UNIVERSITÀ DEGLI STUDI DI PALERMO

PhD Program in Health Promotion and Cognitive Sciences
Dipartimento di Scienze Psicologiche, Pedagogiche, dell'Esercizio Fisico e della Formazione
M-EDF/02

BIOMECHANICS AND NEUROSCIENCE IN SPORTS: FOCUS ON THE EFFECTS OF PRISMATIC ADAPTATION ON POSTURE AND SPORTS SKILLS ACCURACY

IL DOTTORE
DOTT. VALERIO GIUSTINO

IL COORDINATORE
CH.MO PROF. MASSIMILIANO OLIVERI

IL TUTOR
CH.MO PROF. GIUSEPPE BATTAGLIA

IL CO TUTOR
CH.MA PROF.SSA SIMONA PAJAUJIENE

CICLO XXXIV
ANNO ACCADEMICO 2020/2021

INDEX

INTRODUCTION

The present dissertation concerns the research activities carried out by the PhD candidate Valerio Giustino. The research conducted explored the contribution of a biomechanical device (i.e., the occlusal splint) and a neuroscientific procedure (i.e., the prismatic adaptation) on sport performance.

The first chapter briefly describes the concept of sport performance considering its components and its measurement.

The second chapter, focusing on biomechanics in sports, presents the influence of the occlusal splints on performance. In this chapter two experimental research are reported on the effects of the occlusal splints in sports (respectively on cervical range of motion and on hand grip strength). In fact, although the influence of oral devices on sports performance has been extensively explored, the real contribution these can make is still under investigation as the results are in contrast. Firstly, to avoid any misunderstanding, it is appropriate to distinguish the types of oral devices that exist and for what purpose they should be used by athletes. Indeed, the main difference concerns the mouthguards, which have the purpose of preventing oral injuries, and the occlusal splints, which have the purpose of balancing the occlusion. In particular, the latter oral device, since it determines an increase in the vertical dimension of occlusion (i.e., the vertical distance between mandible and maxilla), induces to a modification of the biomechanical structure of the head leading to a change in the cranio-cervical-mandibular posture. According to the concept of the whole-body biomechanics, strictly related to the concept of myofascial chains that connect the different body districts, a modification of a body part can determine changes in both adjacent and distant districts. Therefore, a change in the biomechanical structure of the head could affect characteristics such as strength, power, and body balance. Furthermore, in this chapter a further experimental research, currently submitted, on biomechanics in sports relating to kinematics of cervical spine in rowers is reported.

The third chapter deals with the importance of human posture on sport performance by presenting the concept of body balance and postural control and focuses on the role of proprioception, visual, and vestibular inputs for maintaining body balance. It also describes how to assess human posture qualitatively and quantitatively. This chapter also reports an experimental research on the differences in postural baropodometric characteristics in athletes of different sports.

The fourth chapter introduces the role of neuroscience in sports, focusing on the prismatic adaptation procedure. As a matter of fact, thanks to the encouraging results, the interest in neuroscience applied to sport has grown in the last years. Indeed, the continuous search for obtaining the best possible result and the constant interest in devices and procedures to improve sport performance have prompted the scientific community to investigate the influence that specific neuroscientific procedures can have on sport performance. Among the neuroscientific procedures, prismatic adaptation is a short-term visuomotor plasticity procedure induced by prismatic lenses that allow the visual field to be moved to a certain position in the space to which the motor system adapts. Due to its peculiarity of moving the visual field using prismatic lenses, this procedure was initially explored in patients with difficulty in exploring a visual hemifield, while recently it has also been studied in healthy subjects. The acute effects of prismatic adaptation have been studied on tasks such as walking, aiming, throwing, and on body balance but none of these studies have included athletes. This chapter presents two experimental research on the acute effects of prismatic adaptation. The first study investigated any acute effects on postural baropodometric characteristics and on hand grip strength in healthy subjects, including athletes. A second experimental research, currently submitted, explored any acute effects of prismatic adaptation on penalty kick accuracy and postural control in young soccer players.

Finally, the appendix presents the PhD candidate’s academic career.

I declare that all the articles reported in this dissertation are reproduced according to the Creative Commons policy (CC-BY) or with the permission of the journals.

CHAPTER 1 – Sport performance

Sport performance is the measurement of an athlete's success in participating in sport [1]. In particular, sport performance refers to a complex combination of several factors that influence the results of the competition, and measuring it objectively is of crucial importance especially in elite athletes [2].

The role of both physiological and psychological factors on sport performance has been extensively investigated over time. For instance, concerning the physiological factors, different recovery strategies have been studied by several research groups [3]. Similarly, various periodization approaches have been evaluated to study their contribute on performance enhancement in both individual and team sports [4]. Furthermore, among the other aspects studied in order to obtain better performance, research has examined the influence of the application of supplementation for improving sport performance [5]. Regarding the psychological factors, several research groups examined the fear of failure and the association with psychological stress and burnout that performance can cause in athletes [6]. In a similar way, athletes who play sports have been shown to experience anxiety disorders [7].

These premises show how sport is closely related to the search for the best possible performance. Nevertheless, a complete understanding of the components of performance and being able to measure it is necessary in order to achieve optimal results in sports.

1.1. Components of sport performance

Sport performance depends on a mixture of athlete's characteristics that includes physical components, technical and tactical skills, as well as psychological and social factors [8].

It should be noted that one dimension may predominate over another and in some sports the contribution of the physical components play a main role, while in other sports the technical-tactical skills prevail [8]. For example, in sports such as sprinting or marathoning performance is strictly related to the physical domain, while in team sports with the ball technical and tactical skills are fundamental for success [8]. Moreover, regarding physical domain, some sports require a greater contribution from one component rather than another [9]. For example, sports such as sprinting or throwing are highly dependent on anaerobic power, while marathoning or rowing predominantly requires aerobic endurance [9-11]. Similarly, technical and tactical skills are sport-related and, as for the physical domain, they also depend on the level of the athletes [12,13]. Furthermore, the training program includes exercises that emphasize more the sport-specific component, although it stimulates all of them in a general way [14,15].

Physical components for sport performance are endurance, strength, skill, and recovery [9]. In detail, these dimensions can be respectively described as the following abilities: to perform exercise for a prolonged period (at different intensities); to develop a high power in a single action; to perform a sport-specific motor skill; to restore pre-performance physiological levels from training sessions or competitive events [8,16].

Achieving a high level of specific physical components is essential for obtaining the best possible performance and this depends on training and is closely related to the respiratory and cardiovascular systems, as well as to the musculoskeletal and nervous systems [8]. Furthermore, in order to improve these abilities, the use of devices or procedures is increasingly common among athletes. It is indispensable to report that in order to establish any improvement in physical components during training or in performance during competitions, these must be appropriately measured.

1.2. Measurements of sport performance

The success of sport performance is established through its measurement. The measurement of sport performance has the dual purpose of objectively monitoring performance during training (in order to surpass oneself and to be competitive) and above all, to measure performance during competition (in order to establish its success and obtain the highest possible result) [1]. Hence, the measurement of sport performance, especially in elite athletes, has the connotation of the pursuit of excellence and success, raising the bar of the performance level.

As reported by Raysmith et al. (2019), the achievement of high performance not only allows the access to the final stages of competitions or the achievement of victories, but also involves an influx of money from sponsors and funding [1]. For these reasons, scientific research has extensively investigated the factors that influence the outcomes of sport performance [1].

High performance in sports depends on several factors related to sports science such as training planning, the use of devices for monitoring performance, and the use of equipment for improving performance [17-21].

Concerning the first domain, Doherty et al. (2020) investigated the relationship between a series of training and marathon performance [20]. Similarly, a recent systematic review aimed to identify the main characteristics of resistance training in terms of training intensity distribution, training volume, and periodization models in swimmers [21].

As for the devices used, advances in technology have made it possible to quantitatively measure variables such as movements, workloads, and biometric markers in order to optimize sport performance [17-19]. Indeed, performance analysis in sports represents a sub-discipline of sports science which uses a wide range of technologies with high level of validity and reliability, such as local positioning system (LPS), global positioning system (GPS), pedometers, accelerometers, video tracking and video analysis systems, and physiologic sensors to measure sport performance [17,22].

Regarding the equipment for improving performance, athletes, coaches, technical staff, and physicians are constantly looking for the possible benefits of wearable devices to maximize performance and minimize injuries [23,24]. For instance, Drum et al. (2016) investigated the differences in wearing personalized or custom-made mouthguards, and standard mouthguards, and no wearing mouthguards on general fitness parameters in experienced collegiate football players [23]. Similarly, Hülsdünker et al. (2019) examined the effects of 4-week training with stroboscopic glasses on visuomotor performance and neural visual function in top-level badminton players [24].

The above highlights the importance of technological progress in the development of biomechanical and neuroscientific devices in sports and underlines the contribution that these two disciplines are making increasingly to the improvement of sport performance.

CHAPTER 2 – Biomechanics in sports

Performance analysis in sports, both during training and competition, regards the contribution of different sport areas including biomechanical, physiological, psychological, technical, and tactical contexts [22].

Focusing on biomechanics, it represents the field of sports science that studies human movement, that is, the mechanics applied to the human body. Specifically, it studies human movement from the point of view of the forces that act on the human body and cause movement, and it studies the forces generated by it during the movement.

The mechanics applied to the human body therefore refers to the mechanics of rigid bodies which consists of three branches: statics, dynamics (i.e., kinetics), and kinematics [25-27]. The statics is the study of the conditions of mechanical equilibrium and conservation of the stillness of an object (for example, the analysis of postural sway). The kinetics is the study of the forces that cause or modify the motion of an object (for example, the sprint from the starting blocks for runners). The kinematics is the study of the motion of an object without considering the forces that cause or modify the motion. This discipline therefore considers parameters such as space and time, and the measures deriving from them such as speed and acceleration (for example, the motion of the tennis ball in the serve).

The use of technology in sports biomechanics is essential to assess and monitor statics, kinetics, and kinematics variables, and to improve performance and prevent injuries [28-31]. Precisely to pursue the achievement of these objectives, the research has also focused on the contribution of biomechanical devices such as shoes, insoles, braces, external joint supports, taping, mouthguards, and occlusal splints [32-44].

2.1. Biomechanical devices in sports: the effects of occlusal splints on performance

Although the use of oral appliances in sports is widespread, the scientific literature shows conflicting results on the effectiveness of these devices on improving performance [41,42]. Firstly, it is appropriate to clarify the difference between the two most used oral devices in sports, namely mouthguards and occlusal splints.

Mouthguard aims to protect teeth and gums from the risk of injury, especially in contact sports [45-48]. This device, mandatory for some sports and recommended in others, plays a crucial preventive role against oral injuries [49,50].

Occlusal splint is a removable device that has the purpose of regulating the occlusion, that is, balancing the relationship between the mandible and the maxilla by stabilizing the temporomandibular joint. Occlusal splint, by itself, increases the vertical dimension of occlusion and, apart from the jaw repositioning, this would seem to have an influence on the cranio-cervical-mandibular muscle groups and, consequently, on the adjacent and non-adjacent muscle groups affecting sport performance [51-54].

As for the effects of occlusal splints on sport performance, several research groups have studied the effectiveness of different occlusal splints in features such as body posture, walking and running biomechanics, endurance and strength performance [41,42,55,56].

As a matter of fact, Ohlendorf et al. (2013) showed that body balance ability can be improved by using a dental power splint in the myocentric condylar position, especially with eyes closed than with eyes opened [57]. Conversely, Leroux et al. (2018) detected no changes on body balance among different occlusal conditions (without occlusal splint; with two different occlusal splints increasing the vertical dimension of occlusions by 1 and 2 millimeters, respectively; and with occlusal splint inducing 4 millimeters of lateral deflection of the mandible) in young elite rowers [58].

In a similar way, Maurer et al. (2015) evaluated the influence of four dental occlusion conditions (i.e., neutral and with three different types of occlusal splints) in twenty healthy young recreational runners. Although no differences in the running speed were observed, they found within-subjects differences in terms of more symmetrical running pattern in the occlusal splint conditions compared to the neutral condition [59]. In contrast, Dias et al. (2020) studied the acute effects of occlusal splints on gait and running kinematics finding no significant differences on body sway patterns during gait or running between test conditions using occlusal splint, placebo splint, and no splint [60].

Buscà et al. (2016) detected significantly better performances on measures of maximal upper body isometric strength (i.e., hand grip, back-row) and lower body muscular power (i.e., vertical countermovement jump) in physically active male subjects while wearing an occlusal splint [61]. Similar ergogenic effects on specific measures of vertical jump and swim bench test in highly trained swimmers were found by Miró et al. (2021) when comparing the use of an occlusal splint with the no-occlusal splint condition [62]. In contrast to the latter results, in order to test the acute effects on power and strength, Allen et al. (2014) evaluated the performance of a maximum countermovement vertical jump (CMVJ) and of a 1 repetition maximum (1RM) bench press exercise, with and without an occlusal splint, in a sample of recreationally trained college aged males finding no significant differences between conditions [63].

The effectiveness of these devices is a subject of debate among scientists and for this reason the research on the influence of occlusal splints on sport performance is still current.

2.2. Experimental research on the use of occlusal splints in sports

In the following paragraphs (2.3. and 2.4.) two experimental studies will be presented which investigated the influence of occlusal splints on fitness characteristics in athletes. The first article investigated the effects of the occlusal splint on cervical range of motion (RoM) in sports subjects, while the second article examined the use of the same biomechanical device on hand grip strength in martial arts athletes.

2.3. Influence of Occlusal Vertical Dimension on Cervical Spine Mobility in Sports Subjects [from Battaglia et al. (2016)] [64]

Introduction

The well-known neurological and biomechanical intercommunication existing between the mandibular and cervical systems implies a close interaction between them [65]. In particular, the contact between teeth due to their relative positions, i.e. dental occlusion, determines the position of the mandible [66,67].

Considering the strict correlation between the stomatognathic and the musculoskeletal systems, disorders of the former and of the mandible have been reported to be able affect the spine [68,69]. Alterations of the tooth-mandible-tongue complex influence postural attitude [70], while the temporomandibular joint (TMJ) affects other systems, as well [71,72]. Moreover, symptoms of cervical spine disorders and head, neck and shoulder pain have been observed in subjects with TMJ dysfunction [72]. This is probably due to the biomechanical correlation between the cervical spine and the TMJ. It has been postulated, but not confirmed, that motor performance during physical activity may be influenced by the stomatognathic system and that the position of the TMJ affects muscle activity [70,73]. In addition, some authors have found significant associations between temporomandibular disorders (TMD), cervical spine injury and masticatory muscles [74,75].

Indeed, subjects affected by TMD have been proven to have considerably worse cervical extensor-muscle function [76], neck pain on movement [77,78], and cervical muscle tenderness. In addition, such individuals have decreased pressure-pain thresholds in tissues of the neck region [79]. The neurophysiologic connections between the cervical spine and the temporomandibular area, including the convergence of trigeminal and upper cervical afferent inputs in the trigeminocervical nucleus [80,81] could justify the link to cervical spine impairment. It could also affect posture in sports and sedentary subjects, as suggested by the evident relationships between cervical spine and TMD disability and the positive correlation of the reciprocal dose-response relation with, both severity and frequency of, spinal pain and TMD [82]. Several conflicting studies, reported in the literature, have investigated whether occlusal vertical dimension (OVD) affects sport-related skills [59,83,84]. The OVD corresponds to the height of the lower face when the dental arches are in maximum intercuspation [85]. According to Dawson's definition, a passive and an active OVD may be distinguished. The latter is characterized by contracted elevator muscles in the mandible [86].

The purpose of our study is to investigate the influence of OVD on cervical spine mobility in sports subjects. In particular, we measured cervical range of motion (ROM) before and after increasing OVD in sports and sedentary subjects.

Materials and Methods

Participants

Forty subjects, including 38 males and 2 females, were eligible for the study, but only the males were recruited in order to have an homogeneous sample. All subjects were administered a questionnaire about health status and personal data. After the preliminary interviews and screening, only 36 males were deemed suitable for our study based on the following inclusion criteria: 15-30 years of age (1 subject excluded); ≥3 consecutive years of sports background, for sports subjects (1 subject excluded), according to the standards of sports-specific studies; or ≥3 consecutive years of a sedentary lifestyle, for sedentary subjects [87].

Participants were assigned to one of two groups: a sports group (SG) and the control group (CG) which included 18 subjects each. The SG was composed of sports people (age: 20.11±3.45 yrs; body weight: 79.78±8.86 kg; height: 1.77±0.05 m; BMI: 25.39±2.32 kg/m2) and the CG consisted of age-matched sedentary subjects (age: 25.78±2.26 yrs; body weight: 77.72±9.40 kg; height: 1.77±0.08 m; BMI: 24.88±2.87 kg/m2). All subjects participated voluntarily in the study. However, given that some of the subjects were minors, in those cases a parent also provided written informed consent to participate in this study, which was approved by the

Ethical Board of the University of Palermo and conformed to criteria for the use of persons in research as defined in the Declaration of Helsinki. Researchers clarified the aim of the study and the scientific procedures to be used prior to allowing participants to enter the experimental study.

Anthropometric measurements

Anthropometric measurements were performed according to the evaluation procedures reported in several studies by Battaglia et al. [88,89]. In particular, body weight was measured using a Seca electronic scale (maximum weight recordable: 300 kg; resolution: 100 g; Seca, Hamburg, Germany), with the subjects wearing only undergarments. Height was measured by a standard stadiometer (maximum height recordable: 220 cm; resolution: 1 mm), with subjects barefoot and standing upright. Body mass index (BMI) was calculated as body weight divided by height squared (kg/m2).

Cervical ROM measurement

Cervical ROM was evaluated via a non-invasive technique by way of a Moover® (Sensor Medica®; Guidonia Montecelio, Roma, Italia) accelerometer, a wireless electronic, computer-aided measuring device using freeStep® software (Sensor Medica®; Guidonia Montecelio, Roma, Italia). The Moover® accelerometer permits measurements of range of motion, acceleration values, total amount of motion on the X,Y and Z planes.

The cervical ROM evaluation protocol was standardized and participants were allowed to become familiar with the experimental procedures used. Each individual was seated in a standardized chair (length: 38 cm; breadth: 40 cm; height: 45 cm) with their backs at 90 degree angles and sacrum and shoulder blades adhering to the backrest, feet flat on the floor, hands on thighs and head in a neutral position. The device to gauge cervical ROM was positioned medially, at the level of the frontal bone of the skull, above the bridge of the nose, then fastened to the head via a strap. Verbal commands were given to the subjects to perform neck movements until the maximal ROM. We first assessed mobility in the transverse plane, followed by the frontal plane, and finally the sagittal plane. Subjects performed three different and consecutive movements: maximal left and right rotation (LRR), maximal left and right lateral flexion (LRLF), maximal flexion-extension (FE) movements. All assessments were performed three times and the average values for each were used for purposes of statistical analysis. No warm-up was allowed for before measurements.

Evaluations of cervical ROM were consecutively performed two times in each individual: under pre-test and post-test conditions. During the pre-test phase, each subject performed movements with his mouth closed, whereas for the post-test phase a rigid wax 1-cm-thick occlusal rim was inserted between the dental arches so as to increase the OVD. The software recorded cervical angles of LRR, LRLF, FE movements in degrees. The same investigator took all the measurements.

Dental occlusion-class evaluations

The term occlusion refers to the relationship between the upper and lower teeth, that is, the anatomical position of contact between the two dental arches, which coincides with the maximum dental intercuspation, i.e. with the final phase of the masticatory function, in optimum conditions.

The permanent occlusal relationship, properly called occlusion, begins to take shape with the eruption of the upper first permanent molars which represent the guide for tooth occlusion. The key to occlusion is the relative position of the first molars [90]. On the sagittal plane, dental occlusion classes are classified according to the criterion adopted by Edward H. Angle, which is based on the relationship of the first permanent molars. This classification includes three bite classes:

Class I: by definition, correct occlusion or normocclusion, whereby the mesiobuccal cusp of the maxillary first permanent molar occludes with the mesiobuccal groove of the mandibular first permanent molar, while the cusp of the first maxillary canine is located between the mandibular canine and its adjacent first mandibular premolar.

Class II: incorrect occlusion or distocclusion (overbite), in which the maxillary first molar occludes mesially with the first mandibular molar, while the maxillary canine, instead of aligning with the lower one, is anterior to it. It is characterized by mandibular retrognathism, which, in turn, is divided into two subtypes: Class II Division 1, in which the incisors are directed forwards, usually with the anterior teeth protruding, associated with a lingual dysfunction; Class II Division 2, in which the incisors are retroclined.

Class III: defined as an incorrect occlusion, or mesiocclusion (underbite), whereby the lower first molar occludes mesially with the upper first molar, while the lower front teeth are more prominent than the upper ones. It is characterized by mandibular prognathism with a low position of the tongue.

Occlusion class was assessed with the subjects standing with a natural head posture, called orthoposition, i.e. the physiologic head position.

Statistical analysis

Statistical analysis was performed by one of the authors, who is a biostatistician and epidemiologist. Results were expressed as means ± standard deviations and all data were coded onto Excel files. Statistical analysis was performed using GraphPad Prism® software (Microsoft® Windows®, version 5.0; La Jolla, CA). Repeated measures ANOVA was used, with significance level set at $p \leq 0.05$, to compare differences between pre- and post-intervention performances.

Results

The two groups were similar in their anthropometric characteristics, as measured by BMI (SG:

25.39±2.32 kg/m2 vs. CG: 24.88±2.87 kg/m2; p>0.05) and occlusion-class distribution. In particular, CG included: 10 subjects in occlusal class I; 7 subjects occlusal class II and only 1 subject in class III. Similarly, in the SG, 7 subjects were: occlusal class I, 11; occlusal class II; no participants were in occlusal class III. For this reason, the single, unmatched occlusal class III subject in the CG group was excluded from the data analysis.

Regarding cervical ROM analysis at pre-test, the sports and sedentary groups showed similar total ROM. Moreover, we found that the SG showed no significant difference in cervical ROM in response to increased OVD when compared to the control group. As is shown in table 1, there were no increases in LRR, LRLF, FE for SG (p>0.05), compared to the control group, from pre- to post-test conditions.

TABLE 1 – Study of cervical ROM in response to increased OVD

	Left Rotation			**Right Rotation**			**Total Rotation**		
	Pre-test(°)	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**
CG	68.14±9.03	68.80±9.70	+0.96	67.05±9.39	66.26±8.97	-1.18	135.19±18.42	135.06±18.67	-0.10
SG	68.48±5.94	68.74±7.10	+0.38	73.05±10.37	72.85±9.22	-0.27	141.53±16.31	141.59±16.32	+0.04
	Left Lateral Flexion			**Right Lateral Flexion**			**Total Lateral Flexion**		
	Pre-test(°)	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**
CG	40.21±7.11	41.96±6.60	+4.34	41.38±8.26	39.89±7.67	-3.58	81.59±15.38	81.85±14.28	+0.32
SG	42.35±7.82	43.51±7.13	+2.73	40.21±6.99	41.66±6.37	+3.61	82.56±14.81	85.17±13.50	+3.16
	Flexion			**Extension**			**Total Flexion-Extension**		
	Pre-test(°)	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**
CG	49.83±11.82	53.09±10.11	+6.54	68.11±10.30	62.81±11.56	-7.78	117.94±22.13	115.90±21.67	-1.73
SG	47.78±12.54	51.59±8.62	+7.98	66.38±12.20	64.15±11.87	-3.36	114.16±24.74	115.74±20.48	+1.39

Legend: ROM, Range of Motion; OVD, Occlusal Vertical Dimension; CG, Control Group; SG, Sports Group.

