time test (RTsUL) and Simple lower limbs reaction time test (RTsLL) are separate tests in which the subject must switch off eight LED sensors arranged in a semicircle on a table for the upper limbs and on the ground with a quick movement for the lower limbs. The lighting of the LEDs occurs in an unpredictable and random way. Average times in milliseconds were measured for each subject for each trial.
- Reactive agility test (RA) for the measurement of the agility of moving in space and of some perceptive-cognitive functions (PCF) including visual scanning, reaction time, processing speed, response inhibition and cognitive flexibility. Eight LED light sensors are arranged, in

a surface of four square meters, on eight delimiting cones positioned in the corners of two squares, one external and the other internal. The test begins when two of the eight sensors randomly light up blue at the same time, one of these lights up completely and the other partially, i.e. only the outer edge of the circle. The subject who is placed outside the two squares must move quickly in the area set up to deactivate the disc which lights up partially, ignoring the one which has lit up completely. The total time in seconds to deactivate 24 correct sensors is measured.

Field motor tests

- The Hexagon Test (HAT) is an agility test where the subject starts from the center of a hexagon drawn on the ground with tape. 6 successive jumps are performed back and forth to the center passing each side, the first jump is towards the front line, then the side line and so on.The chronometer will be automatically stopped when the subject has completed the entire circle arriving again at the center on the contact platform.
- The lower limbs tapping test (TLL) is a speed test where the subject sitting on a chair must perform rapid movements of the foot to the right and left of a line on the ground. The time to perform 40 touches is detected. The final result is the average of the times between the two feet.
- The upper limbs tapping test (TUL) is a speed test where the subject must make rapid movements to touch with one hand 2 disks arranged on a table at a distance of 80 cm from each other. The time to perform 25 touches is detected. The final result is the average of the times between the two hands.

8.2.4 Statistical Analysis

A Manova was conducted to evaluate whether there was a statistically significant difference in at least one of the means and the two groups. In this study, t-test analyzes for independent and paired samples were applied, and Cohen's d and increase percentage (ip%) were calculated at the same time. The interpretation of Cohen's d (effect size) is established as follows: 0.1 - 0.2 small, 0.3 - 0.5 medium, 0.5 - 0.8 large, over 0.8 very large (Sawilowsky, 2009).

The baseline statistical significance value for this study was selected at $p < .05$. The percentage increase (ip%) was calculated according to the following formula:

$$ip\% = [(X_{post} – X_{pre})/X_{pre}] * 100.$$

8.3 Result and Discussion

The main hypothesis of this study is whether a training method aimed at improving motor reaction, agility, and quickness using technological tools for perception-action is more effective than traditional training methods.In the post-test, the results of the average times obtained by the EG were significantly lower thus better, than those achieved by the CG in each test. The time differences in each test (DX = -.062 s, $p < .05$ in RTsUL (s), DX = -.07 s, $p < .05$ in RTsLL (s), DX = -.432 s, $p < .05$ in TUL (s), DX = -.84 s, $p < .05$ in TLL (s), DX = -.629 s, $p < .05$ in HAT (s), DX = -.705 s, $p < .05$ in RA (s)) demonstrate that the EG obtained greater benefits from training with perception-action devices compared to the traditional training of the CG.

Observing the values of the percentage increase and Cohen's d effect size it can be noted that the EG achieved performance improvements of -14.9% in RTsUL (DX = -.072 s, $p < .05$, $d = 6.7$), -14.9% in RTsLL (DX = -.091 s, $p < .05$, $d = 12.7$), -10.6% in TUL (DX = -.622 s, $p < .05$, $d = 12.1$), -10.7% in TLL (DX = -.983 s, $p < .05$, $d = -12.4$), -14.1% in HAT (DX = -.677 s, $p < .05$, $d = 5.5$), and -2.9% in RA (DX = -1.089 s, $p < .05$, $d = 10.8$). The d value of the effect size for the EG corresponded to a "very large" effect size ($d > .8$) in all tests, indicating that the differences were significant due to the treatment, specifically the use of perception-action sensors during 6 weeks of training. Positive effects of training have been observed in reaction and eye-foot movement quickness tests in the EG. From a methodological point of view, the results confirm that a 6-week training program with PA sensors is sufficient to improve some of the PCF.