Likewise, data analysis according to occlusal class (I or II) of the SG subjects revealed no statistically significant ROM variations in response to increased OVD (Table 2). Of note, the CG in occlusal class II showed an interesting increase (p>0.05) in the average values of rotation (pre-test: 131.10±21.02 vs. post-test: 137.86±17.42; Δ: +5.15%), with respect to SG subjects belonging to the same class (pre-test: 142.58±18.05 vs. post-test: 143.68±18.49; Δ: +0.77%).

TABLE 2 – Study of cervical ROM in response to increased OVD according to occlusal class

	Left Rotation			**Right Rotation**			**Total Rotation**		
CG	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**
I	68.99±7.88	68.91±11.70	-0.12	67.84±9.70	64.60±8.88	-4.78	136.83±17.59	133.51±20.59	-2.43
II	65.97±11.12	69.41±7.48	+5.22	65.13±9.90	68.44±9.95	+5.09	131.10±21.02	137.86±17.42	+5.15
	Left Rotation			**Right Rotation**			**Total Rotation**		
SG	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**
I	67.39±4.61	67.16±4.37	-0.34	72.50±9.58	71.16±8.19	-1.85	139.89±14.19	138.31±12.56	-1.12
II	69.18±6.77	69.75±8.45	+0.83	73.40±11.28	73.93±10	+0.72	142.58±18.05	143.68±18.49	+0.77
	Left Lateral Flexion			**Right Lateral Flexion**			**Total Lateral Flexion**		
CG	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**
I	38.24±6.97	42.01±5.62	+9.86	39.20±9.62	38.44±8.18	-1.94	77.44±16.59	80.45±13.80	+3.89
II	42.47±7.45	41.93±8.72	-1.28	43.64±5.90	41.10±7.42	-5.83	86.11±13.35	83.03±16.14	-3.58
	Left Lateral Flexion			**Right Lateral Flexion**			**Total Lateral Flexion**		
SG	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**
I	42.20±4.66	41.60±3.42	-1.42	38.94±6.65	40.57±4.02	+4.18	81.14±11.31	82.17±7.44	+1.27
II	42.45±9.54	44.72±8.68	+5.35	41.02±7.39	42.35±7.61	+3.26	83.46±16.93	87.07±16.29	+4.32
	Flexion			**Extension**			**Total Flexion-Extension**		
CG	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**
I	45.48±10.28	55.59±9.76	+22.23	67.43±10.70	60.28±13.79	-10.60	112.91±20.98	115.87±23.56	+2.62
II	53.39±11.55	49.14±10.81	-7.95	67.69±10.59	64.11±6.14	-5.28	121.07±22.14	113.26±16.94	-6.45
	Flexion			**Extension**			**Total Flexion-Extension**		
SG	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**	**Pre-test(°)**	**Post-test(°)**	**Δ(%)**
I	46.04±14.86	46.83±6.54	+1.71	63.11±9.28	62.27±13.65	-1.34	109.16±24.14	109.10±20.19	-0.05
II	48.88±11.46	54.62±8.64	+11.74	68.45±13.76	65.35±11.12	-4.54	117.34±25.22	119.96±19.75	+2.24

Legend: ROM, Range of Motion; OVD, Occlusal Vertical Dimension; CG, Control Group; SG, Sports Group.

Discussion

The main finding of this study was that sports subjects showed no significant difference in cervical ROM in response to increased OVD, when compared to controls. Furthermore, our results indicate that neither sports nor sedentary subjects affected by malaocclusion (class II) revealed any significant variation in cervical spine mobility, compared to those with normocclusion (class I), in response to increased OVD. These findings are concordant with several negative studies reported in the literature [91,92] investigating the use of occlusal splints to significantly improve physical performance in athletes, compared to sedentary subjects. In fact, the results of a number of studies illustrate how persons do not always obtain benefits during physical performance by using a bite [91].

In particular, Manfredi et al. [92] reported on the explosive force variation of basketball players in response to the use of occlusal bites. Although their data showed a significant difference between subjects with and without the occlusal bite, both in players and in control subjects, no statistically significant differences between the two groups were found. That being said, there are, however, several studies in literature that have reported increased sport related skills in response to the use of occlusal splints [59,83,84]. During contact-sports competitions and training, many professional athletes wear occlusal splints in order to reduce the frequency of dental accidents. Custom-made mouthguards are, indeed, highly recommended by a variety of dental associations for prevention of oro-facial and dental injuries during sports-related activities [49,93].

Medical and dentistry studies have ascertained that occlusal factors can influence body balance and, consequently, athletic performance. Researchers who evaluated the relationships between performance and occlusion in athletes have considered two aspects: the fact that wearing a splint improved body posture and that correct occlusion or wearing splints increased muscular force [83]. Despite the data in literature reporting improvements in sports performance in response to a balanced cranial-occlusal system, the results are still controversial [94]. Several kinds of occlusal splints, of differing materials, structures and thicknesses, have been used in a host of studies in order to evaluate the relationship between sports performance and occlusion. Various studies have confirmed a positive correlation between the use of the bite and increased performance.

Greenberg et al [84], for example, showed a correlation between mandibular position and upper body force. In particular, these authors published a clinical study based on the principle that increasing the OVD by occlusal devices seemed to be able to increase muscular force. Moreover, many researchers report that different dental occlusal devices may affect gait stability during static and/or dynamic postures [59,67,70]. To date, however, the literature shows how these data have not always confirmed, when the results are not correlated with the possible dysfunctional conditions of the subjects. In agreement with the results of a study by Lai [91], which showed that the use of occlusal splints improved sports performance in dysfunctional subjects, we found it noteworthy that improvements in cervical spine ROM were demonstrated in our subjects affected by malocclusion (class II) compared to those with normocclusion. However, these results were not statistically significant. The principal limit of our study was the small sample size that did not permit any statistically significant conclusions. For these reasons, these results might not to be evenly spread to all sports people. In all probability, gnathological postural intervention in athletes could have greater impact on sports performance in those cases in which the athlete suffers from postural pathologies or TMD. There is a close interaction between the cervical and mandibular systems, due to the existing biomechanical and neurological interactions [65]. It is well-known that spine posture and craniomandibular system influence each other [68,69].

A recent systematic review showed that muscular-related TMD determines important changes in cervical posture [95].

Few researchers have investigated cervical spine mobility in athletes with TMD [74,78].

One study demonstrated that TMD entails an increased fatigability of cervical muscles during neck extensor muscle endurance tests [76]. Among the several treatments currently indicated for sufferers of TMD, an important role is played by occlusal devices that improve TMD symptoms in patients [96].

In conclusion, due to the paucity of studies and their contrasting results, there is as yet no compelling scientific evidence as to whether OVD positively impacts sports performance or not. Mouthguards, bites and/or similar occlusal devices are increasingly recommended by dentists during professional and amateur sports-related activities. As suggested by several authors, we too deem it necessary that further scientific investigation, regarding the relationships among sports performance, OVD and TMD, be conducted in the field of sport and exercise sciences.

2.4. Influence of Vertical Dimension of Occlusion on Peak Force During Handgrip Tests in Athletes [from Battaglia et al. (2018)] [97]

Background

Athletes of contact sports, especially martial arts like taekwondo, karate and ju-jitsu, require peculiar kinanthropometric characteristics, as well as high levels of technical skills, agility, strength and coordination in order to obtain the best possible result during competitions [98]. Intense physical efforts exerted within short time periods are typical of these athletes [99].

In combat sports, mouthguards are obligatory or optional based on the specific martial art. Scientific research has demonstrated the musculoskeletal connections between the cranio-cervical-mandibular structures and the spinal column and the relative effects on body posture [100-102]. In particular, several authors have investigated the relationship between the stomatognathic system and sports performance [64,103]. Scientific literature has examined the effects of oral devices, such as mouthguards and occlusal splints, on performance variables and exercise capacity [63,64,104-110]. Some authors have found that by restoring a better occlusal balance with splints, sports performances may be improved [52,56,111-114], whereas others have reported contrasting findings [94,107,115]. D'Ermes et al. [52] documented higher performances in every test conducted on athletes wearing occlusal splints, regardless of the sport they practiced.

In athletes wearing a mouthguard, performance measures have demonstrated significant improvements in vertical jump height, as reported by Arent et al. [116]. In contrast, the same authors found no difference in submaximal bench press performance or mean power during the Wingate test while wearing a mouthguard or not. Similarly, Cetin et al. [107] evaluated customized mouthguards on various strength and power endpoints in taekwondo athletes. When athletes wore a custom-fit mouthguard, even though no significant differences were described in some strength measures, such as handgrip test, significant improvements were reported for other parameters, e.g. the Wingate test. Allen et al. [63] assessed CMVJ and bench press 1RM, in a group of trained amateur college students, under 2 test conditions: using a commercial mouthpiece and with no mouthpiece. Although not significant, all results showed some degree of improvement in performances while wearing the mouthpiece.

Literature findings suggest that occlusal splints (OS), which increase VDO, may in fact enhance mandibular stability [117,118].

Mouthguards are generally recommended in contact sports with an opponent (martial arts, etc.). Nevertheless, many athletes find that oral devices hamper their verbal communication, swallowing and breathing or have concerns in regard to the possible effect on their performance [52,104,119].

In this study we aimed to examine whether changes in peak muscular force would occur by applying an occlusal splint to martial arts athletes. Therefore, the aim of our study was to evaluate any changes on isometric handgrip, before and after the application of an occlusal splint, in martial arts athletes.

Methods

Experimental Design

A repeated measures within-subjects design was adopted on a sample of martial arts athletes to study the effects on isometric strength (i.e. peak force) while wearing an occlusal splint during handgrip tests. The participants were studied during two testing sessions, both with (OS) and without (NO OS) the use of the occlusal splint. They were randomly assigned to either condition to avoid the potential confounding effects of fatigue and test-learning.

Participants

The sample size was determined by inviting sports associations of Palermo city of taekwondo, karate and ju-jitsu to participate, in a voluntary form, in this research. However, only thirty young volunteer athletes were initially enrolled, five of which were excluded from the study since they failed to meet the following inclusion criteria: red- or black-belt status for taekwondo; brown- or black-belt status for karate and ju-jitsu; more than 3 consecutive years of sports activity prior to enrolment. Participants were excluded from the study in the presence of musculoskeletal injury.

A total of 25 eligible subjects (age: 20.9±7.06 years; height: 170.5±5.7 cm; weight: 75.1±7.3 kg) were included in the study. All participants were subjected to both test conditions. All the participants were practitioners of martial arts, specifically taekwondo (n = 9), ju-jitsu (n = 10) and karate (n = 6). All participants provided written consent prior to participating in the study by undersigning an institutionally approved informed consent form. However, written informed consent from a parent or legal guardian was required in the case of minors.

The study received approval by a local ethics committee (minutes no. 1/2018) in conformity with the criteria for the use of persons in research as defined by the Declaration of Helsinki.

Procedures

Anthropometric measurements were performed on a predetermined date, prior to the collection of the data. Body weight was assessed using a Seca electronic scale (maximum weight recordable 300 kg; resolution 100 g; Seca; Hamburg, Germany) with the participants wearing only undergarments. Height was measured by a standard stadiometer (maximum height recordable 220 cm; resolution 1mm) with the participants barefoot and standing upright.

Both testing sessions took place before starting a regular training session, at the same time of the day, separated by exactly 48 hours. On day one, each participant was instructed to exert their maximum handgrip strength on an isometric mechanical dynamometer, repeating the same task, alternating their dominant and non-dominant hand. The participants were randomly assigned to perform the tasks with the occlusal splint, at the first session, and without it 48 hours later or vice versa. In the OS condition, participants wore a rigid wax rim (100-mm-long and 10-mmthick) positioned between their dental arches. The preformed wax device (Zeta®-

Industria Zingardi srl, Novi Ligure, Alessandria, Italy) is non-rigid with a certain degree of plasticity and a melting point of 59°C. The standardized procedure for maximal handgrip strength task is as follows: Participants were instructed to exert maximum force on the handgrip dynamometer while standing barefoot, feet at shoulders' width apart and head in neutral position gazing forward, arms extended laterally alongside the trunk, (Kern Map model 80K1-Kern®, Kern & Sohn GmbH, Balingen, Germany). Participants were not allowed make any other ancillary bodily movements during the handgrip task. Each participant exerted 3 seconds of maximal isometric force with each hand, alternating the dominant and the non-dominant hand, for a total of 3 trials with a 3-minute rest between trials on the 2 successive test days (OS and NO OS, respectively). Trials were scored as the maximal isometric strength expressed in kgf units, using the best performance out of the 3, for both OS and NO OS, for data analysis.

Statistical Analyses

Mean values and standard deviations were calculated according to standard statistical analysis methods using Statistica Software 12 (StatSoft®, TIBCO® Software Inc., Palo Alto, CA, USA). Differences between handgrip test data under OS and NO OS conditions, for both hands, were analysed via paired-sample t-tests for comparisons. The a priori alpha level was set at $P < 0.05$ for all analyses. Finally, Bonferroni post hoc tests were used to calculate pairwise differences between performances, for each sports group, provided the P score was significant.

Results

For the dominant hand, a significant increase in hand grip strength resulted from pairwise comparisons for the OS condition ($P = 0.01$), whereas no significant differences were found between OS and NO OS conditions for the non-dominant hand for the entire sample, as reported in Table 1.

Table 1. Values of the peak force on hand grip tests in all the sample.

	NO OS (kgf)	OS (kgf)	*p*-value
DH	37.77 ± 9.15	39.39 ± 9.29	0.01
Non-DH	36.9 ± 9.51	36.44 ± 9.17	N.S.

Legend: *DH, Dominant Hand; Non-DH, Non-Dominant Hand; NO OS, No Occlusal Splint; OS, Occlusal Splint.*

Although the differences between the OS and NO OS conditions for the dominant hand were present in taekwondo (+8.33%), ju-jitsu (+1.05%) and karate (+2.97%), when analysed by martial art, Bonferroni post hoc test showed statistical significance (P = 0.04) only for the taekwondo group, as shown in Table 2.

Table 2. Values of the peak force on DH handgrip test for sports groups.

	NO OS (kgf)	OS (kgf)	*p*-value
Taekwondo	42.03 ± 9.12	45.53 ± 7.93	0.043
Ju-Jitsu	37.31 ± 7.51	37.7 ± 6.79	N.S.
Karate	32.03 ± 9.74	32.98 ± 10.36	N.S.

Legend: *DH, Dominant Hand; NO OS, No Occlusal Splint; OS, Occlusal Splint.*

Discussion

In the past several years, a number of researchers have focused on the effects of wearing occlusal devices considering measures of strength and muscular power in the context of sports performances [56,61,63,107,112]. Although many studies have demonstrated such increases [61], particularly in maximal isometric strength, to date there is still no unanimity on the issue [63,107].

The hypothesis we aimed to examine in this study was whether changes in peak muscular force, as measured by handgrip strength tests, occur by applying an occlusal splint to martial arts athletes. The differences found comparing the 2 conditions adopted in this study, i.e. NO OS and OS, were statistically significant. In particular, benefits were observed on dominant hand handgrip tasks while wearing the occlusal splint, whereas no differences between the OS and NO OS condition in the non-dominant hand were recorded. When analyzed by martial arts, the results of each showed a certain degree of increase in isometric strength, albeit reaching statistical significance only for taekwondo. In order to explain as to why our results showed a significant difference only for taekwondo athletes, we tentatively suggest that, respect to the other athletes of this sample, taekwondo athletes probably underwent a training regime with the occlusal splint that induced better long-term adaptations compared to the other athletes [87]. Other authors had previously found that by achieving a more balanced dental occlusion, sports performances may be improved [52,61], corroborating our findings, herein described.

Occlusal splints entail forward and downward jaw repositioning, thus promoting centric occlusion and optimal mandibular positioning [61]. Occlusal splints, in fact, realign the temporomandibular joint (TMJ), thereby reducing occlusal imbalance [109], thus playing a role in motor activity and sports performances [56,120]. Indeed, proper occlusion bolsters muscle balance of jaw muscles extending to the neck and shoulders, as well as those of the lower limbs [70,121]. Our results are in agreement with Churei, who suggests an influence of oral motor functions on maximal grip strength for the dominant hand [122]. Several prior studies had reported an increase in isometric muscular strength in subjects wearing an occlusal splint [61,121,123] as confirmed by our experimental findings. Nevertheless, not all studies have found this ergogenic effect [124,125]. In fact, in contrast to our findings, Allen et al. showed no difference in strength performance using occlusal splints compared to no splint in symptomatic subjects as well as in physically active men, the latter probably enrolled to study recreationally trained participants [63,124]. Similar, Dunn-Lewis et al. have reported no changes on strength and power in trained males and females, but the limit of their study was to require participants to perform the task naturally, with no specific instructions regarding clenching [126]. Kececi et al. [127] found no significant differences in handgrip test, with and without mouthguards, in professional taekwondo athletes. This is probably because mouthguards per se simply protect the teeth and gums from sports-related oral injuries, with no significant increase in vertical dimension of occlusion (VDO), i.e. the distance between dental arches [61].

Our findings lend further support to the notion that occlusal splints may reinforce more effective regulation of efferent motor pathways, most likely via potentiation of afferent stimuli from periodontal mechanoreceptors and muscle spindle fibers, activated during teeth clenching with balance occlusion [108]. Indeed, literature findings suggest that by wearing an occlusal splint mandibular stability may be increased [52].

According to one research hypothesis, the improvements in the performance of athletes wearing an occlusal device, that increases VDO and modifies cranio-cervical-mandibular posture, might, in part, be due to an optimization of neuro-muscular coordination [52]. However, this improvement, due to the increase in VDO, is not independent of the thickness of the splint. Chakfa et al. [128] investigated the effects of occlusal splints of varying thicknesses on isometric strength of deltoid and cervical muscles finding significant improvements when increasing VDO, up to a certain distance, but reductions in isometric strength thereafter. Likewise, Limonta et al. [129] tested the effects of two kinds of occlusal splints of different thicknesses during isometric contractions of elbow flexors comparing electromyographic and force parameters with respect to a control group wearing no splint. Their results indicated that splint usage produced increases in maximum isometric strength. Moreover, the thicker the splint, the greater the increase. They posit that the thicker splint induces a further lengthening of masticatory muscles and, consequently, a possible reduction in proprioceptive feedback. Indeed, even in healthy subjects, masticatory-muscle repositioning in the vertical axis and jaw repositioning has shown positive ergogenic effects [110,129,130].

Another hypothesis that supports our results concerns the Hoffmann-reflex (H-reflex). A previous study had shown increases of the H-reflex activity of lower extremity muscles when subjects performed jaw clenching [131]. A recent research has demonstrated similar increases for hand muscle H-reflexes [132]. The latter, in turn, could explain the differences found in strength and, in particular, on handgrip testing. All the more, Takahashi et al. [133] demonstrated H-reflex facilitation of forearm muscles during voluntary teeth clenching in proportion to the magnitude of biting force. Moreover, Miyahara et al. [131] and Kawakubo et al. [132] identified the role of central motor command of the trigeminal motoneurons innervating the jaw-closing muscles, afferent impulses from periodontal mechanoreceptors as well as muscle spindles in this facilitation.

Limitations

Admittedly, the main limits of our study regard the small sample size and the single category of sports investigated (i.e. martial arts). Nonetheless, the statistical significance was demonstrated despite these limits. It is necessary to note that the participants used in this study were not professional athletes. For these reasons, the results warrant further investigation to confirm the hypothesis that using an occlusal splint may increase dominant-hand handgrip tasks.

Conclusions

The benefits found with the occlusal splint were statistically significant only on dominant hand handgrip tasks. Therefore, realignment of the temporomandibular joint (TMJ) with occlusal splints could play a significant role in increasing handgrip peak force only for the dominant hand. In conclusion, the results seem to indicate that the use of an occlusal splint may benefit performance measures in competitive sports.

2.5. Other experimental research on biomechanics in sports

In the following paragraph (2.6.) an experimental study in biomechanics research field will be presented. The study was conducted to evaluate the kinematics of cervical spine at different stroke rates on an indoor rowing ergometer in young rowers.

The manuscript is currently submitted, therefore only the abstract of the study is reported.

2.6. Kinematics of cervical spine during rowing ergometer at different stroke rates in young rowers: a pilot study

Abstract

Research on biomechanics in rowing has mostly focused on the lumbar spine so far, given that it is the most frequent injured region in rowers. However, less frequent injuries can affect other parts of the body. Thus, the aim of this pilot study was to explore any potential variations in the kinematics of cervical spine during two different stroke rates on rowing ergometer in young rowers.

Twelve young rowers (Male: 5; Female: 7; age: 13±0.85 years; height: 156.42±8.53 cm; weight: 51.37±11.17 kg), all belonging to regional or national level, were recruited for the study. The experimental protocol consisted of two separate test sessions (i.e., a sequence of 10 consecutive strokes for each test session) at different stroke rates (i.e., 20 strokes/minute, and 30 strokes/minute) on an indoor rowing ergometer. Kinematics of cervical spine was assessed using a wireless, computer aided inertial sensor capable of measuring joint ROM (angle of flexion, angle of extension, total angle of flexion-extension).

Although there were no differences in the flexion and flexion-extension movements during the different stroke rates, a significant increase in the extension movement was found at the higher stroke rate ($p=0.04$, $d=0.66$).

Therefore, we can summarize that young rowers showed changes in cervical ROM according to stroke rate. The lower control of the head during the rowing stroke cycle can led to a higher compensation resulting in an augmented effort, influencing sports performance, and increasing the risk of injury.

CHAPTER 3 – Human posture

The posturology, that is, the discipline that studies human posture, is a relatively new research field of medical sciences [134,135]. Human posture indicates the position of the body in space and aims to maintain body balance in static and dynamic conditions [135]. Hence, the terms posture and balance are not equivalent [134].

The methods widely used for posture evaluation are photography and posturography. The first, also named visual postural analysis, is the study of upright posture through photography in the frontal, sagittal, and horizontal planes; the second one consists of instrumental tests that use a force platform to study the displacement of the center of pressure (CoP) in static and dynamic conditions (i.e., static, and dynamic stabilometry), and to assess the distribution of plantar pressure (i.e., baropodometry).

Human posture depends on many factors such as neurophysiological, biomechanical, and psycho-emotional characteristics and for this reason postural alterations can derive from various causes [134,135]. Some postural alterations can adversely affect muscular efficiency and negatively influence sport performance [134-138]. Therefore, the assessment of human posture is of fundamental importance in the general population as well as in athletes.

3.1. Body balance and postural control [from Martines et al. (2021)] [139]

The ability of body balance and the maintenance of postural control is fundamental for daily activities and for preventing the risk of falling as well as for sport performance in athletes [140,141]. For this reason, the evaluation of body posture is a matter of interest for a wide range of professions such as medical doctors, physiotherapists and kinesiologists [141]. The postural balance, both in static and dynamic conditions, is guaranteed by the physiological function of the sensory receptors such as vestibule organ, visual apparatus, stomatognathic system, and proprioceptive organs [71,142-148]. Each organ continuously transmits sensory information to the central nervous system (CNS), including the brain and the cerebellum, which integrates them and generates an output, constantly modulated on the basis of the sensory inputs that progressively arrive [135,149]. The efferent information is conveyed to the postural tonic system (PTS), the musculature that counteracts the force of gravity and allows the human being to maintain the bipedal position and more generally to control body balance [149,150]. The postural adjustments of the PTS are made to maintain the displacement of the center of gravity (CoG) within the area of the base of support (BoS) [151]. This is the condition for controlling body balance. In order to manage postural balance, humans adopt predictive mechanisms, i.e., anticipatory movements prior to a predicted disturbance, and reactive mechanisms, i.e., compensatory movements following an unpredicted disturbance [151]. As reported in a seminal work, during upright stance the human body can adopt different postural strategies to maintain balance based on the biomechanical model of the inverted pendulum [152]. These strategies are properly called "ankle strategy" and "hip strategy" [140,151,152]. The first manages large size perturbations, while the second is used for small size perturbations [140,152].

Based on these concepts, a non-physiological condition of one or more sensory receptors constantly sends altered signals to the CNS which modulates the tone of the PTS using short-term postural adjustment mechanisms and long-term postural adaptations [153-158]. A pathological condition and related change in body posture, as in vestibular disorders, can lead to a postural disorder characterized by poor balance and an increased risk of falling [159-162].

3.2. The role of proprioception, visual, and vestibular input on body balance and postural control [from Martines et al. (2021)] [139]

Body balance and postural control are guaranteed by the fundamental role of three main peripheral organs, such as: the proprioceptive receptors, the visual system, and the vestibular apparatus [163]. In physiological conditions, the sensory inputs from these organs allow for the optimal maintenance of balance. In case of aberrant information from one of the three aforementioned organs, the other two are able to compensate for the altered/missing information [163-165]. Body imbalance increases when the functioning of two out of three systems is compromised. This means that in patients with vestibular disorders, who already show an alteration of postural control, in situations of visual/proprioceptive disturbance they have a lower ability to maintain balance.

The three main receptors responsible for body balance and postural control are presented below.

Proprioception

Proprioception is the ability to perceive and integrate afferent input from mechanoreceptors, located in the musculoskeletal system and in the skin, in order to determine body segment position and body position, as well as body segment movement and body movement in the space [166,167]. In particular, the muscle spindles and the Golgi tendon organs constitute the muscles and tendons receptors, respectively [168,169]. They are able to provide information on the amount of muscle stretch and muscle tension and are responsible for the responsiveness of the muscle when undergoing these changes in length [170,171]. Regarding the joint receptors, it is possible to include the Pacinian corpuscles and the Ruffini endings which identify the static and dynamic information of the joint, while the Golgi endings are capable of distinguish the tension inputs in the ligaments [172].

Visual Input

The visual apparatus is a complex system capable of transducing, through the eyes, analog inputs (external light signals) into digital signals (electrical signals) to be processed by the CNS [173]. In a simplified way, the light reflected by the objects is refracted by the cornea and the lens and projected onto the curved surface of the retina of the eye, where the light, through a phototransduction process, is converted by the photoreceptors (cones and rods) into a nerve signal [174,175]. Then, the nerve signal is sent first to the bipolar cells and then to the ganglion cells. Lastly, the axons of the ganglion cells leave the retina forming the optic nerve [176]. Then, the electrical signals are conducted respectively by the optic nerve, the optic chiasm and the optic tract ending in the lateral geniculate nucleus of the thalamus and in the visual cortex located in the occipital lobe of the brain [177].

Vestibular Input

The inner ear contains the cochlea, the organ responsible for the perception of sounds, and the vestibular system, defined as the organ of balance and consisting of the semicircular canals, the utricle and the saccule [178-181]. The last two are contained within a bony cavity called the vestibule, located between the semicircular canals and the cochlea [178,179,182,183]. As concern the vestibular system, the three semicircular canals, i.e. the horizontal (lateral), the anterior (superior), and the posterior (inferior), are responsible for the perception of information concerning angular acceleration of the head in the three dimensions of space [184-186]. The utricle and the saccule are sensitive to horizontal and vertical linear acceleration of the head, respectively, and moreover, they convey information on the head position [178,179]. In particular, the sense organs within the utricle and the saccule are the macules, while for the semicircular canals they are the crista ampulliaris. Both macules and crista ampulliaris contain the hair cells that are responsible for the perception of head movements [178,179]. The vestibular system conveys the information to the 4 "major" nuclei of the vestibular nuclear complex, located in the brainstem, through the vestibular component of the vestibulocochlear nerve and then trasmitted to the cerebellum. Since the vestibular nuclear complex forms connections with the oculomotor nuclei, the visual and the vestibular systems are strictly related as for the vestibulo-ocular reflex (VOR) [187]. In a similar way, with the vestibulo-spinal reflex (VSR) the vestibular apparatus is connected to the neck musculature [187]. These further connections underline the marked interdependence between the three main systems (i.e. the proprioceptive, the visual, and the vestibular apparatus) for body balance and postural control.

3.3. Mechanism for postural control and alterations in body balance [from Messina et al. (2021)] [188]

The mechanism for postural control in humans can be described as a non-linear cybernetic system in which the signals coming from the postural receptors (feedback), once they reach the central nervous system (CNS), are integrated generating a response (feedforward) directed to the tonic postural system, that is the antigravity musculature responsible for postural control (Figure 1) [149,150,189]. Postural receptors are represented by all the sensory organs involved in maintaining body balance in static and dynamic conditions, such as the visual and audio-vestibular systems and the proprioceptive organs (Figure 1) [64,143,190-193].

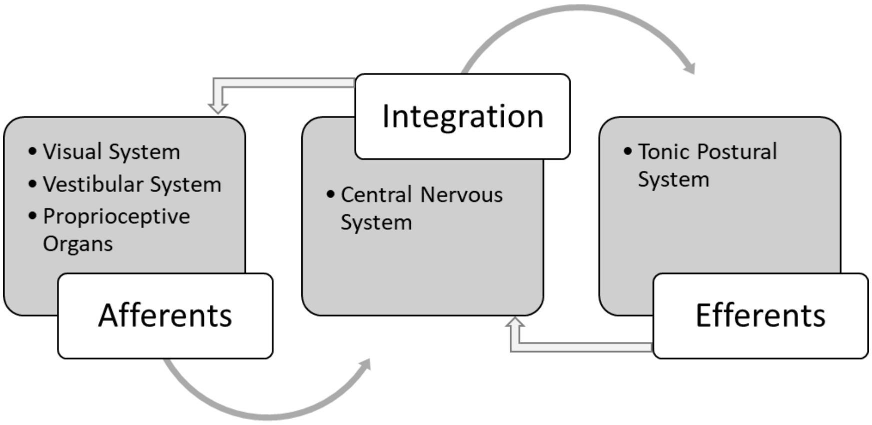


Figure 1 - Non-linear cybernetic system of postural control in human

Age and pathological conditions are factors that affect many functions including the body balance ability [71,148,191,194-196]. In fact, a missing or aberrant afference from a receptor organ, for example from the audio-vestibular system, can lead, if not compensated, to several impairments as conditions of poor body balance [155,158,180,183].

Since balance disorders can negatively affect activities of daily living, can increase the risk of falls, and in athletes can negatively impact performance, a postural analysis is recommended to evaluate any changes due to the pathological condition and after any approach (such as physical activity programs, vestibular rehabilitation, etc.) to improve postural control [164,197-202].

3.4. Visual postural analysis [from Messina et al. (2019)] [203]

The observation of the posture is an essential part of the body posture evaluation. This qualitative assessment take into consideration the spatial location of peculiar points of the body in order to analyze any deviations respect to the vertical line for the sagittal and the frontal plane and possible rotations in the horizontal plane [204]. Moreover, it is possible to examine the alignment of body segments and the differences between rightward and leftward hemibody [204].

For the visual postural analysis the subject is asked to maintain the orthostatic stance as comfortably as possible wearing only underwear, barefoot and looking forward while the posturologist records the location of the landmarks for all the anatomical planes as represented in the figures 2a,b,c. In particular, in the frontal plane the following lines are considered: the bipupillary line, the connection line of acoustic meatus, the line connecting left and right labial commissures, the bi-acromial line, the bi-styloid line and the bi-ischial line (Figure 1). In absence of any postural disorder, all these reference lines should be parallel to each other. To assess postural features in the sagittal plane, the alignment of peculiar points passing through the vertical axis, i.e. the acoustic meatus, the odontoid process of the second cervical vertebra, the body of the third lumbar vertebra and the lateral malleolus, is taken into consideration (Figure 2a). Moreover, the cervical curve of the spine should measure 6-8 cm and the lumbar curve 4-6 cm. In the evaluation of the horizontal plane the main reference lines concern the parallelism between the shoulder girdle and the pelvic girdle (Figure 2c).

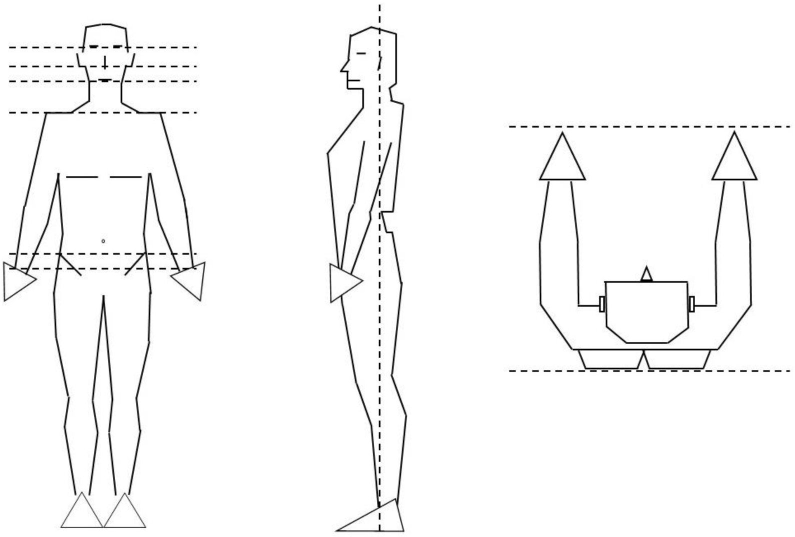


Figure 2a,b,c. The visual postural analysis in the frontal, sagittal and horizontal plane respectively.

3.5. Posturography [from Messina et al. (2019)] [203]

Posturography, or instrumental postural assessment, includes a baropodometric test, an examination that allows the measurement of the foot pressure and the plantar surface and a stabilometric test, for the measurement of the regulation of the activity of the postural tonic system. Posturography is measured using a platform that samples real time postural sway at different frequency based on the type of the platform.

The baropodometry is measured in 5 seconds during which the patient maintains the orthostatic position on the platform with the head in a neutral position facing forward, the arms along the trunk and the feet positioned next to each other. The main features measured through this test are the load distribution between feet, the rearfoot/forefoot ratio of the load pressure for each foot and the plantar surface characteristics.

The duration of the stabilometry is 51.2 seconds and provides that the subject mantains the feet positioned side-by-side and forming an angle of 30° and both heels at 4 cm apart [205].

Basic, participant repeat the stabilometric test in two different conditions: with eyes open and then with eyes closed to examine the impact of sight on posture. Moreover, complementary stabilometric tests are used to investigate the influence of all the other receptors on stability, such as the test with caloric vestibular stimulation for the vestibule or the stabilometric assessment with mouth open to evaluate the effect of the stomatognathic system on postural control [57,206]. In the Table 1 are illustrated some methods to analyze the influence of sensory information from postural organs on body balance. The parameters considered for the postural sway are the coordinates of the center of pressure (CoP) and in particular the Sway Path Length (SPL), i.e. the path length of the center of pressure, and the Ellipse Sway Area (ESA), i.e. the surface that contains the movement of the CoP.

Table 1. Some stabilometric tests for postural receptors

Visuo-Oculomotor System	With eyes closed With eyes towards different directions With prisms
Audio-Vestibular System	Caloric vestibular stimulation Galvanic vestibular stimulation
Stomatognathic System	With mouth open With occlusal splint

3.6. Other experimental research on human posture in sports

In the following paragraph (3.7.) will be presented an experimental study in the research field of posturology applied to sport that evaluate the differences on plantar pressure distribution between athletes and sedentary women; and moreover, to examine any differences on plantar pressure distribution between athletes of different sports.

3.7. How do Sports Affect Static Baropodometry? An Observational Study Among Women Living in Southern Italy [from Feka et al. (2019)] [207]

Introduction

Posture is not a simple matter to investigate, and the perspectives or approaches can vary according to the areas of interest. Previous findings have highlighted how postural measurements with the use of photography or costly devices like magnetic resonance imaging are still scientifically inaccurate, while, on the other hand, the X-ray examination includes radiation problems [208]. In addition, the neurological control of posture and locomotion is co-dependent at different levels of the central nervous system [136,208-210]. However, to maintain postural control in different environmental situations, these systems must be strongly integrated [209,210]. Additionally, the fundamental importance of the foot on upright standing and locomotion has been clearly established [211]. It is the first body part to receive the impact, and serves as a base for support [208]. There are several factors, though, that affect the erect position and some authors have already reported a few details about them [212]. The human ability to keep balance is influenced by different external and internal elements, such as genetics, the state of the vestibular apparatus, age, the area of support, centre of mass positioning, coordination, strength, flexibility, emotional state, frequency of participation in motor activities and training status [136,209,212]. Nevertheless, a complete understanding of foot function during locomotion is important for essential research on normal human behaviour, as well as in clinical situations [213]. Being able to do daily tasks and sports activities is necessary to coordinate body parts with appropriate actions, reactions, and skills [212]. Since, it is known that participating in different sports causes physiological and anthropometric changes in human body and according to several studies, sports participation may result in changing/improving physical fitness, as well as increasing lean body mass, bone mineral content and other body parameters [211]. However, some sports practised at an early age (e.g. gymnastics) can delay the onset of puberty and menarche compared with other school girls or female swimmers [214]. Furthermore, anthropometrics change as a result of the specificity of the sport that is practised [211,214,215]. Different authors suggested that baropodometry was a reliable instrument to determine plantar pressure distribution [208,216], while Alves et al. [217] reported that baropodometric results should be interpreted with caution in science and in clinical practice. In this regard, Phethean and Nester [218] pointed out the influence of body weight, body mass index (BMI), and gender on plantar pressure distribution. Moreover, plantar pressure refers to the pressure measured on the plantar surface of the foot [219], and, of interest, a proper biomechanics of the foot is responsible for upholding body posture and balanced distribution of plantar pressure [208]. However, changes in plantar pressure distribution are linked to many factors that may significantly interfere with physical training and, consequently, sports performance [220]. Remarkably, Potdevin et al. [221] investigated plantar pressure asymmetry in order to discuss the opportunity to make a diagnose of pathological gait and guide further rehabilitation process. Neto et al. [209] stated that baropodometry allowed an understanding of the physiopathology of postural alterations, while the same analysis was suggested to assess dysfunctions of the feet [208,222]. Previous studies have also reported the influence of different sports on plantar static and dynamic load distribution [223-225].

Nowadays, what seems to be clear is that being overweight, obese, active (athletes), or having any kind of health problems affects plantar pressure distribution [222,226-228]. While the majority of published scientific papers investigated mostly males [229], in our case, the purpose of the study was two-fold: (a) to explore the differences in plantar pressure distribution between athletes and sedentary women; and (b) to investigate the differences, if any, in plantar pressure between sports within the athletes group.

Material and Methods

Subjects

The total of 173 healthy females participated in the study; 75 of them practised different sports, such as soccer (n = 18), rowing (n = 11), dancing (n = 12), swimming (n = 16), and judo (n = 18), while 98 did not participate in any sport (they led a sedentary lifestyle). The subjects were divided into 2 groups: 75 athletes, group A; and 98 sedentary women, group S. The anthropometric data of the participants, presented in means, are included in Table 1. All athletes enrolled in the study had practised their specific sports for at least 3 years.

Study design and measurements

A cross-sectional study was carried out. The same researcher (Francesco Pomara) recorded the shoe size, body weight to the nearest 100 g using scales (Seca 709, Hamburg, Germany), and body height to the nearest 1 mm using a wall stadiometer (Seca 220, Hamburg, Germany). Furthermore, mean ± standard deviation (SD) of BMI (determined as weight in kilograms divided by height in meters squared) and Body Surface Area (BSA) were calculated in both groups. The BSA was obtained through the Mosteller formula [230]. Furthermore, orthopaedic and nervous pathologies concerning the women's families and personal medical histories of each participant were considered as exclusion criteria. For plantar support, the FreeMed posturography system was used, including the FreeMed baropodometric platform and FreeStep v. 1.0.3 software. The sampling rate was set at 25 Hz. The sensors, coated with 24K gold, guarantee the repeatability and reliability of the instrument (produced by Sensor Medica, Guidonia Montecelio, Roma). The participants were asked to maintain the standardized Romberg test position (standing upright with eyes closed) on the baropodometric platform [163]. Each foot was divided into the anterior (fore-foot) and posterior (rear-foot) area, with an approximation to 1 mm.

Statistical analysis

All data are expressed as mean ± SD. Differences between the groups were analysed with the use of Student's t-test for independent samples. The one-way analysis of variance (ANOVA) with Tukey's multiple comparison post-hoc test was adopted in the case of multiple comparisons. The analysis was performed with the InStat GraphPad Prism 7.0 software (San Diego, CA, USA). The results were considered to be statistically significant at $p < 0.05$.

Ethical approval

The research related to human use has been complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Ethics Committee of the University of Palermo.

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

Table 1 provides an overview of the included participants with information referring to age (years), height (cm), body weight (kg), BMI (kg/m^2), BSA (m^2), and shoe size for both the sedentary and athlete group. However, no significant differences were found between the groups.

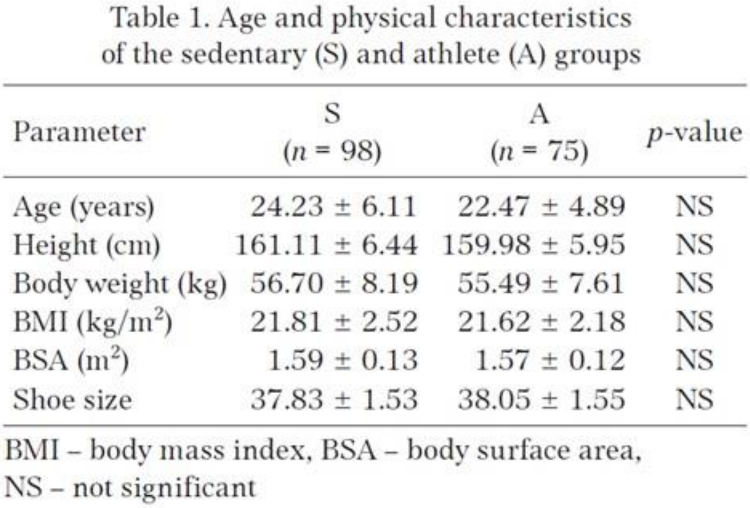


Table 1. Age and physical characteristics of the sedentary (S) and athlete (A) groups

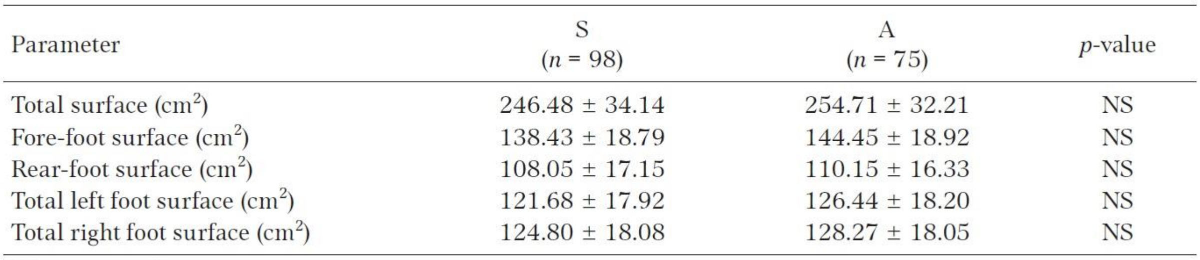
Parameter	S (n = 98)	A (n = 75)	p-value
Age (years)	24.23 ± 6.11	22.47 ± 4.89	NS
Height (cm)	161.11 ± 6.44	159.98 ± 5.95	NS
Body weight (kg)	56.70 ± 8.19	55.49 ± 7.61	NS
BMI (kg/m^2)	21.81 ± 2.52	21.62 ± 2.18	NS
BSA (m^2)	1.59 ± 0.13	1.57 ± 0.12	NS
Shoe size	37.83 ± 1.53	38.05 ± 1.55	NS

BMI – body mass index, BSA – body surface area, NS – not significant

Table 2 shows plantar surface areas (cm^2) in the groups. Also, the total surface (cm^2) comparison between the groups is presented, as well as the fore-foot surface (cm2) and rear foot surface (cm2). The total left foot surface and total right foot surface (cm2) were determined as well. In this case, no significant differences were found between the groups.

Table 3 presents the loads on the plantar areas expressed in percentages, as well as the mean pressure and maximum peak pressure values in the 2 groups. As shown in the table, there were significant differences in these parameters except the total left foot load (%) and total right foot load (%). However, athletes had a higher fore-foot load percentage than the sedentary group (p = 0.0006) and, consequently, a lower rear-foot load percentage (p = 0.0006), as well as lower values of the maximum peak pressure and pressure mean (p = 0.0001 and p = 0.0182, respectively).