8.4 Conclusion

The training program using PAD sensors appears to be an effective way to improve agility, quickness and certain aspects of physical and cognitive factors in volleyball players during the pre-season physical preparation phase. Strength and conditioning coaches could utilize this information in the training planning process. In conclusion, a 6-week training program incorporating exercises using light perception-action technological devices has improved physical performance and, to some extent, cognitive performance in volleyball players, proving to be more effective than traditional training methods.

8.5 Limitations

The limitations of this study are related to the small sample size consisting only of female participants from a single sports discipline. Although the tests used were valid as field tests, they should still be standardized and normalized to the characteristics of the subjects. Research of this nature would require funding to support comparison activities with laboratory-based tests. The next chapter addresses a laboratory-based situation where an innovative technology utilizing transcranial magnetic stimulation is used to study aspects related to motor coordination.

CHAPTER IX
EXPERIMENT 3

HIGH FREQUENCIES (HF) REPETITIVE TRANSCRANIAL MAGNETIC STIMULATION (RTMS) INCREASE MOTOR COORDINATION PERFORMANCES IN VOLLEYBALL PLAYERS.

Original works published on

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9.1 Introduction

Expertise in a sport is the capacity to continuously display great athletic abilities. Although it is commonly acknowledged that elite athletes perform better than beginners, it is unclear if higher performance is the result of more skilled sensorymotor coordination. Athletes need to be able to recognize the visual fields that contain the most information, focus their attention in the right places, and efficiently and effectively extract meaning from these fields (Williams & Elliott, 1999).

The dorsolateral prefrontal cortex (DLPFC), a crucial region of the brain, fulfills a critical role in executive attention by actively maintaining access to stimulus representations and goals in highly distracting environments (Kane & Engle, 2002) typical of team sports such as volleyball. In team sport, coordination has been considered ‘key to expert performance. In volleyball, the importance of coordination during the performance were positively associated with the teams’ success in major international tournaments (Lidor & Ziv, 2010b). Repetitive transcranial magnetic stimulation (rTMS) is a neuromodulation technique that makes use of electromagnetic coils placed on the scalp to create a magnetic field that, depending on the delivery settings, either stimulates or inhibits cortical activity. There is general agreement that rTMS below 1 Hz at the motor cortex lowers cortical excitability whereas rTMS over 5 Hz raises cerebral cortex excitability (Fitzgerald et al., 2006). Our research hypothesis assumes that HF-rTMS of the DLPFC, having facilitating effects, can improve the coordination in volleyball players and increase cortical excitability.

9.2 Materials and methods

Participants This study was a double-blinded (participant and evaluator) matched-pair experimental design. Twenty righthanded (Oldfield, 1971) professional female volleyball players of Foggia and Cerignola (south of Italy) local team were recruited for the study and were randomly assigned either the active rTMS (n = 10) or the sham stimulation group (n = 10)

9.2.1 Study design

The subjects recruited for the study were randomly divided into four groups and invited to the physiology laboratory of the University of Foggia on four consecutive days. Upon entering the laboratory, each subject was explained the entire experimental procedure which began after the signing of the informed consents. Subsequently the tests were performed with this temporal sequence: detection of anthropometric parameters, motor coordination tests, positioning on the chair and identification of the RMT and recording of twenty stimuli for MEP analysis, HF-rTMS and, immediately after the end of the stimulation, the subjects performed again the motor coordination test and the recording of twenty stimuli for analysis of the MEP.

9.2.1.1 rTMS protocol

The stimulation was performed in one session with 10 Hz, 80% (Yue WU, Wenwei XU, Xiaowei LIU, Qing XU, Li TANG, 2015) of the RMT of the right first dorsal interosseous muscle, 5 s of stimulation, and 15 s of rest, for a total of 1500 pulses. Sham stimulation was performed in the same manner except that the coil was held at an angle of 90◦, and only one edge of it rested on the scalp.