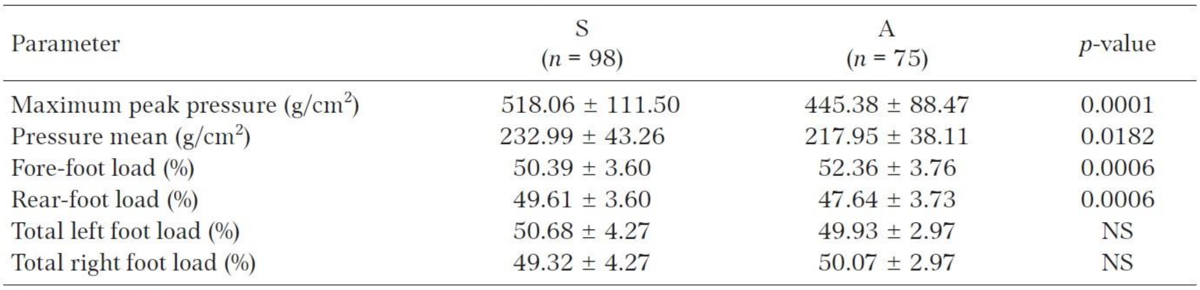
Table 2. Plantar surface areas (cm^2) in the sedentary (S) and athlete (A) groups



Parameter	S (*n* = 98)	A (*n* = 75)	*p*-value
Total surface (cm^2)	246.48 ± 34.14	254.71 ± 32.21	NS
Fore-foot surface (cm^2)	138.43 ± 18.79	144.45 ± 18.92	NS
Rear-foot surface (cm^2)	108.05 ± 17.15	110.15 ± 16.33	NS
Total left foot surface (cm^2)	121.68 ± 17.92	126.44 ± 18.20	NS
Total right foot surface (cm^2)	124.80 ± 18.08	128.27 ± 18.05	NS

NS – not significant

Table 3. Percentage loads on the plantar areas, maximum peak pressure, and mean pressure values in the sedentary (S) and athlete (A) groups



Parameter	S (*n* = 98)	A (*n* = 75)	*p*-value
Maximum peak pressure (g/cm^2)	518.06 ± 111.50	445.38 ± 88.47	0.0001
Pressure mean (g/cm^2)	232.99 ± 43.26	217.95 ± 38.11	0.0182
Fore-foot load (%)	50.39 ± 3.60	52.36 ± 3.76	0.0006
Rear-foot load (%)	49.61 ± 3.60	47.64 ± 3.73	0.0006
Total left foot load (%)	50.68 ± 4.27	49.93 ± 2.97	NS
Total right foot load (%)	49.32 ± 4.27	50.07 ± 2.97	NS

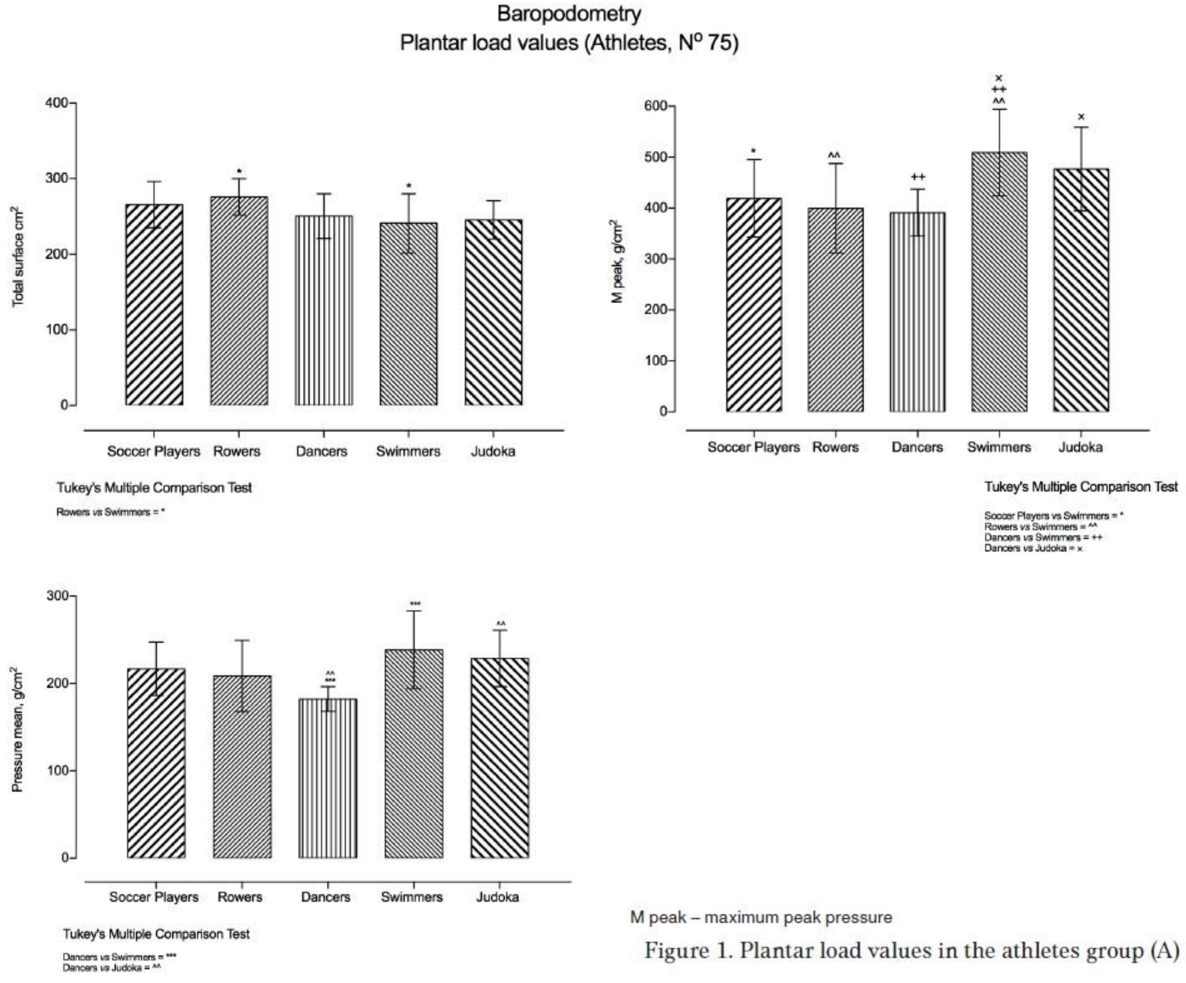
NS – not significant

Table 4 provides the plantar surface values (mean ± SD) for athlete subgroups, which were analysed with one-way ANOVA; in all parameters, significant differences were recorded. In fact, soccer players and rowers had the highest plantar surface values, considering the total plantar support, left and right plantar areas, and total fore-foot and rear-foot surfaces ($p < 0.05$), compared with other sports groups (Figure 1).

Table 4. Plantar surface values (mean ± standard deviation) in athlete subgroups

Parameter	Soccer players (n = 18)	Rowers (n = 11)	Dancers (n = 12)	Swimmers (n = 16)	Judokas (n = 18)	p-value ANOVA
Total surface (cm^2)	265.83 ± 30.58	275.82 ± 23.95	250.58 ± 29.37	241.06 ± 39.00	245.56 ± 25.44	0.0183
Fore-foot surface (cm^2)	155.17 ± 19.17	152.27 ± 14.48	139.67 ± 15.93	136.88 ± 22.34	139.33 ± 14.26	0.0474
Rear-foot surface (cm^2)	110.67 ± 14.08	123.55 ± 11.18	110.92 ± 15.61	104.19 ± 20.58	106.22 ± 13.71	0.0262
Total left foot surface (cm^2)	134.33 ± 17.54	137.00 ± 13.18	124.25 ± 16.50	119.13 ± 22.18	120.06 ± 13.63	0.0132
Total right foot surface (cm^2)	131.50 ± 14.42	138.82 ± 11.62	126.33 ± 13.69	121.94 ± 17.86	125.50 ± 12.83	0.0378

ANOVA – analysis of variance



M peak – maximum peak pressure

Figure 1. Plantar load values in the athletes group (A)

In Table 5, percentage and absolute plantar load values (mean ± SD) in athlete subgroups are presented. Indeed, a stratification of parameters was found showing different loads on the plantar support among the sport-related subgroups.

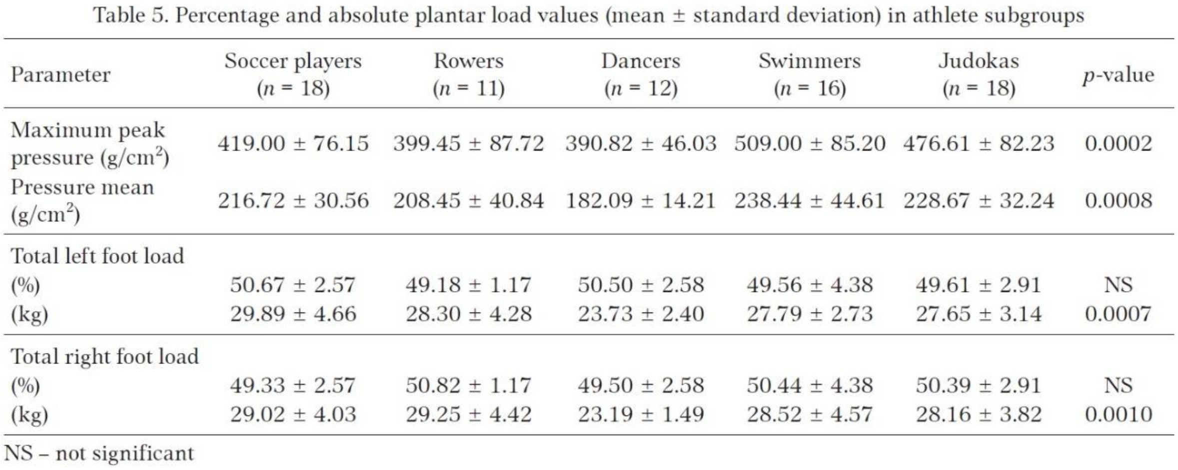


Table 5. Percentage and absolute plantar load values (mean ± standard deviation) in athlete subgroups

Parameter	Soccer players (n = 18)	Rowers (n = 11)	Dancers (n = 12)	Swimmers (n = 16)	Judokas (n = 18)	p-value
Maximum peak pressure (g/cm^2)	419.00 ± 76.15	399.45 ± 87.72	390.82 ± 46.03	509.00 ± 85.20	476.61 ± 82.23	0.0002
Pressure mean (g/cm^2)	216.72 ± 30.56	208.45 ± 40.84	182.09 ± 14.21	238.44 ± 44.61	228.67 ± 32.24	0.0008
Total left foot load						
(%)	50.67 ± 2.57	49.18 ± 1.17	50.50 ± 2.58	49.56 ± 4.38	49.61 ± 2.91	NS
(kg)	29.89 ± 4.66	28.30 ± 4.28	23.73 ± 2.40	27.79 ± 2.73	27.65 ± 3.14	0.0007
Total right foot load						
(%)	49.33 ± 2.57	50.82 ± 1.17	49.50 ± 2.58	50.44 ± 4.38	50.39 ± 2.91	NS
(kg)	29.02 ± 4.03	29.25 ± 4.42	23.19 ± 1.49	28.52 ± 4.57	28.16 ± 3.82	0.0010

NS – not significant

Also in this case, significant differences among means were detected with the one way ANOVA. Posthoc results are illustrated in Figure 1.

Discussion

The aim of the present study was to investigate the differences in plantar pressure distribution between athletes and sedentary women, considering all the collected information regarding plantar pressure distribution and sports specifics.

The characteristics of different sports and physical activities may significantly affect static human balance and posture [231]; for this reason, we decided to perform an observational study to explore the differences, if any, between these parameters in the 2 study groups, as well as between the sports within the athletes group. Moreover, in our data regarding age, height, weight, BMI, BSA, and shoe number, no significant differences were observed. In the comparison of the athletes with sedentary women, the main findings showed no significant differences in total plantar pressure surface, total left or right foot surface, fore-foot or rear-foot surface between these groups. Interestingly, differences were observed in the fore-/rear-foot and left/right load distribution parameters between the athletes and sedentary women, and also within the group of athletes. Our results remain in line with others findings [211,232-234]. We may hypothesize that athletes tend to lean forward or use fore-foot rather than rear foot surface owing to the specifics of their sports. As mentioned before, several authors reported the same results when they compared athletes practising different sports, athletes practising the same sport, sedentary people, and people with different health problems [136,211,222,234-241]. In our observations, sedentary participants showed more pressure in the fore-foot than in the rear-foot surface (50.39% and 49.61%, respectively). In fact, our findings do not agree with the ideal load values reported by Tribastone and Tribastone [242] and Magee [243], who suggested that 60% of the weight should rest on the heel and 40% on the anterior region of the foot.

However, our data are in line with a report by Rosário [208], who stated that there was an higher percentage in plantar pressure in the fore-foot surface. In accordance with the study aim, we also observed differences within the athletes group. Our data show that all athletes, regardless the practised sport, tend to lean forward, using more fore-foot than rear-foot rest. These results are in agreement with other findings, whose authors state that this phenomenon is due to the athletes' training and the specificity of the practised sport [136,211,219,234].

According to Prochazkova et al. [211], dancers show greater balance ability as compared with other sports participants. In their research, there were significant differences in plantar pressure distribution between dancers and athletes practising other sports, such as football, basketball, running, and fitness. In the current study, dancers tended to use the fore-foot rather than rear-foot surface owing to the specificity of the sport (139.67 cm2 and 110.92 cm2, respectively). Furthermore, these findings show that long-term and intensive dance practice influences the dancers' gait stereotype [211]. According to other authors, after dancers, soccer players present considerable balance ability, compared with other sports [211,244]. In addition, it has been already discovered that plantar pressure distribution in soccer players is more significant in the forefoot region [219]. In fact, owing to their sport specifics, plantar pressure in soccer players is higher in the preferred foot than in the non-preferred foot, while according to literature, the preferred foot plays a more important role than the non-preferred one in forwarding motions, and the non-preferred foot ensures strong impact with the ground for stability [219]. Our results regarding soccer are in complete agreement with this information. Furthermore, significant differences were found in all parameters that were calculated (total surface, fore-foot surface and rear-foot surface, as well as total left and right surface). Soccer players tend to use fore-foot more than rear-foot [219]. Swimmers usually do not practise or perform static or dynamic balance; however, taking into consideration the specifics of the sport, swimmers also tend to use more fore-foot than rear-foot [136]. This fact has been confirmed in the present study, in which the fore-foot and rear-foot surface turned out to be 136.88 cm2 and 104.19 cm2, respectively. Even rowers have shown that they use more fore foot (152.27 cm2) than rear-foot (123.55 cm2). These data are in agreement with results reported by Vieira et al. [245]. However, it should be highlighted that the literature regarding the use of baropodometry in rowers is scarce. Furthermore, also judokas, as other sports participants discussed previously, have shown the tendency to use more fore-foot (139.33 cm2) compared with rear-foot (106.22 cm2). The forward head posture of judokas has already been reported in the literature [246].

In all sports, there is a significant difference in total surface, fore-foot and rear-foot surface, as well as total left and right foot surface.

Even though posture may change as a result of exercises, according to Baumfeld et al. [216], plantar pressure distribution does not change in normal participants, no matter how hard their daily activity may be; authors showed no adaptations to a short-term exposure to exercise.

One of the possible study limitations can be the fact that the sample size was small and the baropodometric data must be normalized by shoe number and other variables considered as gold standards in this case. This bias does not allow us to generalize, but interestingly, we discovered that sports practice may affect plantar surface and load distribution also in women.

Conclusions

The study demonstrated that there were no significant differences in plantar surface areas between the athlete and sedentary groups. Furthermore, the evaluation of the plantar pressure distribution showed a tendency to lean forward in the athletes group when compared with the sedentary group. In addition, the analysis performed among the athletes revealed significant differences between sports. The phenomenon of leaning forward could be due to sports specific adaptations.

CHAPTER 4 – Neuroscience in sports

It is widely recognized that the practice of exercise induces several beneficial effects on cognitive functions such as improvements in memory and attention [247,248]. Although the effects of exercise on cognitive functions are strictly related to exercise characteristics concerning the type and the load, Niedermeier et al. (2020) found that even a single short bout of physical activity improves significantly cognitive domains of visual attention and perceived attention in physically active students versus sedentary ones [249].

Similarly, the scientific literature has also investigated the effects of cognitive training strategies on motor skills in athletes, detecting a positive influence on performance [250,251]. As a matter of fact, Papaioannou et al. (2004) detected a significant effectiveness in enhancing a soccer-shooting task accuracy using a combinations of goal setting and self-talk strategies in professional and semi-professional soccer players [252].

A steadily increasing interest in sports science is understanding the interactions between brain activity and exercise in order to maximize performance [253]. Scientific research has focused on the use of neuroscientific technologies in order to measure brain activation during muscle activity (specifically during exercise tasks) for resolving the determinants of performance [253]. The most common non-invasive functional neuroimaging used for studying the mechanisms of performance are the functional magnetic resonance imaging (fMRI), the electroencephalography (EEG), and the functional near-infrared spectroscopy (fNIRS) [253-255].

Moreover, in recent decades, the study of non-invasive brain stimulation (NIBS) techniques is constantly increasing in sports science in order to investigate any improvements in performance by stimulating different brain regions [256]. The NIBS techniques commonly used in sports are the transcranial magnetic stimulation (TMS) and the transcranial electric stimulation (tES) (which, depending on the modality in which the current is administered, includes the transcranial direct current stimulation (tDCS), the transcranial alternating current stimulation (tACS), and the transcranial random noise stimulation (tRNS)) [254,257-260].

In recent years, other methods have been developed in the field of neuroscience to modulate brain activity such as prismatic adaptation (PA), a visuo-motor procedure that uses prismatic lenses that shift the visual field and which has been shown to be able to modulate the excitability of different brain regions [261,262]. However, the effects of this procedure have not yet been studied in athletes.

4.1. Prismatic adaptation: a short-term visuomotor plasticity procedure

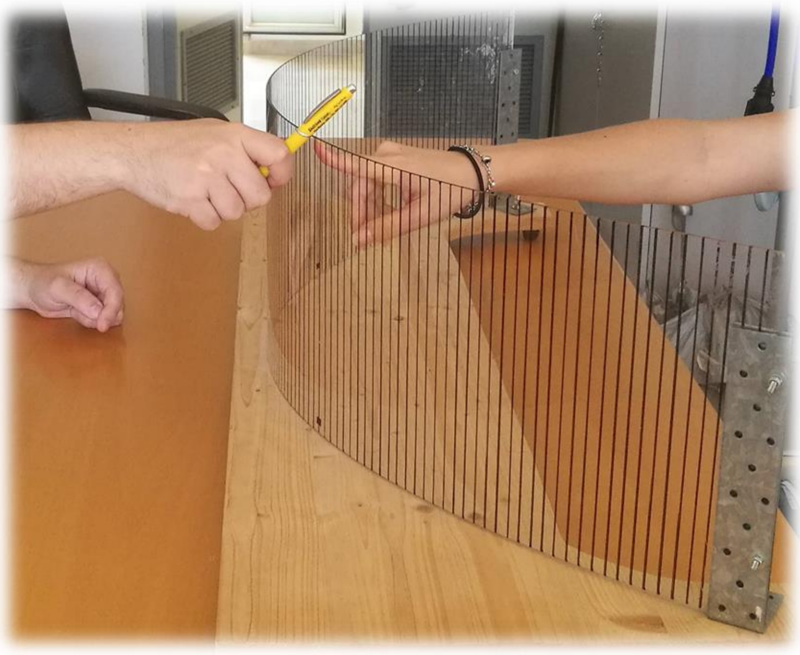
PA is a short-term visuomotor plasticity procedure induced by prismatic lenses that allow to move the visual field to a certain position in the space to which the motor system adapts.

https://upload.wikimedia.org/wikipedia/commons/thumb/3/31/WedgePrism%28BorderlineTree%29.jpg/640px-WedgePrism%28BorderlineTree%29.jpg?1641982783125

This visuomotor adaptation procedure involves the use of prisms that can have a left-based orientation (the side with greater thickness is on the left) that induce a perceptual shift of the visual field to the right (rightward deviation), or a right-based orientation (the side with the greater thickness is on the right) that induce a perceptual shift of the visual field to the left (leftward deviation).

During the PA procedure the subject is asked to repeatedly perform pointing movements, at the points indicated by the experimenter, while wearing the prismatic lenses that induce a perceptual shift of the visual field towards the side of the deviation.

The initial pointing movements are directed towards the visually shifted position of the target, missing its real position and observing large pointing errors, while the subsequent pointing movements are more accurate and the pointing error decrease until reaching the real position. When the prisms are removed, during the execution of the same pointing movements, is detected a pointing error in the opposite direction to that of the deviation, named “after-effect”.



In detail, the procedure provides that the subject, sitting on a chair in a neutral position with the index finger of the right hand resting on the sternum, is asked to perform the pointing movements towards a curved Plexiglas panel positioned at a distance of 57 cm and placed on a table. The panel, which covers a total visual angle of 120° and graded with parallel vertical lines corresponding to the degrees of the visual angle, is placed with the concave side facing the subject and the convex side facing the experimenter. Three vertical lines are marked on the panel corresponding to the central position (0°), to the left position (21° to the left), and to the right position (21° to the right). During the PA procedure, the experimenter pseudorandomly points to one of the three marked positions on the panel. The subject is asked to point with the index finger of the right hand at the point on the panel indicated by the experimenter and then return with the index finger of the right hand resting on the sternum. During each trial the experimenter measured the pointing accuracy of the five phases by noting the pointing errors to the right from the target with positive values (i.e., +1, +2, +3, etc. for each degree of deviation), those to the left with negative values (i.e., -1, -2, -3, etc. for each degree of deviation).

The scientific literature reports different PA procedures that can vary in number of phases and number of pointing trials for each phase. The procedure commonly used by several research groups consists of the following five phases: the pre-exposure (no prisms); the blind pre-exposure (no prisms); the early exposure (wearing prisms); the late exposure (i.e., adaptation - wearing prisms); the blind post-exposure (i.e., after-effect - no prisms). The pointing movements are performed in all five experimental phases for a total of 180 trials including: 30 trials for the pre-exposure; 30 trials for the blind pre-exposure; a total of 90 trials for the early exposure and the late exposure; 30 trials for the blind post-exposure. In this procedure: only during the conditions of exposure is asked to wear prismatic lenses; in the conditions of blind exposure the arm is hidden.

4.2. The use of prismatic adaptation

Prismatic lenses were developed by Rossetti et al. (1998) and presented to the scientific community in a letter published in Nature [263]. In this seminal work, the authors investigated the effect of PA in patients with right-hemisphere stroke hypothesizing a shift of the subjective midline to the right after PA. Indeed, these subjects show hemispatial neglect (a neurological deficit of perception, attention, representation and/or execution of actions of the left visual hemifield) and the authors reported that the adaptation to a visual distortion using prismatic lenses could stimulate the neural structures responsible for those skills. Their results showed that all participants exposed to PA (with rightward deviation thus inducing a shift of the visual field rightward) shifted the subjective midline to the right and that this improvement lasted for at least two hours after prisms removal suggesting that this procedure could be used as a rehabilitation program [263].

Based on these results, as PA induces a lateral displacement of the visual field, the effects of PA on visuomotor processes have been extensively studied in recent decades in patients who have difficulty exploring a visual hemifield such as unilateral spatial neglect (USN) and stroke patients, in whom there is an inability to orient themselves to contra-lesional stimuli [263-269]. Recently, many research groups have investigated the effects of PA in healthy subjects [270-272]. In particular, the first researches were conducted to study the brain regions activated by this procedure, the following ones to study any beneficial effects of this procedure in the general population [273-278].

Studies associated with fMRI have shown the activation of the primary motor cortex (M1), the parietal cortex, and the cerebellum highlighting that PA procedure could influence the functions of these areas, such as visuospatial attention, orienting of attention, spatial/temporal representation, visually guided actions, and postural control [262,279]. Although several research groups have investigated any beneficial effects on motor tasks or abilities such as walking, aiming and throwing, and body balance in healthy subjects, to the best of our knowledge, no studies have considered a particular healthy population, namely athletes [280-282].

The visuomotor performance, determined by neural visual processes, plays a main role in sport performance because it represents one of the fundamental perceptual-cognitive skills for perceiving the environment [283]. Indeed, a visual-perceptual technique using strobe glasses that cause intermittent vision has recently been employed in athletes for performance enhancement [24,283-286]. For instance, Hülsdünker et al. (2019) examined the effects of 4-week training with strobe glasses (named, stroboscopic visual training) on visuomotor performance and neural visual function in top-level badminton players finding higher significant visuomotor performance improvement after the use of strobe glasses compared to the normal visual conditions [24]. Similarly, Ellison et al. (2020) detected enhancement on the eye-hand coordination performance after a training using strobe glasses in a group of sports participants [287]. In a similar way, Wilkins et al. (2017) explored the effects of 7-week stroboscopic visual training program on 10 measures of visual and perceptual skills in three elite youth football goalkeepers compared with three matched control participants [288]. Authors found no differences in the changes from pre-test to post-test between groups in 9 of the 10 measures although goalkeepers who used strobe glasses showed consistent improvements in visual response time.

These preliminary studies provide interesting results on the role of visual-perceptual techniques for improving sport performance and, for this reason, new further practical applications of neuroscience in sports could also be provided by the use of PA in athletes.

4.3. Experimental research on the use of prismatic adaptation in sports

In the following paragraphs (4.4. and 4.5.) two experimental research will be presented that investigated the influence of the use of PA on body posture, fitness characteristics, and accuracy on a sport-specific task. The first paper investigated the effects of PA on plantar pressure distribution and hand grip strength in healthy subjects, including athletes, while the second research explored any influences of PA on body balance and penalty kick accuracy in young male soccer players. The last work is currently submitted, therefore only the abstract of the study is reported.

4.4. Investigating prismatic adaptation effects in handgrip strength and in plantar pressure in healthy subjects [from Bonaventura et al. (2020)] [289]

Introduction

In the last decades, prismatic adaptation (PA) effects have been widely investigated either in visuomotor processes [261,290] and higher level cognitive domains [291]. PA induces a lateral displacement of the visual field, enhancing cortical activity in the hemisphere ipsilateral to the lenses deviation side [262], an activation involving both posterior brain regions of the dorsal stream (i.e. occipito-parietal cortex) and anterior regions, mainly in the frontal cortex.

This pattern of neuromodulation explains why PA has also been used to study the physiological mechanisms of postural control, in both neurological patients [292,293] and healthy subjects

[270]. An aspect of body posture particularly suitable to be studied with PA is the weight distribution among feet, that allows a symmetrical distribution of plantar pressure [294] in terms of reaction force to the ground [295]. Plantar pressure is controlled by both subcortical [296,297] and higher level brain mechanisms, such as the elaboration of an internal model of the body [298] and attention processes [299].

PA could also be useful to study and modulate processes associated to regulation of muscle strength. Remarkably, hand strength relies on sensorimotor processes that regulate corrections and adjustments depending on the executed force task [300,301]. Attentional resources, directionally shifted by PA, are also involved in regulating feet and hand movements. Indeed, a reduction of muscle force has been found when attention is shared between hand and leg [302]. Relevant differences occur between the parameters of hand strength and plantar pressure distribution in terms of hemispheric asymmetries and activated regions in each hemisphere. Indeed, stronger involvement of anterior regions (i.e., motor cortex) is required to control hand strength [303]. On the other hand, posterior brain regions (i.e., parietal cortex) might be more involved in regulating pressure distribution among feet, allowing the access to an internal model of the body and the control of its position in the space [304]. Another point concerns hemispheric asymmetries in postural control and muscle strength. Previous studies have shown a right hemisphere pivotal role on balance control and body posture in stroke patients [305,306] as well as in healthy subjects [307,308]. Conversely, motor control of each hand symmetrically depends on the activation of the contralateral brain hemisphere [309].

In this line, previously reported rightward-PA effects (i.e., right hemisphere activation) on body posture have been explained in terms of modulation of higher level cognitive processes [310], subserved by posterior regions of the right dorsal stream [311]. For instance, in a previous study, rightward-PA has been shown to rebalance the abnormal body weight distribution and therefore, the posture bias of patients after cerebrovascular accident [293]. The authors suggested that the rebalance in body weight distribution occurred through a PA-induced modulation of higher order processes of spatial orientation related to parietal lobe [293].

A previous study investigating changes in body sway in two groups of healthy subjects reported a forward displacement of the center of pressure (CoP) after both leftward and rightward PA [270]. Authors suggested that the observed changes in CoP reflected a displacement in the projection of body pressure, reflecting a change in body scheme. Unluckily, whether these effects extended directly to weight distribution among feet was not investigated. Additionally, asymmetries between plantar pressure and hands were not explored. Overall, to date, no studies have investigated whether PA might affect hand strength through modulation of anterior regions of the dorsal stream [312,313]. Indirect evidence might be found in neurophysiological and electrophysiological studies showing that PA modulates oscillatory activity over motor cortex (M1) as well as motor evoked potentials' amplitude [262,279].

The present study aimed at exploring interhemispheric asymmetries in the PA effects on hand strength and plantar pressure distribution. To this end, we evaluated hand strength and plantar pressure immediately before and after leftward vs. rightward PA in two groups of healthy subjects. Since PA affects either sensorimotor and higher level attentive processes modulating the dorsal stream activity [264,314], wearing prisms could affect both hand and feet functions. Specifically, since body posture depends more on posterior dorsal stream regions of the right hemisphere [307,308,315] while hands strength is controlled by left and right motor cortices [316], we expected 1) changes in body posture occurring only after rightward PA; 2) changes in hand strength following either leftward and rightward PA.

Material and methods

Participants

Forty-six (male=23; mean age=25 ± 3 years) right-handed healthy participants were randomly assigned to a leftward Prismatic Adaptation group (l-PA; n=23; mean age=26 ± 3.92 years) or a rightward Prismatic Adaptation group (r-PA; n=23; mean age=25 ± 1.87 years). The l-PA group wore a 20° left shifting prismatic lenses and the r-PA group wore a 20° right shifting prismatic lenses. Participants handedness was assessed using the Edinburgh Handedness Inventory [317].

Exclusion criteria were prior diagnosis of psychiatric disease, brain injury, acute orthopaedic injury, pregnancy, depression, not corrected vision impairment or other neurologic diseases. Four subjects were excluded from the experiment: one subject due to pregnancy and three subjects due to knees' injuries. The study was in compliance with the Helsinki declaration. Participants were informed about the experimental procedures and provided their written informed consent to voluntarily participate in the experiment. Experimenter and participants were both naïve to the experimental hypothesis tested. Table 1 shows participants demographic characteristics.

Table 1. Sample demographic characteristics.

	r-PA group (n=23)	l-PA group (n=23)
Age (years)	26±3.92	25±1.87
Years of education	17±1.85	17±1.27
Handedness	66%±0.2	62%±0.2
Weight (kg)	62.05±11.41	63.52±13.36
Height (cm)	170±9.85	167.65±10.55

Legend: r-PA = rightward prismatic adaptation group; l-PA = leftward prismatic adaptation group.

Experimental design

Baropodometric and handgrip measurements were collected twice: the first time before PA (Pre-PA) and the second after PA (Post-PA). The delay between the first and the second measurement was ~ 15 min, that is in the frame time of the PA effects [277,318].

Postural assessment

Baropodometric evaluation was conducted using the freeMed® posturographic system (Sensor Medica®; Guidonia Montecelio, Roma, Italia), consisting of the freeMed® Maxi platform and the freeStep® software. Signal was digitalized at a sampling frequency of 50 Hz. The baropodometric test, lasting 5 s, was performed in a sound-isolated room. Each participant was required to stand barefoot in orthostatic stance on the platform with the head in neutral position, gazing forward, arms along the trunk and feet placed side-by-side with both heels in line. The following parameters were considered: rearfoot/forefoot and total plantar pressure (%); rearfoot/forefoot and total surface area (cm^2).

Handgrip test

Each participant performed 3 trials of 3 s of maximal isometric handgrip on a mechanical dynamometer (KernMap model 80K1 - Kern®, Kern & Sohn GmbH, Balingen, Germany), alternatively with the dominant and the non-dominant hand, with 3 min rest between each trial. The subjects performed the handgrip test while seating in a chair, back at 90° angle with sacrum, shoulder blades immobilized to the backrest, head in neutral position, gazing forward, and elbow joint positioned at a 90° angle, as recommended by the American Society of Hand Therapists [319]. The best performance out of the 3 trials (kg) was included in the statistical analyses.

PA procedure

We followed the same PA procedure as in previous studies [262,279]. Subject sat in basic position (right index finger at the sternum) in front of the concave side of a curved Plexiglas panel at a distance of 57-cm. The panel was graded with vertical lines corresponding to the degrees of the visual angle (covering a total visual angle of 120°). Three vertical lines of the panel were marked to indicate central position (0°), left position (21° to the left), right position (21° to the right). During PA, the experimenter, facing the opposite side of the panel, randomly pointed in one of the three marked positions of the panel.

The task required to point with the right index finger the panel point indicated by the experimenter and then return to the basic position. Pointing accuracy was collected in five experimental conditions: preexposure, blind pre-exposure, early exposure (first 9 trials while wearing prisms), late exposure (last 9 trials while wearing prisms), blind post-exposure (after prisms removal). In the blind exposure conditions the pointing task was performed with hidden arm. Prismatic lenses were worn only during the exposure condition.

Exposure condition included 90 trials, while the other conditions included 30 trials. All the trials were equally and randomly distributed in the three marked positions of the panel.

Data analysis

Analyses were conducted on the mean accuracy of the 5 experimental conditions: pre-exposure, blind pre-exposure, early exposure, late exposure, blind post-exposure. Prismatic adaptation was analysed using a 5×2 repeated measures ANOVA, with Condition (all 5 experimental conditions) as within-subjects factor and Group (l-PA vs. r-PA) as between-subjects factor.

Handgrip

Handgrip performances were analysed using a 2×2×2 repeated measures ANOVA with Time (pre-PA vs. post-PA) and Hand (left vs. right) as within-subjects factors and Group (l-PA vs. r-PA) as between-subjects factor.

Plantar surface area

Total plantar surface data were analysed using a 2×2×2 repeated measures ANOVA with Time (pre-PA vs. post-PA) and Feet (left vs. right) as within-subjects factors and Group (l-PA vs. r-PA) as between-subjects factor.

Forefoot/rearfoot plantar surface data were analysed using a 2×2×2×2 repeated measures ANOVA with Feet (left vs. right), Time (pre-PA vs. post-PA) and Area (forefoot vs. rearfoot) as within-subjects factors and Group (l-PA vs. r-PA) as between-subjects factor.

Plantar pressure

Total plantar pressure data were analysed using a 2×2 ANOVA, with Time (pre-PA vs. post-PA) as within-subjects factor and Group (l-PA vs. r-PA) as between-subjects factor. Since changes in pressure distribution in one foot are accompanied by proportional changes in the other one (i.e., the two variables negatively correlate), analyses have been conducted only on pressure distribution in the right foot. Namely, whether pressure on the left foot increases, it proportionally decreases on the right foot. Similarly, forefoot plantar data were analysed using a 2×2×2 ANOVA with Time (pre-PA vs. post-PA) and Feet (left vs. right) as within-subjects and Group (l-PA vs. r-PA) as between-subjects factors. As for total pressure distribution among feet, whether pressure on the forefoot increases, pressure distribution in the rearfoot proportionally decreases, therefore analyses were conducted only in the forefoot data.

Bonferroni post-hoc tests were used to test main effects and interactions when appropriate. All the analyses were conducted using IBM SPSS Statistics software 23 (International Business Machines Corporation, Armonk, New York, United States).

Results

Prismatic adaptation

Fig. 1 shows prismatic adaptation for l-PA and r-PA group across the five experimental conditions. ANOVA showed significant effects of the factors Group [F(1,44)=46.776; p < .001; ηp2=.325] and Condition [F(4,41)=5.108; p= .029; ηp2=.104] and a significant Group×Condition interaction [F(4,41)=662.583; p < .001; ηp2=.938]. Lenses deviation was reflected by the difference between pre-exposure and early exposure trials, either in the l-PA (p < .001) and in the r-PA (p < .001) groups. Conversely, due to subjects' adaptation to prismatic deviation, no differences were found between pre-exposure and late exposure neither in the l-PA (p= .085) nor in the r-PA (p= 1) group. The presence of after effect was confirmed by a significant difference between blind pre-exposure and blind post-exposure either in the l-PA (p < .001) and in the r-PA (p < .001) group (Fig. 1).

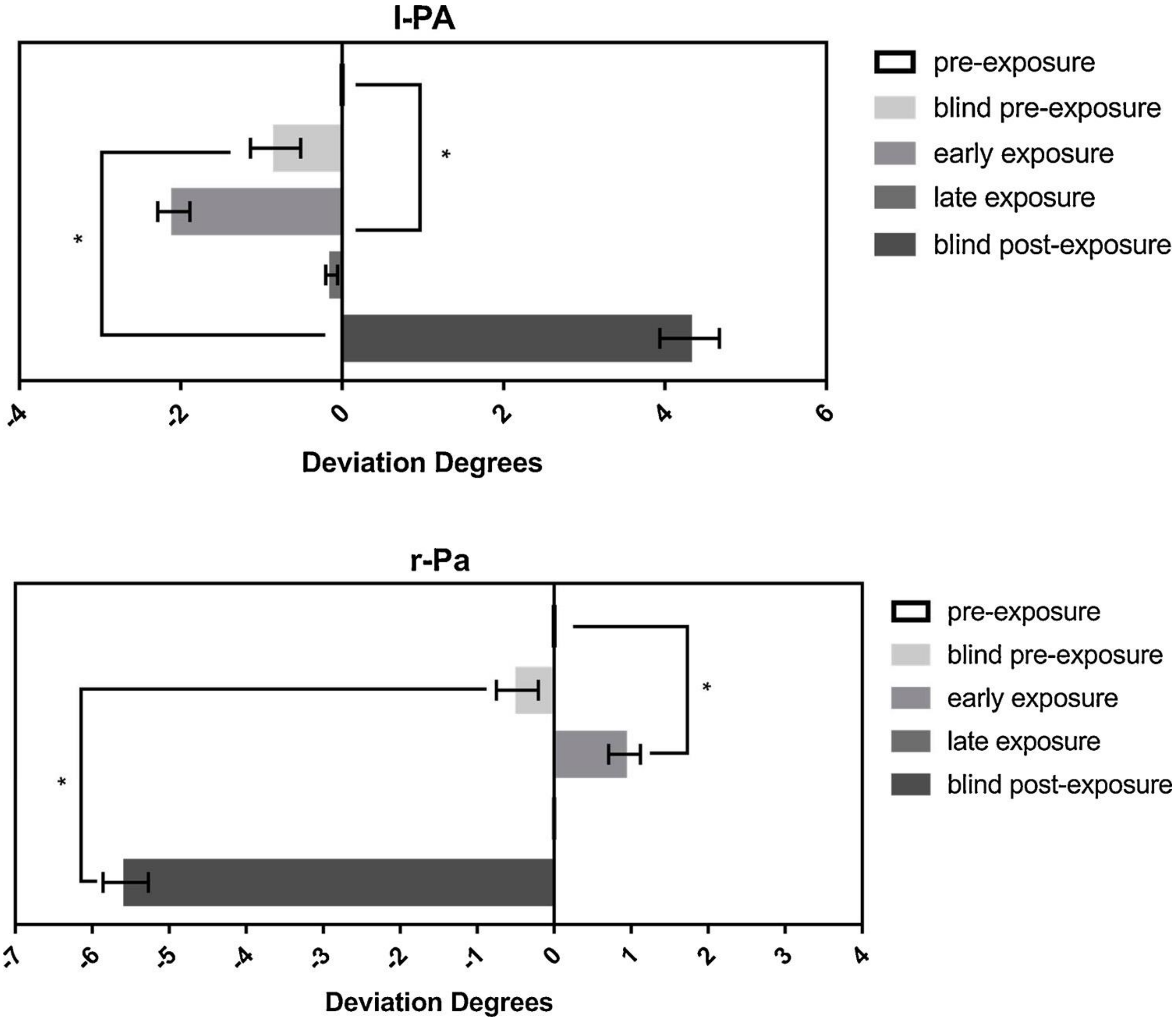


Fig. 1. Mean pointing displacement during Prismatic Adaptation in the five experimental conditions across groups (leftward prismatic adaptation group and rightward prismatic adaptation group).
Legend: l-PA=leftward prismatic adaptation group; r-PA=rightward prismatic adaptation group; Error bars=Standard error of mean; *p<.001. Negative values indicate leftward pointing displacement, positive values indicate rightward pointing displacement.

Handgrip

Fig. 2 shows handgrip performance for the left and the right hand during the first and the second measurement across l-PA and r-PA groups.

ANOVA revealed significant main effects of the factors Hand [F(1,44)=37.730, p< .001, ηp2=.441] and Time [F(1,44)=8.205, p= .006, ηp2=.157] while the factor Group [F(1,44)=.035, p= .853, ηp2=.001] and the interaction Hand×Time [F(1,44)=3.345, p= .074, ηp2=.071] were not significant. The interaction Hand×Time×Group was significant [F(1,44)=4.659, p= .036, ηp2=.096]. Post-hoc tests revealed that l-PA reduced right hand strength (33.160 vs. 32.352, p= .034) and r-PA reduced left hand strength (31.506 vs. 30.389, p= .006) (Fig. 2).

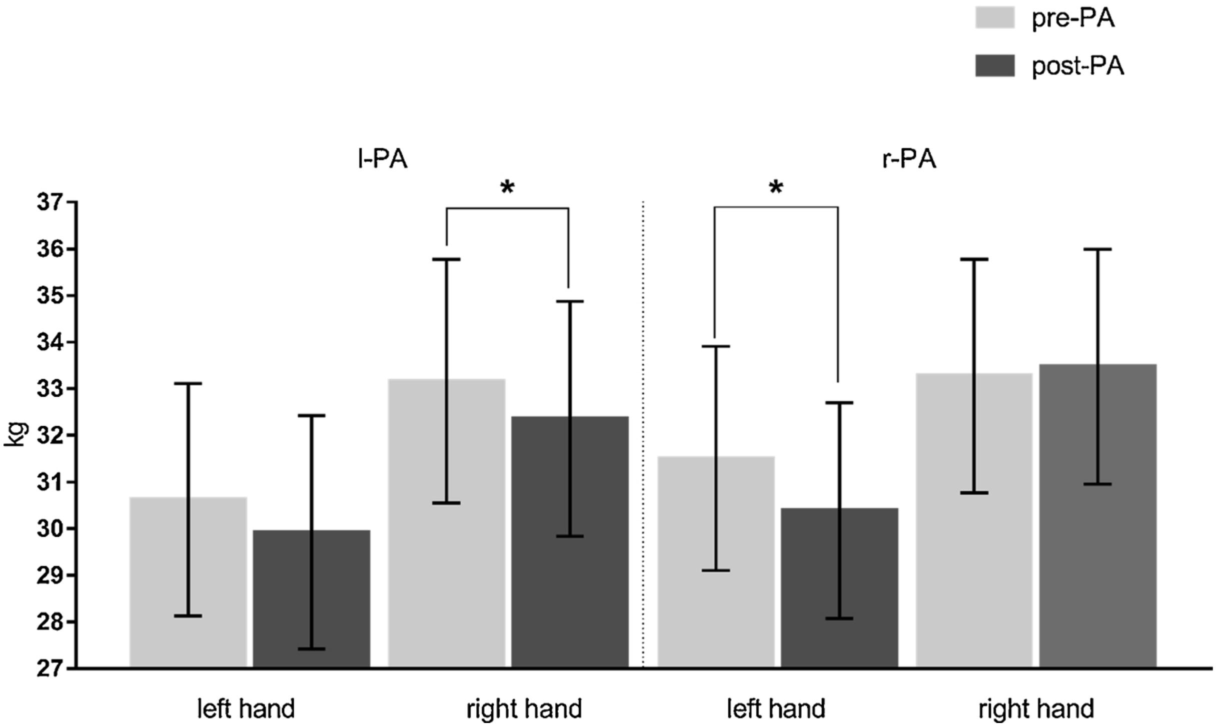


Fig. 2. Differences in handgrip strength (left and right): mean values before and after prismatic adaptation (pre- PA, post-PA) across groups (leftward prismatic adaptation group and rightward prismatic adaptation group).
Legend: l-PA=leftward prismatic adaptation group; r-PA=rightward prismatic adaptation group; pre-PA=before prismatic Adaptation; post-PA=after prismatic adaptation; Error bars=Standard error of mean; * p < .05.

Plantar surface area

ANOVA on the total plantar surface area revealed a significant effect of the factor Feet [F(1,44)=12.576, p= .001, ηp2=.222], while the factors Time [F(1,44)=.137, p= .713, ηp2=.003] and Group [F(1,44)=2.917, p= .095, ηp2=.062] were not significant. The interaction Feet×Time was significant [F(1,44)=6.846, p= .012, ηp2=.135], the interaction Feet×Time×Group was not significant [F(1,44)=.179, p= .674, ηp2=.004].

ANOVA on the forefoot/rearfoot plantar surface area revealed a significant effect of the factors Feet [F(1,44)=118.368, p < .001, ηp2=.729] and Area [F(1,44)=12.582, p< .001, ηp2=.222], and no effect of the factors Time [F(1,44)=.102, p=.751, ηp2=.002] and Group [F(1,44)=2.895, p=.096, ηp2=.062]. The interaction Feet×Area [F(1,44)=4.305, p=.044, ηp2=.089], Time×Area [F(1,44)=6.417, p= .015, ηp2=.127], Feet×Time×Group [F(1,44)=5.806, p=.029, ηp2=.104] were significant. None of the post hoc tests revealed significant differences (all p values > .05).

Plantar pressure

ANOVA on the total plantar pressure revealed a significant effect of the factor Time [F(1,44)=6.887, p=.012, ηp2=.135] and not of the factor Group [F(1,44)=1.028, p= .316, ηp2=.023] neither of the interaction Time×Group [F(1,44)=.969, p= .330, ηp2=.022]. Post hoc tests on the main factor of Time revealed a decrease of plantar pressure on the right foot (49.537 vs. 48.006, p= .012) after PA, regardless of the lenses deviation side. There was no significant difference among the pre-PA measurements (all p values>.05).

Fig. 3 shows forefoot/rearfoot plantar pressure distribution in the l-PA and r-PA groups during the first and the second measurement. ANOVA on the forefoot/rearfoot plantar pressure revealed that neither the main factor Time [F(1,44)=.987, p= .326, ηp2=.022] nor the factor Feet [F(1,44)=1.978, p= .167, ηp2=.043] were significant, whereas the interaction Time×Group was significant [F(1,44)=5.847, p=.020, ηp2=.117]. The post-hoc tests revealed an increase in forefoot plantar pressure (48.947 vs. 51.342, p= .020) in both feet after r-PA (Fig. 3).

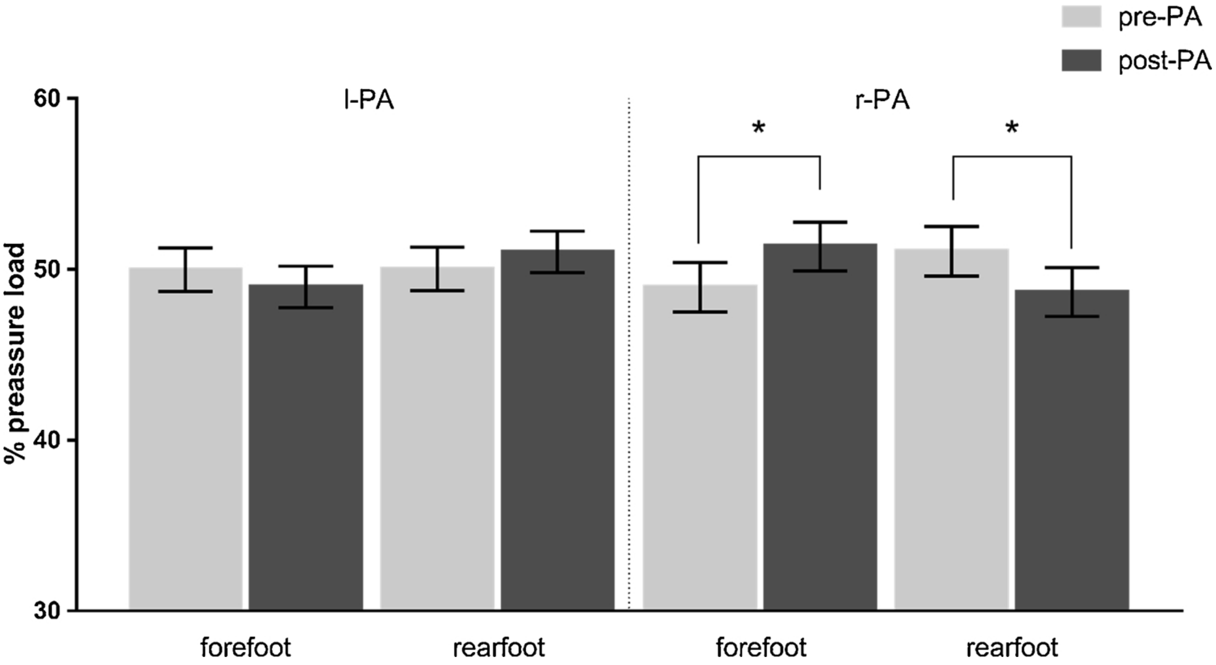


Fig. 3. Plantar pressure distribution (forefoot/rearfoot) before and after prismatic adaptation (pre- PA, post-PA) across groups (leftward prismatic adaptation group and rightward prismatic adaptation group). Legend: l-PA=leftward prismatic adaptation group; r-PA=rightward prismatic adaptation group; pre-PA=before Prismatic Adaptation; post-PA=after Prismatic Adaptation; Error bars=Standard error of mean; * $p < .05$.

Discussion

The main result of the present study was that PA differently affected muscle strength and plantar pressure depending on the side of prismatic deviation. Namely, we found a significant decrease in muscle strength in the hand contralateral to the lenses deviation side after either leftward or rightward PA. A forward displacement of plantar pressure of both feet was found selectively after r-PA.