9.2.1.2 Interlimb coordination performance

Homolateral hand and foot coordination was evaluated by means of a validated field test (Capranica et al., 2005), which proved to discriminate the effects of training in situational (Capranica et al., 2005; Cortis et al., 2011; Tessitore et al., 2011) and closed skill sports (Capranica et al., 2005). The participants were positioned in a seated posture on a table, without shoes, with their elbows and knees flexed at a 90-degree angle. They were instructed to adhere to the spatial and temporal requirements of the movement patterns. Specifically, they had to perform repetitive flexion and extension movements around the joints of the wrist and ankle, maintaining a 1:1 ratio between the two movements. Two different coordination modes were examined in the experiment: in-phase (IP) and anti-phase (AP). In the in-phase mode, the extension of the hand was associated with the dorsal flexion of the foot, while the flexion of the hand was associated with the plantar flexion of the foot. In the anti-phase mode, the flexion of the hand was associated with the dorsal flexion of the foot, and the extension of the hand was associated with the plantar flexion of the foot.

Each coordination mode was tested at three different frequencies (80, 120, and 180 beats per minute) determined by a metronome. The duration of each test trial was 60 seconds. The time was measured by a previously trained operator, using a manual chronometer, the correct execution of the test was observed from the beginning until the analyzed subject was no longer able to comply with the spatial and/or temporal indications of the exercise.

9.2.2 Statistical analysis

Statistical analyses were performed by the GraphPad 6 Software, Inc., for Windows, version 6.01. The data are presented as mean (M) ± standard deviation (SD), and statistical significance was set at $p < 0.05$. The Shapiro–Wilk test was used to check the normal distribution of variables. The differences in antropometric parametres between the active and sham rTMS groups were analyzed with an independent t-test. A 2 (Groups: Athletes, Controls) × 2 (Coordination Mode: IP, AP) × 3 (Execution Frequency: 80, 120, 180 bpm) ANOVA for repeated measures was applied to the time (s) of correct execution of the inter-limb coordination test. If the overall F test was significant, Tukey's post-hoc comparisons were used. To test the significant difference changes in MEPs parameter (active rTMS vs. sham) an independent t-test was used.

9.3 Result and Discussion

The significant finding of this paper was that HF-rTMS of the DLPFC seems to improve performance in terms of the homolateral interlimb coordination, with a significantly decreased RMT and MEP latency of the ipsilateral motor cortex. After stimulation, in active group increase the time of correct execution of the interlimb motor coordination test in both condition (in-phase/ anti-phase). It seem that HF-rTMS could increase coordination performances when the velocity of the execution is higher (120 bpm and 180 bpm). Moreover, in active rTMS group significant differences emerged after stimulation in RMT and in MEP latency, while no differences emerged after stimulation in MEP amplitude. In the present study, the RMT and the MEP latency decreased after HF-rTMS of the DLPFC, which indicates increased motor cortex excitability. The important finding from our study is that non-invasive brain stimulation in the left DLPFC did not prevent excitability from rising in the M1 motor cortex. These results lend credence to the idea that prefrontal rTMS may influence corticomotor excitability indirectly and enhance cognitive performance by causing even more remote changes in the cortical and subcortical systems.

9.4 Conclusions and limitations

Our study shows that a single session of HF-rTMS of the DLPFC in volleyball players seems to improve coordination and cortical excitability. These results could provide useful tools to modulate sports training. In fact, these results, if confirmed, could lead trainers to offer their athletes rTMS sessions suitably blended with training. However, despite the interesting results, the study has some limitations such as a small sample, that should be increasing and investigated in the future to clarify all aspects. Furthermore, the effects of rTMS at different frequencies should also be evaluated (in our study we performed rTMS only at 10 Hz) to establish the best protocol to obtain an improvement in performance. Furthermore, a study including male athletes and non-athletes should also be conducted. In conclusion, despite the limitations described above, we believe that these results could be of great interest to the scientific community and they could have practical implications in the future.

CONCLUSION OF THE RESEARCH

The results obtained from the tests conducted in this research thesis are generally positive and reassuring, confirming the initial hypotheses. The use of innovative digital tools in the field of sports represents an aspect that should be considered in the near future. Many of these tools are now accessible to everyone, thanks to their affordability. It is hoped that the satisfactory results of the experiments conducted in this study can contribute to the dissemination of such tools and their utilization by industry professionals. Overall, this research work has demonstrated how the use of methodologies that employ state-of-the-art technological tools can generate innovative solutions to enhance the effectiveness of training, leading to positive outcomes in sports performance for young athletes at intermediate and advanced levels. Based on the paradigm that athletes have constant access to sensory information during sports activities, which they use to guide and adapt their motor behavior, this research project aimed to examine whether the use of perception-action devices can contribute to the improvement of certain perceptual-cognitive functions and coordination characteristics, such as reaction speed, agility, and quickness, in individuals engaged in sports activities.