As a secondary result, we found a decrease of plantar pressure on the right foot after PA, regardless of the lenses deviation side. This effect could be explained by a compensatory postural adjustment activated by the visuomotor unbalance determined by PA, and leading to greater pressure on the non-preferred foot in order to obtain body stabilization. Further studies would better address asymmetries between dominant and non-dominant foot in body stabilization following visuomotor perturbation.

This is the first study investigating the effect of PA on handgrip strength and plantar pressure.

We suggest that the weakening of strength we observed in hands depends on inhibitory processes taking place both during the handgrip task and PA. Namely, it has been shown that PA induces an enhancement of excitability levels of M1 ipsilateral to the lenses deviation side [262,279], whereas, due to interhemispheric inhibitory processes, excitability levels in the contralateral M1 decrease [320]. On the other hand, during muscle contraction, activity in the M1 contralateral to the tested hand increases, while excitability levels in the M1 ipsilateral to the tested hand decrease [321,322]. It has been reported that the inhibition of M1 ipsilateral to the activated hand lasts until muscles contractions of medium-intensity are reached; when maximal voluntary contractions (MVC) are reached, the pattern of activation changes [323,324]. Studies using near-infrared spectroscopy and functional magnetic resonance imaging have shown that M1 contralateral to the tested hand is activated when muscle strength is exerted from 20 % to 60 % MVC and then cortical reactivity reaches a plateau. At this point, higher muscle contractions (i.e., above 60 %) are obtained through activation of the M1 ipsilateral to the tested hand, that complements activation of the contralateral one [323,324]. Noteworthy, in our task 100 % of the MVC was required. This implies that the contribution of the M1 ipsilateral to the tested hand was pivotal in order to execute the grip task. We suggest that PA disrupted the recruitment of the M1 ipsilateral to the tested hand since this was inhibited by interhemispheric inhibitory processes occurring during PA [320].

In other words, PA inhibited the hemisphere contralateral to the lenses deviation side, thus preventing M1 recruitment to exert 100 % of MVC during the handgrip task. If so, one should expect that PA either increase or decrease handgrip depending on the level of muscle contraction. Further studies will better address this issue.

In sum, these results do not contradict studies reporting an enhanced cortical activation in M1 ipsilateral to the lenses deviation side [262]. In particular, our findings add evidence to previous studies investigating PA effects with TMS over M1 and reporting that PA induces changes in excitability levels of M1 ipsilateral to the lenses deviation side [262].

However, for hand strength weakening, we cannot exclude the occurrence of homeostatic plasticity phenomena, a natural neuron mechanism that reduce neuron's activity to prevent overstimulation and cells damage [325]. Indeed, the combination of M1 activation induced by motor grip and PA might have caused a suppressive effect and a consequent hand strength reduction [326]. In particular, a previous study has shown that PA excitatory effects may be reversed whether they are administered immediately after a conditioning excitatory paradigm of transcranial direct current stimulation [279]. Further studies combining behavioural with neurophysiological measures of M1 activation (i.e. analysis of motor evoked potentials) could better clarify this issue.

In addition to hand strength reduction, we found a selective plantar pressure forward displacement after r-PA but not l-PA. This result adds evidence to a previous study [270] reporting a forward displacement of the center of pressure (CoP) after both l-PA and r-PA, showing that r-PA may induce a shift either of the vertical projection of the center of pressure (as measured with stabilometry) and of the plantar pressure in terms of interaction between feet and ground reaction force (as measured with baropodometry) [295]. However, unlike Michael et al., we did not find an effect on plantar pressure after l-PA. Besides differences in the measurements (baropodometry vs. stabilometry), a methodological issue may account for this lack of result. Namely, in our study subjects performed an additional pointing task to measure PA after effect (blind post-exposure) [327]. Since subjects were prevented to watch their arm moving in order to adjust the pointing bias, an access to body postural representation was probably strongly needed [328]. We may speculate that the blind post exposure caused a stronger modulation of the right hemisphere in order to retrieve internal and extra-personal body space representation [310] and to correct for the arm shift. Activation of the right hemisphere is potentiated after r-PA but not after l-PA (inducing left hemispheric activation). This could explain the plantar pressure displacement selectively observed following right PA. This hypothesis finds confirmation in previous studies showing that body sway and body weight distribution among feet are regulated by the internal body representation, linked to attentive process [270,310] taking place mostly in the right brain hemisphere [307,308,315].

These findings suggest that PA may induce the recalibration of representation of space [263] and of body space [270]. Further studies might explore the link between the direction of the PA induced shift in body posture and PA deviation side.

In conclusion, our results suggest that PA exerts effects on body posture and hand strength relying on different mechanisms. The PA effects on hand strength would be related to modulation of interhemispheric inhibition of sensorimotor processes, involving both hemispheres. On the other hand, the PA effects on body posture would be related to modulation of higher-level processes such as body representation, involving mainly the right hemisphere.

4.5. Acute effects of prismatic adaptation on penalty kick accuracy and postural control in young soccer players: a pilot study

Abstract

In soccer, a successful penalty kick requires kicking accuracy towards the side to shoot. Prismatic Adaptation (PA) is a procedure performed using prismatic lenses that shift the visual field during a movement task. PA is closely related to the visual perception system and can have a direct effect on the accuracy required for the penalty kick. Hence, the aim of this pilot study was to investigate any acute effects of PA on penalty kick accuracy and postural control in young soccer players.

A number of seven young male soccer players (16 years old), right-handedness and right-footedness, was recruited for the study. All participants performed three experimental sessions held a week from each other. Each session included a sequence of 30 penalty kicks, without goalkeeper, aimed at one of the three lines marked on a football goal. The sequence of 30 penalty kicks was performed before and immediately after PA in which lens deviation side was different between the three sessions (i.e., right deviation, left deviation, neutral). Moreover, a

stabilometric test was performed before and immediately after each session of PA.

Although not statistically significant, we found an interesting trend of improvement in penalty kick accuracy after PA, regardless of the lens deviation side (p=0.08). In detail, with the right deviation we found an improvement in the accuracy of the penalty kick toward the right target on the football goal, while with the left deviation we found an improvement in the accuracy of the penalty kick toward the left target on the football goal. No significant interaction was found between lens deviation side, before and after PA, and accuracy toward the target on the football goal. A significant effect was found on the sway path length parameter (p=0.002) and on the sway average speed parameter (p=0.004) of the stabilometric test with eyes open after PA, regardless of the lens deviation side. The post-hoc analysis showed that, after PA, the only left deviation of the lenses revealed an interaction with both sway path length parameter (p=0.016) and on the sway average speed parameter (p=0.009).

Our results suggest that PA may have a positive effect on penalty kick accuracy and induces an acute effect on postural control. These findings hypothesize the use of PA as an integrative training program in order to improve penalty kick performance and body balance in soccer.

CONCLUSION

This dissertation addressed the effects of a biomechanical oral device, such as the occlusal splint, and of a neuroscientific procedure, that is the prismatic adaptation, on the improvement of sport performance.

In fact, the pursuit of obtaining the best possible result is the prerogative of athletes (especially high-level ones), coaches and athletic trainers, as well as sports clubs.

To achieve this goal, various devices, techniques, and procedures have been studied and used over time. Among these, also the use of doping substances, in some cases already banned, in other cases banned after their discovery. As for the occlusal splint, the scientific literature does not agree on its real contribution to improving performance. While, regarding the prismatic adaptation, although other visual-perceptual techniques have already been used in athletes, this procedure, to the best of our knowledge, has not yet been investigated in sports.

Our findings on the acute effects of the use of occlusal splint in athletes are not quite concordant. In fact, in response to the increase in the vertical dimension of occlusion (which induces to a biomechanical change in the cranio-cervical-mandibular position), no significant differences were found on cervical ROM in sports subjects compared to controls. However, a significant increase on hand grip strength in the dominant hand in taekwondo, ju-jitsu, and karate athletes was found.

Regarding the prismatic adaptation, our results suggest positive acute effects of this procedure on fitness characteristics and postural characteristics in athletes. Moreover, although the results of the pilot study are not significant, this procedure seems to have an interesting trend for improving sports skill accuracy. In particular, we found that both leftward and rightward prismatic adaptation induce a significant decrease of strength in the hand contralateral to the deviation side of the lenses and that the rightward prismatic adaptation is associated with an increase of the forefoot plantar pressure in both feet. Moreover, we detected a significant acute effect of prismatic adaptation on body balance in young soccer players, as well as a positive trend concerning the penalty kick accuracy.

Although the contribution on performance of other sports science research fields (e.g., studies on periodization, recovery strategies, nutrition and supplementation) has been extensively investigated, and notwithstanding biomechanics is making a notable contribution only in recent years, few studies have involved neuroscience applied to sport.

The results presented highlight the fundamental contribution that the research in biomechanics and neuroscience applied to sport can make for the improvement of performance. As a matter of fact, previous biomechanical studies and seminal neuroscientific research have revealed interesting findings for performance enhancement in athletes. The research of the present dissertation emphasizes the need to continue the investigation in these fields to demonstrate the effective contribution that biomechanical devices and neuroscientific procedures can make to sport performance.

Practical implications

The innovative aspects of the studies presented concern the use of prismatic adaptation in sports to explore any effect on fitness, postural characteristics, and on penalty kick accuracy in athletes. The results found are relevant and encouraging in continuing the research also in athletes of other sports to study, in addition to the effects on fitness and postural characteristics, the accuracy in sport-specific skills (for example, in the tennis serve, or in the volleyball serve, etc.). If these results are confirmed, the use of prismatic adaptation could have relevant practical implications in sports. Indeed, it could be envisaged to include prismatic adaptation as an integrative training program to improve the accuracy of sport-specific skills.

REFERENCES

1. Raysmith, B.P.; Jacobsson, J.; Drew, M.K.; Timpka, T. What Is Performance? A Scoping Review of Performance Outcomes as Study Endpoints in Athletics. *Sports (Basel)* **2019**, *7*, doi:10.3390/sports7030066.
2. Kostrzewa, M.; Laskowski, R.; Wilk, M.; Blach, W.; Ignatjeva, A.; Nitychoruk, M. Significant Predictors of Sports Performance in Elite Men Judo Athletes Based on Multidimensional Regression Models. *Int J Environ Res Public Health* **2020**, *17*, doi:10.3390/ijerph17218192.
3. Kellmann, M.; Bertollo, M.; Bosquet, L.; Brink, M.; Coutts, A.J.; Duffield, R.; Erlacher, D.; Halson, S.L.; Hecksteden, A.; Heidari, J., et al. Recovery and Performance in Sport: Consensus Statement. *Int J Sports Physiol Perform* **2018**, *13*, 240-245, doi:10.1123/ijspp.2017-0759.
4. Mujika, I.; Halson, S.; Burke, L.M.; Balague, G.; Farrow, D. An Integrated, Multifactorial Approach to Periodization for Optimal Performance in Individual and Team Sports. *Int J Sports Physiol Perform* **2018**, *13*, 538-561, doi:10.1123/ijspp.2018-0093.
5. Kreider, R.B.; Kalman, D.S.; Antonio, J.; Ziegenfuss, T.N.; Wildman, R.; Collins, R.; Candow, D.G.; Kleiner, S.M.; Almada, A.L.; Lopez, H.L. International Society of Sports Nutrition position stand: safety and efficacy of creatine supplementation in exercise, sport, and medicine. *J Int Soc Sports Nutr* **2017**, *14*, 18, doi:10.1186/s12970-017-0173-z.
6. Gustafsson, H.; Sagar, S.S.; Stenling, A. Fear of failure, psychological stress, and burnout among adolescent athletes competing in high level sport. *Scand J Med Sci Sports* **2017**, *27*, 2091-2102, doi:10.1111/sms.12797.
7. Patel, D.R.; Omar, H.; Terry, M. Sport-related performance anxiety in young female athletes. *J Pediatr Adolesc Gynecol* **2010**, *23*, 325-335, doi:10.1016/j.jpag.2010.04.004.
8. Bangsbo, J. Performance in sports--With specific emphasis on the effect of intensified training. *Scand J Med Sci Sports* **2015**, *25 Suppl 4*, 88-99, doi:10.1111/sms.12605.
9. Handelsman, D.J. Chapter 24 - Performance Enhancing Hormones in Sports Doping. In *Endocrinology: Adult and Pediatric (Seventh Edition)*, Jameson, J.L., De Groot, L.J., de Kretser, D.M., Giudice, L.C., Grossman, A.B., Melmed, S., Potts, J.T., Weir, G.C., Eds. W.B. Saunders: Philadelphia, 2016; https://doi.org/10.1016/B978-0-323-18907-1.00024-Xpp. 441-454.e444.
10. Zoppirolli, C.; Hebert-Losier, K.; Holmberg, H.C.; Pellegrini, B. Biomechanical determinants of cross-country skiing performance: A systematic review. *J Sports Sci* **2020**, *38*, 2127-2148, doi:10.1080/02640414.2020.1775375.
11. Storey, A.; Smith, H.K. Unique aspects of competitive weightlifting: performance, training and physiology. *Sports Med* **2012**, *42*, 769-790, doi:10.2165/11633000-000000000-00000

10.1007/BF03262294.

12. Kolman, N.S.; Kramer, T.; Elferink-Gemser, M.T.; Huijgen, B.C.H.; Visscher, C. Technical and tactical skills related to performance levels in tennis: A systematic review. *J Sports Sci* **2019**, *37*, 108-121, doi:10.1080/02640414.2018.1483699.
13. Hill-Haas, S.V.; Dawson, B.; Impellizzeri, F.M.; Coutts, A.J. Physiology of small-sided games training in football: a systematic review. *Sports Med* **2011**, *41*, 199-220, doi:10.2165/11539740-000000000-00000.

14. Crowley, E.; Harrison, A.J.; Lyons, M. The Impact of Resistance Training on Swimming Performance: A Systematic Review. *Sports Med* **2017**, *47*, 2285-2307, doi:10.1007/s40279-017-0730-2.
15. Beattie, K.; Kenny, I.C.; Lyons, M.; Carson, B.P. The effect of strength training on performance in endurance athletes. *Sports Med* **2014**, *44*, 845-865, doi:10.1007/s40279-014-0157-y.
16. Altarriba-Bartes, A.; Pena, J.; Vicens-Bordas, J.; Mila-Villaroel, R.; Calleja-Gonzalez, J. Post-competition recovery strategies in elite male soccer players. Effects on performance: A systematic review and meta-analysis. *PLoS One* **2020**, *15*, e0240135, doi:10.1371/journal.pone.0240135.
17. Li, R.T.; Kling, S.R.; Salata, M.J.; Cupp, S.A.; Sheehan, J.; Voos, J.E. Wearable Performance Devices in Sports Medicine. *Sports Health* **2016**, *8*, 74-78, doi:10.1177/1941738115616917.
18. Chambers, R.; Gabbett, T.J.; Cole, M.H.; Beard, A. The Use of Wearable Microsensors to Quantify Sport-Specific Movements. *Sports Med* **2015**, *45*, 1065-1081, doi:10.1007/s40279-015-0332-9.
19. Seshadri, D.R.; Drummond, C.; Craker, J.; Rowbottom, J.R.; Voos, J.E. Wearable Devices for Sports: New Integrated Technologies Allow Coaches, Physicians, and Trainers to Better Understand the Physical Demands of Athletes in Real time. *IEEE Pulse* **2017**, *8*, 38-43, doi:10.1109/MPUL.2016.2627240.
20. Doherty, C.; Keogh, A.; Davenport, J.; Lawlor, A.; Smyth, B.; Caulfield, B. An evaluation of the training determinants of marathon performance: A meta-analysis with meta-regression. *J Sci Med Sport* **2020**, *23*, 182-188, doi:10.1016/j.jsams.2019.09.013.
21. Gonzalez-Rave, J.M.; Hermosilla, F.; Gonzalez-Mohino, F.; Casado, A.; Pyne, D.B. Training Intensity Distribution, Training Volume, and Periodization Models in Elite Swimmers: A Systematic Review. *Int J Sports Physiol Perform* **2021**, *16*, 913-926, doi:10.1123/ijspp.2020-0906.
22. Gomez-Ruano, M.A.; Ibanez, S.J.; Leicht, A.S. Editorial: Performance Analysis in Sport. *Front Psychol* **2020**, *11*, 611634, doi:10.3389/fpsyg.2020.611634.
23. Drum, S.N.; Swisher, A.M.; Buchanan, C.A.; Donath, L. Effects of a Custom Bite-Aligning Mouthguard on Performance in College Football Players. *J Strength Cond Res* **2016**, *30*, 1409-1415, doi:10.1519/JSC.0000000000001235.
24. Hulsdunker, T.; Rentz, C.; Ruhnow, D.; Kasbauer, H.; Struder, H.K.; Mierau, A. The Effect of 4-Week Stroboscopic Training on Visual Function and Sport-Specific Visuomotor Performance in Top-Level Badminton Players. *Int J Sports Physiol Perform* **2019**, *14*, 343-350, doi:10.1123/ijspp.2018-0302.
25. Winter, S.; Gordon, S.; Watt, K. Effects of fatigue on kinematics and kinetics during overground running: a systematic review. *J Sports Med Phys Fitness* **2017**, *57*, 887-899, doi:10.23736/S0022-4707.16.06339-8.
26. Thompson, S.F.; Guess, T.M.; Plackis, A.C.; Sherman, S.L.; Gray, A.D. Youth Baseball Pitching Mechanics: A Systematic Review. *Sports Health* **2018**, *10*, 133-140, doi:10.1177/1941738117738189.
27. Brachman, A.; Kamieniarz, A.; Michalska, J.; Pawlowski, M.; Slomka, K.J.; Juras, G. Balance Training Programs in Athletes - a Systematic Review. *J Hum Kinet* **2017**, *58*, 45-64, doi:10.1515/hukin-2017-0088.
28. Adesida, Y.; Papi, E.; McGregor, A.H. Exploring the Role of Wearable Technology in Sport Kinematics and Kinetics: A Systematic Review. *Sensors (Basel)* **2019**, *19*, doi:10.3390/s19071597.
29. Camomilla, V.; Bergamini, E.; Fantozzi, S.; Vannozzi, G. Trends Supporting the In-Field Use of Wearable Inertial Sensors for Sport Performance Evaluation: A Systematic Review. *Sensors (Basel)* **2018**, *18*, doi:10.3390/s18030873.

30. Dellaserra, C.L.; Gao, Y.; Ransdell, L. Use of integrated technology in team sports: a review of opportunities, challenges, and future directions for athletes. *J Strength Cond Res* **2014**, *28*, 556-573, doi:10.1519/JSC.0b013e3182a952fb.
31. Johnston, W.; O'Reilly, M.; Argent, R.; Caulfield, B. Reliability, Validity and Utility of Inertial Sensor Systems for Postural Control Assessment in Sport Science and Medicine Applications: A Systematic Review. *Sports Med* **2019**, *49*, 783-818, doi:10.1007/s40279-019-01095-9.
32. Yeung, S.S.; Yeung, E.W.; Gillespie, L.D. Interventions for preventing lower limb soft-tissue running injuries. *Cochrane Database Syst Rev* **2011**, 10.1002/14651858.CD001256.pub2, CD001256, doi:10.1002/14651858.CD001256.pub2.
33. Leppanen, M.; Aaltonen, S.; Parkkari, J.; Heinonen, A.; Kujala, U.M. Interventions to prevent sports related injuries: a systematic review and meta-analysis of randomised controlled trials. *Sports Med* **2014**, *44*, 473-486, doi:10.1007/s40279-013-0136-8.
34. Thacker, S.B.; Gilchrist, J.; Stroup, D.F.; Kimsey, C.D. The prevention of shin splints in sports: a systematic review of literature. *Med Sci Sports Exerc* **2002**, *34*, 32-40, doi:10.1097/00005768-200201000-00006.
35. Crago, D.; Bishop, C.; Arnold, J.B. The effect of foot orthoses and insoles on running economy and performance in distance runners: A systematic review and meta-analysis. *J Sports Sci* **2019**, *37*, 2613-2624, doi:10.1080/02640414.2019.1651582.
36. Reneker, J.C.; Latham, L.; McGlawn, R.; Reneker, M.R. Effectiveness of kinesiology tape on sports performance abilities in athletes: A systematic review. *Phys Ther Sport* **2018**, *31*, 83-98, doi:10.1016/j.ptsp.2017.10.001.
37. Lau, K.K.; Cheng, K.C. Effectiveness of taping on functional performance in elite athletes: A systematic review. *J Biomech* **2019**, *90*, 16-23, doi:10.1016/j.jbiomech.2019.04.016.
38. Turgut, E.; Can, E.N.; Demir, C.; Maenhout, A. Evidence for taping in overhead athlete shoulders: a systematic review. *Res Sports Med* **2021**, 10.1080/15438627.2021.1988950, 1-30, doi:10.1080/15438627.2021.1988950.
39. Reeves, J.; Jones, R.; Liu, A.; Bent, L.; Plater, E.; Nester, C. A systematic review of the effect of footwear, foot orthoses and taping on lower limb muscle activity during walking and running. *Prosthet Orthot Int* **2019**, *43*, 576-596, doi:10.1177/0309364619870666.
40. Guo, S.; Liu, P.; Feng, B.; Xu, Y.; Wang, Y. Efficacy of kinesiology taping on the management of shin splints: a systematic review. *Phys Sportsmed* **2021**, 10.1080/00913847.2021.1949253, 1-9, doi:10.1080/00913847.2021.1949253.
41. Cesanelli, L.; Cesaretti, G.; Ylaite, B.; Iovane, A.; Bianco, A.; Messina, G. Occlusal Splints and Exercise Performance: A Systematic Review of Current Evidence. *Int J Environ Res Public Health* **2021**, *18*, doi:10.3390/ijerph181910338.
42. Dias, A.; Redinha, L.; Mendonca, G.V.; Pezarat-Correia, P. A systematic review on the effects of occlusal splint therapy on muscle strength. *Cranio* **2020**, *38*, 187-195, doi:10.1080/08869634.2018.1505085.
43. Ferreira, G.B.; Guimaraes, L.S.; Fernandes, C.P.; Dias, R.B.; Coto, N.P.; Antunes, L.A.A.; Antunes, L.S. Is there enough evidence that mouthguards do not affect athletic performance? A systematic literature review. *Int Dent J* **2019**, *69*, 25-34, doi:10.1111/idj.12406.
44. Knapik, J.J.; Hoedebecke, B.L.; Rogers, G.G.; Sharp, M.A.; Marshall, S.W. Effectiveness of Mouthguards for the Prevention of Orofacial Injuries and Concussions in Sports: Systematic Review and Meta-Analysis. *Sports Med* **2019**, *49*, 1217-1232, doi:10.1007/s40279-019-01121-w.
45. Galic, T.; Kuncic, D.; Poklepovic Pericic, T.; Galic, I.; Mihanovic, F.; Bozic, J.; Herceg, M. Knowledge and attitudes about sports-related dental injuries and

mouthguard use in young athletes in four different contact sports-water polo, karate, taekwondo and handball. *Dent Traumatol* **2018**, *34*, 175-181, doi:10.1111/edt.12394.

46. Vidovic, D.; Bursac, D.; Skrinjaric, T.; Glavina, D.; Gorseta, K. Prevalence and prevention of dental injuries in young taekwondo athletes in Croatia. *Eur J Paediatr Dent* **2015**, *16*, 107-110.
47. Zamora-Olave, C.; Willaert, E.; Montero-Blesa, A.; Riera-Punet, N.; Martinez-Gomis, J. Risk of orofacial injuries and mouthguard use in water polo players. *Dent Traumatol* **2018**, *34*, 406-412, doi:10.1111/edt.12434.
48. Esmaeilpoor, A.; Mohebbi, S.Z.; Moghadam, N.; Ahmadian, M.; Razeghi, S.; Khami, M.R. Self-reported experience of orofacial injury, preventive practice, and knowledge of Iranian adolescent martial art athletes towards sports-related orofacial injuries. *BMC Sports Sci Med Rehabil* **2021**, *13*, 134, doi:10.1186/s13102-021-00363-4.
49. Knapik, J.J.; Marshall, S.W.; Lee, R.B.; Darakjy, S.S.; Jones, S.B.; Mitchener, T.A.; delaCruz, G.G.; Jones, B.H. Mouthguards in sport activities : history, physical properties and injury prevention effectiveness. *Sports Med* **2007**, *37*, 117-144, doi:10.2165/00007256-200737020-00003.
50. Newsome, P.R.; Tran, D.C.; Cooke, M.S. The role of the mouthguard in the prevention of sports-related dental injuries: a review. *Int J Paediatr Dent* **2001**, *11*, 396-404, doi:10.1046/j.0960-7439.2001.00304.x.
51. Militi, A.; Cicciu, M.; Sambataro, S.; Bocchieri, S.; Cervino, G.; De Stefano, R.; Fiorillo, L. Dental occlusion and sport performance. *Minerva Stomatol* **2020**, *69*, 112-118, doi:10.23736/S0026-4970.20.04350-2.
52. D'Ermes, V.; Basile, M.; Rampello, A.; Di Paolo, C. Influence of occlusal splint on competitive athletes performances. *Ann Stomatol (Roma)* **2012**, *3*, 113-118.
53. Dias, A.; Redinha, L.; Vaz, J.R.; Cordeiro, N.; Silva, L.; Pezarat-Correia, P. Effects of occlusal splints on shoulder strength and activation. *Ann Med* **2019**, *51*, 15-21, doi:10.1080/07853890.2019.1566766.
54. Parrini, S.; Rossini, G.; Nebiolo, B.; Airale, M.; Franceschi, A.; Cugliari, G.; Deregibus, A.; Castroflorio, T. Variations in athletic performance with occlusal splint in track and field athletes: a randomized clinical trial. *J Sports Med Phys Fitness* **2021**, 10.23736/S0022-4707.21.12081-X, doi:10.23736/S0022-4707.21.12081-X.
55. Roettger, M. Performance enhancement and oral appliances. *Compend Contin Educ Dent* **2009**, *30 Spec No 2*, 4-8.
56. Gelb, H.; Mehta, N.R.; Forgione, A.G. The relationship between jaw posture and muscular strength in sports dentistry: a reappraisal. *Cranio* **1996**, *14*, 320-325, doi:10.1080/08869634.1996.11745984.
57. Ohlendorf, D.; Riegel, M.; Lin Chung, T.; Kopp, S. The significance of lower jaw position in relation to postural stability. Comparison of a premanufactured occlusal splint with the Dental Power Splint. *Minerva Stomatol* **2013**, *62*, 409-417.
58. Leroux, E.; Leroux, S.; Maton, F.; Ravalec, X.; Sorel, O. Influence of dental occlusion on the athletic performance of young elite rowers: a pilot study. *Clinics (Sao Paulo)* **2018**, *73*, e453, doi:10.6061/clinics/2017/e453.
59. Maurer, C.; Stief, F.; Jonas, A.; Kovac, A.; Groneberg, D.A.; Meurer, A.; Ohlendorf, D. Influence of the Lower Jaw Position on the Running Pattern. *PLoS One* **2015**, *10*, e0135712, doi:10.1371/journal.pone.0135712.
60. Dias, A.; Redinha, L.; Rodrigues, M.J.; Silva, L.; Pezarat-Correia, P. A kinematic analysis on the immediate effects of occlusal splints in gait and running body sway patterns. *Cranio* **2020**, 10.1080/08869634.2020.1721173, 1-7, doi:10.1080/08869634.2020.1721173.
61. Busca, B.; Morales, J.; Solana-Tramunt, M.; Miro, A.; Garcia, M. Effects of Jaw Clenching While Wearing a Customized Bite-Aligning Mouthpiece on Strength in

Healthy Young Men. *J Strength Cond Res* **2016**, *30*, 1102-1110, doi:10.1519/JSC.0000000000001192.

62. Miro, A.; Busca, B.; Solana-Tramunt, M.; Aguilera-Castells, J.; Arboix-Alio, J.; Vergnoux, F.; Arellano, R. Effects of wearing a customized bite-aligning mouthguard on powerful actions in highly trained swimmers. *J Exerc Sci Fit* **2021**, *19*, 259-268, doi:10.1016/j.jesf.2021.09.003.
63. Allen, C.R.; Dabbs, N.C.; Zachary, C.S.; Garner, J.C. The acute effect of a commercial bite-aligning mouthpiece on strength and power in recreationally trained men. *J Strength Cond Res* **2014**, *28*, 499-503, doi:10.1519/JSC.0b013e3182a95250.
64. Battaglia, G.; Giustino, V.; Iovane, A.; Bellafiore, M.; Martines, F.; Patti, A.; Traina, M.; Messina, G.; Palma, A. Influence of Occlusal Vertical Dimension on Cervical Spine Mobility in Sports Subjects. *Acta Medica Mediterr* **2016**, *32*, 1589-1595, doi:10.19193/0393-6384_2016_5_135.
65. Packer, A.C.; Dibai-Filho, A.V.; de Souza Costa, A.C.; dos Santos Berni, K.C.; Rodrigues-Bigaton, D. Relationship between neck disability and mandibular range of motion. *J Back Musculoskelet Rehabil* **2014**, *27*, 493-498, doi:10.3233/BMR-140471.
66. Passero, P.L.; Wyman, B.S.; Bell, J.W.; Hirschey, S.A.; Schlosser, W.S. Temporomandibular joint dysfunction syndrome. A clinical report. *Phys Ther* **1985**, *65*, 1203-1207, doi:10.1093/ptj/65.8.1203.
67. Ohlendorf, D.; Seebach, K.; Hoerzer, S.; Nigg, S.; Kopp, S. The effects of a temporarily manipulated dental occlusion on the position of the spine: a comparison during standing and walking. *Spine J* **2014**, *14*, 2384-2391, doi:10.1016/j.spinee.2014.01.045.
68. Kim, H.S.; Na, H.J.; Kim, H.J.; Kang, D.W.; Oh, S.H. Evaluation of proximal contact strength by postural changes. *J Adv Prosthodont* **2009**, *1*, 118-123, doi:10.4047/jap.2009.1.3.118.
69. Solow, B.; Sonnesen, L. Head posture and malocclusions. *Eur J Orthod* **1998**, *20*, 685-693, doi:10.1093/ejo/20.6.685.
70. Fujimoto, M.; Hayakawa, L.; Hirano, S.; Watanabe, I. Changes in gait stability induced by alteration of mandibular position. *J Med Dent Sci* **2001**, *48*, 131-136.
71. Martines, F.; Messina, G.; Patti, A.; Battaglia, G.; Bellafiore, M.; Messina, A.; Rizzo, S.; Salvago, P.; Sireci, F.; Traina, M. Effects of tinnitus on postural control and stabilization: a pilot study. *Acta Medica Mediterr* **2015**, *31*, 907-912.
72. Bjorne, A. Assessment of temporomandibular and cervical spine disorders in tinnitus patients. *Prog Brain Res* **2007**, *166*, 215-219, doi:10.1016/S0079-6123(07)66019-1.
73. Tecco, S.; Polimeni, A.; Saccucci, M.; Festa, F. Postural loads during walking after an imbalance of occlusion created with unilateral cotton rolls. *BMC Res Notes* **2010**, *3*, 141, doi:10.1186/1756-0500-3-141.
74. de Wijer, A.; Steenks, M.H.; de Leeuw, J.R.; Bosman, F.; Helders, P.J. Symptoms of the cervical spine in temporomandibular and cervical spine disorders. *J Oral Rehabil* **1996**, *23*, 742-750, doi:10.1046/j.1365-2842.1996.d01-187.x.
75. von Piekartz, H.; Hall, T. Orofacial manual therapy improves cervical movement impairment associated with headache and features of temporomandibular dysfunction: a randomized controlled trial. *Man Ther* **2013**, *18*, 345-350, doi:10.1016/j.math.2012.12.005.
76. Armijo-Olivo, S.; Silvestre, R.A.; Fuentes, J.P.; da Costa, B.R.; Major, P.W.; Warren, S.; Thie, N.M.; Magee, D.J. Patients with temporomandibular disorders have increased fatigability of the cervical extensor muscles. *Clin J Pain* **2012**, *28*, 55-64, doi:10.1097/AJP.0b013e31822019f2.
77. Bevilaqua-Grossi, D.; Chaves, T.C.; de Oliveira, A.S. Cervical spine signs and symptoms: perpetuating rather than predisposing factors for temporomandibular

disorders in women. *J Appl Oral Sci* **2007**, *15*, 259-264, doi:10.1590/s1678-77572007000400004.

78. Weber, P.; Correa, E.C.; Ferreira Fdos, S.; Soares, J.C.; Bolzan Gde, P.; Silva, A.M. Cervical spine dysfunction signs and symptoms in individuals with temporomandibular disorder. *J Soc Bras Fonoaudiol* **2012**, *24*, 134-139, doi:10.1590/s2179-64912012000200008.
79. Fernandez-de-las-Penas, C.; Galan-del-Rio, F.; Fernandez-Carnero, J.; Pesquera, J.; Arendt-Nielsen, L.; Svensson, P. Bilateral widespread mechanical pain sensitivity in women with myofascial temporomandibular disorder: evidence of impairment in central nociceptive processing. *J Pain* **2009**, *10*, 1170-1178, doi:10.1016/j.jpain.2009.04.017.
80. Svensson, P.; Wang, K.; Arendt-Nielsen, L.; Cairns, B.E.; Sessle, B.J. Pain effects of glutamate injections into human jaw or neck muscles. *J Orofac Pain* **2005**, *19*, 109-118.
81. Hu, J.W.; Sun, K.Q.; Vernon, H.; Sessle, B.J. Craniofacial inputs to upper cervical dorsal horn: implications for somatosensory information processing. *Brain Res* **2005**, *1044*, 93-106, doi:10.1016/j.brainres.2005.03.004.
82. Wiesinger, B.; Malker, H.; Englund, E.; Wanman, A. Does a dose-response relation exist between spinal pain and temporomandibular disorders? *BMC Musculoskelet Disord* **2009**, *10*, 28, doi:10.1186/1471-2474-10-28.
83. Baldini, A.; Cravino, G. Dental occlusion and athletic performances. A review of literature. *Mondo Ortodontico* **2011**, *36*, 131-141.
84. Greenberg, M.S.; Cohen, S.G.; Springer, P.; Kotwick, J.E.; Vegso, J.J. Mandibular position and upper body strength: a controlled clinical trial. *J Am Dent Assoc* **1981**, *103*, 576-579, doi:10.14219/jada.archive.1981.0306.
85. Orthlieb, J.D.; Laurent, M.; Laplanche, O. Cephalometric estimation of vertical dimension of occlusion. *J Oral Rehabil* **2000**, *27*, 802-807, doi:10.1046/j.1365-2842.2000.00592.x.
86. Dawson, P.E. Evaluation, diagnosis, and treatment of: occlusal problems. **1989**.
87. Battaglia, G.; Paoli, A.; Bellafiore, M.; Bianco, A.; Palma, A. Influence of a sport-specific training background on vertical jumping and throwing performance in young female basketball and volleyball players. *J Sports Med Phys Fitness* **2014**, *54*, 581-587.
88. Battaglia, G.; Bellafiore, M.; Bianco, A.; Paoli, A.; Palma, A. Effects of a dynamic balance training protocol on podalic support in older women. Pilot Study. *Aging Clin Exp Res* **2010**, *22*, 406-411, doi:10.3275/6713
10.1007/BF03337736.
89. Bellafiore, M.; Battaglia, G.; Bianco, A.; Paoli, A.; Farina, F.; Palma, A. Improved postural control after dynamic balance training in older overweight women. *Aging Clin Exp Res* **2011**, *23*, 378-385, doi:10.3275/7354
10.1007/BF03337762.
90. Angle, E.H. Classification of malocclusion. *Dent. Cosmos.* **1899**, *41*, 350-375.
91. Lai, V.; Deriu, F.; Chessa, G. [The influence of occlusion on sporting performance]. *Minerva Stomatol* **2004**, *53*, 41-47.
92. Manfredi, M.; Lombardo, L.; Bragazzi, R.; Gracco, A.; Siciliani, G. An investigation into explosive force variation using occlusal bites. *Prog Orthod* **2009**, *10*, 54-63.
93. Badel, T.; Jerolimov, V.; Panduric, J.; Carek, V. [Custom-made mouthguards and prevention of orofacial injuries in sports]. *Acta Med Croatica* **2007**, *61 Suppl 1*, 9-14.
94. Perinetti, G. Dental occlusion and body posture: no detectable correlation. *Gait Posture* **2006**, *24*, 165-168, doi:10.1016/j.gaitpost.2005.07.012.

95. Chaves, T.C.; Turci, A.M.; Pinheiro, C.F.; Sousa, L.M.; Grossi, D.B. Static body postural misalignment in individuals with temporomandibular disorders: a systematic review. *Braz J Phys Ther* **2014**, *18*, 481-501, doi:10.1590/bjpt-rbf.2014.0061.
96. Seifeldin, S.A.; Elhayes, K.A. Soft versus hard occlusal splint therapy in the management of temporomandibular disorders (TMDs). *Saudi Dent J* **2015**, *27*, 208-214, doi:10.1016/j.sdentj.2014.12.004.
97. Battaglia, G.; Messina, G.; Giustino, V.; Zangla, D.; Barcellona, M.; Iovane, A.; Palma, A. Influence of Vertical Dimension of Occlusion on Peak Force During Handgrip Tests in Athletes. *Asian J Sports Med* **2018**, *9*, e68274, doi:10.5812/asjsm.68274.
98. Shariat A., S.B.S., Kargarfard M., Shaw I., Ching Lam E.T. Kinanthropometric attributes of elite male judo, karate and taekwondo athletes. *Rev Bras Med Esporte* **2017**, *23*, 260-263.
99. Catikkas, F.; Kurt, C.; Atalag, O. Kinanthropometric attributes of young male combat sports athletes. *Coll Antropol* **2013**, *37*, 1365-1368.
100. Sakaguchi, K.; Mehta, N.R.; Abdallah, E.F.; Forgione, A.G.; Hirayama, H.; Kawasaki, T.; Yokoyama, A. Examination of the relationship between mandibular position and body posture. *Cranio* **2007**, *25*, 237-249, doi:10.1179/crn.2007.037.
101. Bergamini, M.; Pierleoni, F.; Gizdulich, A.; Bergamini, C. Dental occlusion and body posture: a surface EMG study. *Cranio* **2008**, *26*, 25-32, doi:10.1179/crn.2008.041.
102. Michelotti, A.; Buonocore, G.; Manzo, P.; Pellegrino, G.; Farella, M. Dental occlusion and posture: an overview. *Prog Orthod* **2011**, *12*, 53-58, doi:10.1016/j.pio.2010.09.010.
103. Patti, A.; Bianco, A.; Messina, G.; Paoli, A.; Bellafiore, M.; Battaglia, G.; Iovane, A.; Traina, M.; Palma, A. The influence of the stomatognathic system on explosive strength: a pilot study. *J Phys Ther Sci* **2016**, *28*, 72-75, doi:10.1589/jpts.28.72.
104. Bourdin, M.; Brunet-Patru, I.; Hager, P.E.; Allard, Y.; Hager, J.P.; Lacour, J.R.; Moyen, B. Influence of maxillary mouthguards on physiological parameters. *Med Sci Sports Exerc* **2006**, *38*, 1500-1504, doi:10.1249/01.mss.0000228952.44850.eb.
105. Garner, D.P.; McDivitt, E. Effects of mouthpiece use on airway openings and lactate levels in healthy college males. *Compend Contin Educ Dent* **2009**, *30 Spec No 2*, 9-13.
106. von Arx, T.; Flury, R.; Tschan, J.; Buergin, W.; Geiser, T. Exercise capacity in athletes with mouthguards. *Int J Sports Med* **2008**, *29*, 435-438, doi:10.1055/s-2007-965341.
107. Cetin, C.; Kececi, A.D.; Erdogan, A.; Baydar, M.L. Influence of custom-made mouth guards on strength, speed and anaerobic performance of taekwondo athletes. *Dent Traumatol* **2009**, *25*, 272-276, doi:10.1111/j.1600-9657.2009.00780.x.
108. Hirase, T.; Inokuchi, S.; Matsusaka, N.; Nakahara, K.; Okita, M. Effects of a resistance training program performed with an interocclusal splint for community-dwelling older adults: a randomized controlled trial. *J Phys Ther Sci* **2016**, *28*, 1499-1504, doi:10.1589/jpts.28.1499.
109. Grosdent, S.; O'Thanh, R.; Domken, O.; Lamy, M.; Croisier, J.L. Dental occlusion influences knee muscular performances in asymptomatic females. *J Strength Cond Res* **2014**, *28*, 492-498, doi:10.1519/JSC.0b013e3182a7665a.
110. Golem, D.L.; Arent, S.M. Effects of over-the-counter jaw-repositioning mouth guards on dynamic balance, flexibility, agility, strength, and power in college-aged male athletes. *J Strength Cond Res* **2015**, *29*, 500-512, doi:10.1519/JSC.0000000000000641.
111. Ebben, W.P.; Flanagan, E.P.; Jensen, R.L. Jaw clenching results in concurrent activation potentiation during the countermovement jump. *J Strength Cond Res* **2008**, *22*, 1850-1854, doi:10.1519/JSC.0b013e3181875117.

112. Smith, S.D. Muscular strength correlated to jaw posture and the temporomandibular joint. *N Y State Dent J* **1978**, *44*, 278-285.
113. Baldini, A.; Beraldi, A.; Nota, A.; Danelon, F.; Ballanti, F.; Longoni, S. Gnathological postural treatment in a professional basketball player: a case report and an overview of the role of dental occlusion on performance. *Ann Stomatol (Roma)* **2012**, *3*, 51-58.
114. Busca, B.; Morales, J.; Solana-Tramunt, M.; Miro, A.; Garcia, M. Effects of Jaw Clenching While Wearing a Customized Bite-Aligning Mouthpiece on Strength in Healthy Young Men. *Journal of Strength and Conditioning Research* **2016**, *30*, 1102-1110, doi:10.1519/Jsc.0000000000001192.
115. Hart, D.L.; Lundquist, D.O.; Davis, H.C. The effect of vertical dimension on muscular strength. *J Orthop Sports Phys Ther* **1981**, *3*, 57-61, doi:10.2519/jospt.1981.3.2.57.
116. Shawn M. Arent, J.M.a.D.L.G. Effects of a neuromuscular dentistry-designed mouthguard on muscular endurance and anaerobic power. *Comparative Exercise Physiology* **2010**, *7*, 73-79, doi:10.1017/S1755254010000231.
117. Solow, R.A. Customized anterior guidance for occlusal devices: classification and rationale. *J Prosthet Dent* **2013**, *110*, 259-263, doi:10.1016/S0022-3913(13)60373-X.
118. Terebesi, S.; Giannakopoulos, N.N.; Brustle, F.; Hellmann, D.; Turp, J.C.; Schindler, H.J. Small vertical changes in jaw relation affect motor unit recruitment in the masseter. *J Oral Rehabil* **2016**, *43*, 259-268, doi:10.1111/joor.12375.
119. Gardiner, D.M.; Ranalli, D.N. Attitudinal factors influencing mouthguard utilization. *Dent Clin North Am* **2000**, *44*, 53-65.
120. Bracco P, D.A., Piscetta R. Effects of different jaw relations on postural stability in human subjects. *Neurosci Lett* **2004**, *356*, 228-230.
121. Wang, K.; Ueno, T.; Taniguchi, H.; Ohyama, T. Influence on isometric muscle contraction during shoulder abduction by changing occlusal situation. *Bull Tokyo Med Dent Univ* **1996**, *43*, 1-12.
122. Churei, H. [Relation between teeth clenching and grip force production characteristics]. *Kokubyo Gakkai Zasshi* **2003**, *70*, 82-88.
123. Forgione, A.G.; Mehta, N.R.; Westcott, W.L. Strength and bite, Part 1: An analytical review. *Cranio* **1991**, *9*, 305-315.
124. Allen, M.E.; Walter, P.; McKay, C.; Elmajian, A. Occlusal splints (MORA) vs. placebos show no difference in strength in symptomatic subjects: double blind/cross-over study. *Can J Appl Sport Sci* **1984**, *9*, 148-152.
125. Yates, J.W.; Koen, T.J.; Semenick, D.M.; Kuftinec, M.M. Effect of a mandibular orthopedic repositioning appliance on muscular strength. *J Am Dent Assoc* **1984**, *108*, 331-333.
126. Dunn-Lewis, C.; Luk, H.Y.; Comstock, B.A.; Szivak, T.K.; Hooper, D.R.; Kupchak, B.R.; Watts, A.M.; Putney, B.J.; Hydren, J.R.; Volek, J.S., et al. The effects of a customized over-the-counter mouth guard on neuromuscular force and power production in trained men and women. *J Strength Cond Res* **2012**, *26*, 1085-1093, doi:10.1519/JSC.0b013e31824b4d5b.
127. Kececi, A.D.; Cetin, C.; Eroglu, E.; Baydar, M.L. Do custom-made mouth guards have negative effects on aerobic performance capacity of athletes? *Dent Traumatol* **2005**, *21*, 276-280, doi:10.1111/j.1600-9657.2005.00354.x.
128. Chakfa, A.M.; Mehta, N.R.; Forgione, A.G.; Al-Badawi, E.A.; Lobo, S.L.; Zawawi, K.H. The effect of stepwise increases in vertical dimension of occlusion on isometric strength of cervical flexors and deltoid muscles in nonsymptomatic females. *Cranio* **2002**, *20*, 264-273.
129. Limonta, E.; Arienti, C.; Rampichini, S.; Venturelli, M.; Ce, E.; Veicsteinas, A.; Esposito, F. Effects of Two Different Self-Adapted Occlusal Splints on Electromyographic and Force Parameters During Elbow Flexors Isometric

Contraction. *J Strength Cond Res* **2018**, *32*, 230-236, doi:10.1519/JSC.0000000000002178.