The research questions were addressed, and the provided answers are as follows:

➢ Are there significant differences in motor performance between visual motor reaction tests and coordination abilities?

Yes, there are significant differences between visual motor reaction tests and coordination abilities, although both types of motor tests are important for assessing a person's motor skills, they focus on different aspects of motor performance and can reveal significant differences between them.

➢ Can DPA be used as assessment tools?

Perception-action devices like LED lights can be used as assessment tools in sports, as demonstrated by many studies referenced in this thesis. These devices can be employed to create visual stimuli that require rapid motor responses from athletes. For example, they can be used to measure an athlete's reaction speed by recording the time taken to respond to a light signal or perform a specific action in response to a change in LED color.

Furthermore, perception-action devices can be used to assess athletes' agility and coordination.

- Can the use of technological tools like DPA be integrated into a training program to improve performance? Can the use of DPA improve reaction time and movement to visual stimuli in advanced athletes? Can the use of DPA enhance agility and quickness?

Yes, the use of technological tools like LED-based DPA can be integrated into a training program to enhance sports performance. Furthermore, these tools can be employed to develop athletes' agility, quickness, and coordination. They can be utilized to create luminous patterns, courses, and circuit training that demand rapid, precise, and coordinated movements from athletes, as seen in the second experiment of this thesis. Chapter VIII demonstrated how through training with perception-action devices, volleyball players were able to enhance their ability to adapt to visual information and perform complex movements with increased fluidity and efficiency. However, it is important to emphasize that the use of LED luminous devices should be integrated appropriately and based on careful planning. Coaches and industry experts should assess the specific needs of athletes and tailor the workouts according to performance goals and the sporting context.

The last experiment of this thesis shifted to a field more related to applied physiology in sports. The study was conducted in a laboratory within a hospital setting, utilizing the transcranial magnetic stimulation equipment extensively described in Chapter Four.

- The initial question posed was whether the use of non-invasive technological tools that utilize magnetic waves to stimulate areas of the brain can have positive effects on motor coordination tests.

The results of the study indicate that a single session of high-frequency transcranial magnetic stimulation (HF-rTMS) of the dorsolateral prefrontal cortex (DLPFC) in volleyball players appears to have a positive effect on motor coordination and cortical excitability. These findings may have promising implications for optimizing sports training.

GENERAL LIMITATION

In general, it is important to acknowledge some initial limitations during the experimental phase, primarily caused by the global pandemic crisis between 2020 and 2021. This resulted in some restrictions in conducting experiments with a larger sample of participants.

ELEMENTS OF ORIGINALITY

Experiment 1

The use of perception-action devices as a tool for measuring cognitive and motor abilities in adolescent subjects. We are not aware of any studies in the literature that relate cognitive and motor components such as motor reaction times and agility in young individuals who engage in multisport activities, considering gender differences and biological age.

Experiment 2

The use of perception-action devices as a tool for measuring cognitive and motor abilities in adult athletes. The FitlightTM system has proven to be a reliable tool for measuring reaction times and can therefore be used to administer tests. The use of perception-action devices with LED lights for reactive agility training in advanced athletes. The other system, the ReactionX XLiGHT, on the other hand, has the best characteristics to be used as a training tool given the lower cost and the provision of numerous pre-set and easily accessible programs, as well as the possibility of creating new ones.

Experiment 3

The use of non-invasive technological tools such as high-frequency TMS to detect short-term effects on motor coordination tests in athletes.

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Sitography

Active floor (Pavigym combo 3.0): https://exergame.com/products/active-floor-games/pavigym-combo-3-0/

Blazepod® (Play Coyotta ltd, Tel Aviv, Israele): https://blazepod.eu/

Chronojump Bosco System: https://chronojump.org.

E.M.S. Italy, http:// www. emsme dical. net

Fitlight Corp. 2019 . https://www.fitlighttraining.com/products/

ReactionX: www.ql-sport.com

Reaxlight® (Reaxing s.r.l., Milano, Italia): https://reaxing.com/

SMARTfit ®(SMARTfit, Inc., Camarillo, California): https://smartfitinc.com/