130. McArdle, W.D.; Goldstein, L.B.; Last, F.C.; Spina, R.; Lichtman, S.; Meyer, J.E.; Berger, A.I. Temporomandibular joint repositioning and exercise performance: a double-blind study. *Med Sci Sports Exerc* **1984**, *16*, 228-233.
131. Miyahara, T.; Hagiya, N.; Ohyama, T.; Nakamura, Y. Modulation of human soleus H reflex in association with voluntary clenching of the teeth. *J Neurophysiol* **1996**, *76*, 2033-2041, doi:10.1152/jn.1996.76.3.2033.
132. Kawakubo, N.; Miyamoto, J.J.; Katsuyama, N.; Ono, T.; Honda, E.; Kurabayashi, T.; Taira, M.; Moriyama, K. Effects of cortical activations on enhancement of handgrip force during teeth clenching: an fMRI study. *Neurosci Res* **2014**, *79*, 67-75, doi:10.1016/j.neures.2013.11.006.
133. Takahashi, T.; Ueno, T.; Ohyama, T. Modulation of H reflexes in the forearm during voluntary teeth clenching in humans. *Eur J Appl Physiol* **2003**, *90*, 651-653, doi:10.1007/s00421-003-0943-y.
134. do Rosario, J.L. Photographic analysis of human posture: a literature review. *J Bodyw Mov Ther* **2014**, *18*, 56-61, doi:10.1016/j.jbmt.2013.05.008.
135. Carini, F.; Mazzola, M.; Fici, C.; Palmeri, S.; Messina, M.; Damiani, P.; Tomasello, G. Posture and posturology, anatomical and physiological profiles: overview and current state of art. *Acta Biomed* **2017**, *88*, 11-16, doi:10.23750/abm.v88i1.5309.
136. Hrysomallis, C. Balance ability and athletic performance. *Sports Med* **2011**, *41*, 221-232, doi:10.2165/11538560-000000000-00000.
137. Han, J.; Anson, J.; Waddington, G.; Adams, R.; Liu, Y. The Role of Ankle Proprioception for Balance Control in relation to Sports Performance and Injury. *Biomed Res Int* **2015**, *2015*, 842804, doi:10.1155/2015/842804.
138. Bishop, C.; Turner, A.; Read, P. Effects of inter-limb asymmetries on physical and sports performance: a systematic review. *J Sports Sci* **2018**, *36*, 1135-1144, doi:10.1080/02640414.2017.1361894.
139. Martines, F.; Giustino, V.; Dispenza, F.; Galletti, F.; Rizzo, S.; Salvago, P.; Messina, G. Body Balance and Postural Control in Patients with Dizziness. In *Dizziness. Prevalence, Risk Factors and Management*, Martines, F., Salvago, P., Eds. Nova Science Publishers, Inc.: New York, 2021; pp. 173-193.
140. Panjan, A.; Sarabon, N. Review of methods for the evaluation of human body balance. *Sport Science Review* **2010**, *19*, 131.
141. Duarte, M.; Freitas, S.M. Revision of posturography based on force plate for balance evaluation. *Revista brasileira de fisioterapia (Sao Carlos (Sao Paulo, Brazil))* **2010**, *14*, 183-192.
142. Jenek, B.; Skorupińska, A. Review of body balance research methods. *Med Rehabil* **2018**, *22*, 50-56.
143. Thomas, E.; Bianco, A.; Messina, G.; Palma, A.; Mucia, M.; Rizzo, S.; Salvago, P.; Sireci, F.; Martines, F.; Rosito, L. The influence of sounds in postural control. In *Hearing Loss: Etiology, Management and Societal Implications*, 2017; pp. 1-12.
144. Alotaibi, A.Z.; Alghadir, A.; Iqbal, Z.A.; Anwer, S. Effect of absence of vision on posture. *J Phys Ther Sci* **2016**, *28*, 1374-1377, doi:10.1589/jpts.28.1374.
145. Wade, M.G.; Jones, G. The role of vision and spatial orientation in the maintenance of posture. *Phys Ther* **1997**, *77*, 619-628, doi:10.1093/ptj/77.6.619.
146. Strini, P.J.; Machado, N.A.; Gorreri, M.C.; Ferreira Ade, F.; Sousa Gda, C.; Fernandes Neto, A.J. Postural evaluation of patients with temporomandibular disorders under use of occlusal splints. *J Appl Oral Sci* **2009**, *17*, 539-543, doi:10.1590/s1678-77572009000500033.

147. Proske, U.; Gandevia, S.C. The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. *Physiol Rev* **2012**, *92*, 1651-1697, doi:10.1152/physrev.00048.2011.
148. Martines, F.; Maira, E.; Ferrara, S. Age-related hearing impairment (ARHI): a common sensory deficit in the elderly. **2011**.
149. Scoppa, F. Posturologia: il modello neurofisiologico, il modello biomeccanico, il modello psicosomatico. *Otoneurologia* **2000**, *2002*, 3-13.
150. Gagey, P.M. *Critique of Posturology: A Psychology of Discovery*; 2016.
151. Pollock, A.S.; Durward, B.R.; Rowe, P.J.; Paul, J.P. What is balance? *Clinical rehabilitation* **2000**, *14*, 402-406.
152. Winter, D.A. Human balance and posture control during standing and walking. *Gait & posture* **1995**, *3*, 193-214.
153. Whipple, R.; Wolfson, L.; Derby, C.; Singh, D.; Tobin, J. Altered sensory function and balance in older persons. *J Gerontol* **1993**, *48 Spec No*, 71-76, doi:10.1093/geronj/48.special_issue.71.
154. Lord, S.R.; Dayhew, J. Visual risk factors for falls in older people. *J Am Geriatr Soc* **2001**, *49*, 508-515, doi:10.1046/j.1532-5415.2001.49107.x.
155. Thomas, E.; Martines, F.; Bianco, A.; Messina, G.; Giustino, V.; Zangla, D.; Iovane, A.; Palma, A. Decreased postural control in people with moderate hearing loss. *Medicine (Baltimore)* **2018**, *97*, e0244, doi:10.1097/MD.0000000000010244.
156. Dischiavi, S.L.; Wright, A.A.; Hegedus, E.J.; Bleakley, C.M. Biotensegrity and myofascial chains: A global approach to an integrated kinetic chain. *Med Hypotheses* **2018**, *110*, 90-96, doi:10.1016/j.mehy.2017.11.008.
157. Czaprowski, D.; Stolinski, L.; Tyrakowski, M.; Kozinoga, M.; Kotwicki, T. Non-structural misalignments of body posture in the sagittal plane. *Scoliosis Spinal Disord* **2018**, *13*, 6, doi:10.1186/s13013-018-0151-5.
158. Salvago, P.; Rizzo, S.; Bianco, A.; Martines, F. Sudden sensorineural hearing loss: is there a relationship between routine haematological parameters and audiogram shapes? *International journal of audiology* **2017**, *56*, 148-153.
159. Gorski, L.P.; Silva, A.M.d.; Cusin, F.S.; Cesaroni, S.; Ganança, M.M.; Caovilla, H.H. Body balance at static posturography in vestibular migraine☆. *Brazilian journal of otorhinolaryngology* **2019**, *85*, 183-192.
160. Quitschal, R.M.; Fukunaga, J.Y.; Gananca, M.M.; Caovilla, H.H. Evaluation of postural control in unilateral vestibular hypofunction. *Braz J Otorhinolaryngol* **2014**, *80*, 339-345, doi:10.1016/j.bjorl.2014.05.015.
161. Muncie, H.L.; Sirmans, S.M.; James, E. Dizziness: Approach to Evaluation and Management. *Am Fam Physician* **2017**, *95*, 154-162.
162. Post, R.E.; Dickerson, L.M. Dizziness: a diagnostic approach. *Am Fam Physician* **2010**, *82*, 361-368, 369.
163. Khasnis, A.; Gokula, R. Romberg's test. *Journal of postgraduate medicine* **2003**, *49*, 169.
164. Scorpecci, A.; Massoud, M.; Giannantonio, S.; Zangari, P.; Lucidi, D.; Martines, F.; Foligno, S.; Di Felice, G.; Minozzi, A.; Luciani, M., et al. Otogenic lateral sinus thrombosis in children: proposal of an experience-based treatment flowchart. *European archives of oto-rhino-laryngology : official journal of the European Federation of Oto-Rhino-Laryngological Societies* **2018**, *275*, 1971-1977, doi:10.1007/s00405-018-5033-1.
165. Di Stadio, A.; Dipietro, L.; Toffano, R.; Burgio, F.; De Lucia, A.; Ippolito, V.; Garofalo, S.; Ricci, G.; Martines, F.; Trabalzini, F., et al. Working Memory Function in Children with Single Side Deafness Using a Bone-Anchored Hearing Implant: A Case-Control Study. *Audiol Neurootol* **2018**, *23*, 238-244, doi:10.1159/000493722.

166. Han, J.; Waddington, G.; Adams, R.; Anson, J.; Liu, Y. Assessing proprioception: A critical review of methods. *J Sport Health Sci* **2016**, *5*, 80-90, doi:10.1016/j.jshs.2014.10.004.
167. Goble, D.J. Proprioceptive acuity assessment via joint position matching: from basic science to general practice. *Phys Ther* **2010**, *90*, 1176-1184, doi:10.2522/ptj.20090399.
168. Blecher, R.; Heinemann-Yerushalmi, L.; Assaraf, E.; Konstantin, N.; Chapman, J.R.; Cope, T.C.; Bewick, G.S.; Banks, R.W.; Zelzer, E. New functions for the proprioceptive system in skeletal biology. *Philos Trans R Soc Lond B Biol Sci* **2018**, *373*, doi:10.1098/rstb.2017.0327.
169. Kistemaker, D.A.; Van Soest, A.J.; Wong, J.D.; Kurtzer, I.; Gribble, P.L. Control of position and movement is simplified by combined muscle spindle and Golgi tendon organ feedback. *J Neurophysiol* **2013**, *109*, 1126-1139, doi:10.1152/jn.00751.2012.
170. Kroger, S. Proprioception 2.0: novel functions for muscle spindles. *Curr Opin Neurol* **2018**, *31*, 592-598, doi:10.1097/WCO.0000000000000590.
171. Mileusnic, M.P.; Loeb, G.E. Force estimation from ensembles of Golgi tendon organs. *J Neural Eng* **2009**, *6*, 036001, doi:10.1088/1741-2560/6/3/036001.
172. Proske, U.; Gandevia, S.C. The kinaesthetic senses. *J Physiol* **2009**, *587*, 4139-4146, doi:10.1113/jphysiol.2009.175372.
173. Kuriakose, T. Visual Function and Its Assessment. In *Clinical Insights and Examination Techniques in Ophthalmology*, Springer: 2020; pp. 31-43.
174. Smith, R.L.; Sivaprasad, S.; Chong, V. Retinal biochemistry, physiology and cell biology. *Retinal Pharmacotherapeutics* **2016**, *55*, 18-27.
175. Doly, M. Transduction of the light message: from the photon to the optic nerve. *Fundamental & clinical pharmacology* **1994**, *8*, 147-154.
176. Bloomfield, S.A.; Dacheux, R.F. Rod vision: pathways and processing in the mammalian retina. *Prog Retin Eye Res* **2001**, *20*, 351-384, doi:10.1016/s1350-9462(00)00031-8.
177. Mehra, D.; Moshirfar, M. Neuroanatomy, Optic Tract. In *StatPearls*, Treasure Island (FL), 2021.
178. Emanuel, D.C.; Maroonroge, S.; Letowski, T.R. Auditory function. *Helmet-Mounted Displays: Sensation, Perception and Cognitive Issues* **2009**.
179. Maroonroge, S.; Emanuel, D.C.; Letowski, T.R. Basic anatomy of the hearing system. *Helmet-Mounted Displays: Sensation, Perception and Cognition Issues. Fort Rucker, Alabama: US Army Aeromedical Research Laboratory* **2000**, 279-306.
180. Giustino, V.; Lorusso, F.; Rizzo, S.; Salvago, P.; Martines, F. Sudden sensorineural hearing loss. In *Sensorineural Hearing loss: Pathophysiology, Diagnosis and Treatment*, 2019; pp. 207-216.
181. Rizzo, S.; Valeria, S.; Terrana, P.; Lauricella, L.; Scaturro, D.; Martines, F.; Letizia Mauro, G. Presbyastasis: from diagnosis to management. In *Sensorineural Hearing Loss: Pathophysiology, Diagnosis and Treatment*, 2019; pp. 355-364.
182. Cavallaro, A.; Cannizzaro, C.; Martines, F.; Lavanco, G.; Salvago, P.; Plescia, F.; Brancato, A. Pharmacological treatment of sensorineural hearing loss. In *Sensorineural Hearing Loss: Pathophysiology, Diagnosis and Treatment*, 2019; pp. 281-297.
183. Rizzo, S.; Bentivegna, D.; Thomas, E.; La Mattina, E.; Mucia, M.; Salvago, P.; Sireci, F.; Martines, F. Sudden sensorineural hearing loss, an invisible male: State of the art. In *Hearing Loss: Etiology, Management and Societal Implications*, 2017; pp. 75-86.
184. Highstein, S.M.; Rabbitt, R.D.; Holstein, G.R.; Boyle, R.D. Determinants of spatial and temporal coding by semicircular canal afferents. *J Neurophysiol* **2005**, *93*, 2359-2370, doi:10.1152/jn.00533.2004.

185. Rabbitt, R.D. Semicircular canal biomechanics in health and disease. *J Neurophysiol* **2019**, *121*, 732-755, doi:10.1152/jn.00708.2018.
186. Gagliardo, C.; Martines, F.; Bencivinni, F.; La Tona, G.; Lo Casto, A.; Midiri, M. Intratumoral haemorrhage causing an unusual clinical presentation of a vestibular schwannoma. *Neuroradiol J* **2013**, *26*, 30-34, doi:10.1177/197140091302600105.
187. Naranjo, E.N.; Cleworth, T.W.; Allum, J.; Inglis, J.T.; Lea, J.; Westerberg, B.D.; Carpenter, M.G. Vestibulo-spinal and vestibulo-ocular reflexes are modulated when standing with increased postural threat. *Journal of neurophysiology* **2016**, *115*, 833-842.
188. Messina, G.; Giustino, V.; Corrao, A.; Rizzo, S.; Salvago, P.; Martines, F. Postural Disorders in Patients with Dizziness: From Postural Analysis to Vestibular Rehabilitation Programs. In *Dizziness. Prevalence, Risk Factors and Management*, Martines, F., Salvago, P., Eds. Nova Science Publishers, Inc.: New York, 2021; pp. 229-245.
189. Thomas, E.; Ferrara, S.; Messina, G.; Passalacqua, M.; Rizzo, S.; Salvago, P.; Palma, A.; Martines, F. The motor development of preterm infants after the neonatal intensive care unit. In *Neonatal Intensive Care Units (NICUs): Clinical and Patient Perspectives, Levels of Care and Emerging Challenges*, 2017.
190. Peterka, R.J. Sensory integration for human balance control. *Handbook of clinical neurology* **2018**, *159*, 27-42.
191. Manchester, D.; Woollacott, M.; Zederbauer-Hylton, N.; Marin, O. Visual, vestibular and somatosensory contributions to balance control in the older adult. *J Gerontol* **1989**, *44*, M118-127, doi:10.1093/geronj/44.4.m118.
192. Asslander, L.; Hettich, G.; Mergner, T. Visual contribution to human standing balance during support surface tilts. *Hum Mov Sci* **2015**, *41*, 147-164, doi:10.1016/j.humov.2015.02.010.
193. Okawara, N.; Usuda, S. Influences of visual and supporting surface conditions on standing postural control and correlation with walking ability in patients with post-stroke hemiplegia. *J Phys Ther Sci* **2015**, *27*, 1323-1327, doi:10.1589/jpts.27.1323.
194. Woollacott, M.H.; Shumway-Cook, A. Changes in posture control across the life span--a systems approach. *Phys Ther* **1990**, *70*, 799-807, doi:10.1093/ptj/70.12.799.
195. Chong, R.K.; Horak, F.B.; Frank, J.; Kaye, J. Sensory organization for balance: specific deficits in Alzheimer's but not in Parkinson's disease. *J Gerontol A Biol Sci Med Sci* **1999**, *54*, M122-128, doi:10.1093/gerona/54.3.m122.
196. Cushing, S.L.; Chia, R.; James, A.L.; Papsin, B.C.; Gordon, K.A. A test of static and dynamic balance function in children with cochlear implants: the vestibular olympics. *Arch Otolaryngol Head Neck Surg* **2008**, *134*, 34-38, doi:10.1001/archoto.2007.16.
197. Palmer, K.T.; D'Angelo, S.; Harris, E.C.; Linaker, C.; Coggon, D. Sensory impairments, problems of balance and accidental injury at work: a case–control study. *Occupational and environmental medicine* **2015**, *72*, 195-199.
198. Moncada, L.V.V.; Mire, L.G. Preventing Falls in Older Persons. *Am Fam Physician* **2017**, *96*, 240-247.
199. Parker, T.M.; Osternig, L.R.; van Donkelaar, P.; Chou, L.S. Balance control during gait in athletes and non-athletes following concussion. *Med Eng Phys* **2008**, *30*, 959-967, doi:10.1016/j.medengphy.2007.12.006.
200. Alsalaheen, B.A.; Mucha, A.; Morris, L.O.; Whitney, S.L.; Furman, J.M.; Camiolo-Reddy, C.E.; Collins, M.W.; Lovell, M.R.; Sparto, P.J. Vestibular rehabilitation for dizziness and balance disorders after concussion. *J Neurol Phys Ther* **2010**, *34*, 87-93, doi:10.1097/NPT.0b013e3181dde568.
201. Hamed, A.; Bohm, S.; Mersmann, F.; Arampatzis, A. Exercises of dynamic stability under unstable conditions increase muscle strength and balance ability in the elderly. *Scand J Med Sci Sports* **2018**, *28*, 961-971, doi:10.1111/sms.13019.

202. Martines, F.; Salvago, P.; Dispenza, F.; Rizzo, S.; Letizia Mauro, G.; Puglisi, S. Treatment with a new nutraceutical compound on patients suffering from balance disorders: Dizziness handicap inventory scores. *Acta Med. Mediterr* **2019**, *35*, 2029-2034.
203. Messina, G.; Giustino, V.; Dispenza, F.; Galletti, F.; Iovane, A.; Rizzo, S.; Martines, F. Posturology: The Scientific Investigation of Postural Disorders. In *Advances in Audiology Research*, Kristensen, V.M., Ed. Nova Science Publishers, Inc.: New York, 2019; pp. 117-128.
204. Ferreira, E.A.; Duarte, M.; Maldonado, E.P.; Bersanetti, A.A.; Marques, A.P. Quantitative assessment of postural alignment in young adults based on photographs of anterior, posterior, and lateral views. *Journal of manipulative and physiological therapeutics* **2011**, *34*, 371-380.
205. Scoppa, F.; Gallamini, M.; Belloni, G.; Messina, G. Clinical stabilometry standardization: Feet position in the static stabilometric assessment of postural stability. *Acta Med. Mediterr* **2017**, *33*, 707-713.
206. Rode, G.; Tiliket, C.; Charlopain, P.; Boisson, D. Postural asymmetry reduction by vestibular caloric stimulation in left hemiparetic patients. *Scand J Rehabil Med* **1998**, *30*, 9-14, doi:10.1080/003655098444264.
207. Feka, K.; Pomara, F.; Russo, G.; Piccione, M.C.; Petrucci, M.; Giustino, V.; Messina, G.; Iovane, A.; Palma, A.; Bianco, A. How do sports affect static baropodometry? An observational study among women living in southern Italy. *Human Movement* **2019**, *20*, 9-16.
208. Rosario, J.L. A review of the utilization of baropodometry in postural assessment. *J Bodyw Mov Ther* **2014**, *18*, 215-219, doi:10.1016/j.jbmt.2013.05.016.
209. Neto, H.P.; Grecco, L.A.; Braun Ferreira, L.A.; Christovao, T.C.; Duarte Nde, A.; Oliveira, C.S. Clinical analysis and baropodometric evaluation in diagnosis of abnormal foot posture: A clinical trial. *J Bodyw Mov Ther* **2015**, *19*, 429-433, doi:10.1016/j.jbmt.2014.09.007.
210. Takakusaki, K. Functional Neuroanatomy for Posture and Gait Control. *J Mov Disord* **2017**, *10*, 1-17, doi:10.14802/jmd.16062.
211. Prochazkova, M.; Tepla, L.; Svoboda, Z.; Janura, M.; Cieslarova, M. Analysis of foot load during ballet dancers' gait. *Acta Bioeng Biomech* **2014**, *16*, 41-45.
212. Kilroy, E.A.; Crabtree, O.M.; Crosby, B.; Parker, A.; Barfield, W.R. The Effect of Single-Leg Stance on Dancer and Control Group Static Balance. *Int J Exerc Sci* **2016**, *9*, 110-120.
213. Giacomozzi, C.; Leardini, A.; Caravaggi, P. Correlates between kinematics and baropodometric measurements for an integrated in-vivo assessment of the segmental foot function in gait. *J Biomech* **2014**, *47*, 2654-2659, doi:10.1016/j.jbiomech.2014.05.014.
214. Peltenburg, A.L.; Erich, W.B.; Bernink, M.J.; Zonderland, M.L.; Huisveld, I.A. Biological maturation, body composition, and growth of female gymnasts and control groups of schoolgirls and girl swimmers, aged 8 to 14 years: a cross-sectional survey of 1064 girls. *Int J Sports Med* **1984**, *5*, 36-42, doi:10.1055/s-2008-1025878.
215. Klentrou, P.; Plyley, M. Onset of puberty, menstrual frequency, and body fat in elite rhythmic gymnasts compared with normal controls. *Br J Sports Med* **2003**, *37*, 490-494, doi:10.1136/bjsm.37.6.490.
216. Baumfeld, D.; Baumfeld, T.; da Rocha, R.L.; Macedo, B.; Raduan, F.; Zambelli, R.; Alves Silva, T.A.; Nery, C. Reliability of Baropodometry on the Evaluation of Plantar Load Distribution: A Transversal Study. *Biomed Res Int* **2017**, *2017*, 5925137, doi:10.1155/2017/5925137.

217. Alves, R.; Borel, W.P.; Rossi, B.P.; Vicente, E.J.D.; Chagas, P.S.d.C.; Felício, D.C. Test-retest reliability of baropodometry in young asyntomatic individuals during semi static and dynamic analysis. *Fisioterapia em Movimento* **2018**, *31*.
218. Phethean, J.; Nester, C. The influence of body weight, body mass index and gender on plantar pressures: results of a cross-sectional study of healthy children's feet. *Gait Posture* **2012**, *36*, 287-290, doi:10.1016/j.gaitpost.2012.03.012.
219. Wong, P.L.; Chamari, K.; Mao, D.W.; Wisloff, U.; Hong, Y. Higher plantar pressure on the medial side in four soccer-related movements. *Br J Sports Med* **2007**, *41*, 93-100, doi:10.1136/bjsm.2006.030668.
220. de Paula Lima, P.O.; Camelo, P.R.P.; Ferreira, V.; do Nascimento, P.J.S.; Bezerra, M.A.; Almeida, G.P.L.; de Oliveira, R.R. Evaluation of the isokinetic muscle function, postural control and plantar pressure distribution in capoeira players: a cross-sectional study. *Muscles Ligaments Tendons J* **2017**, *7*, 498-503, doi:10.11138/mltj/2017.7.3.498.
221. Potdevin, F.J.; Femery, V.G.; Decatoire, A.; Bosquet, L.; Coello, Y.; Moretto, P. Using effect size to quantify plantar pressure asymmetry of gait of nondisabled adults and patients with hemiparesis. *J Rehabil Res Dev* **2007**, *44*, 347-354, doi:10.1682/jrrd.2006.07.0077.
222. Kaercher, C.W.; Genro, V.K.; Souza, C.A.; Alfonsin, M.; Berton, G.; Filho, J.S. Baropodometry on women suffering from chronic pelvic pain--a cross-sectional study. *BMC Womens Health* **2011**, *11*, 51, doi:10.1186/1472-6874-11-51.
223. Gravante, G.; Russo, G.; Pomara, F.; Rubino, G.; Ridola, C.; Amato, G. Influence of physical activity on plantar pressures and on ground projection of the body barycentre. *Medicina dello Sport* **2002**, *55*, 269-278.
224. Russo, G.; Truglio, G.; Gravante, G.; Benigno, A.; Pomara, F.; Angelomè, C.; Amato, G. Static and dynamic baropodometric analysis in runners and body-builders. *Medicina dello Sport* **1998**, *51*, 299-305.
225. Russo G; Gravante G; Amato G; Genduso D; Amato C; F., P. Analysis of plantar support and pressure centre in adolescents: a comparison between athletes and sedentary people. *Chirurgia Del Piede* **2003**, *27*, 19-24.
226. Tomankova, K.; Pridalova, M.; Svoboda, Z.; Cuberek, R. Evaluation of Plantar Pressure Distribution in Relationship to Body Mass Index in Czech Women During Walking. *J Am Podiatr Med Assoc* **2017**, *107*, 208-214, doi:10.7547/15-143.
227. Sims, E.L.; Hardaker, W.M.; Queen, R.M. Gender differences in plantar loading during three soccer-specific tasks. *Br J Sports Med* **2008**, *42*, 272-277, doi:10.1136/bjsm.2007.042432.
228. Messina, G. The Tongue, Mandible, Hyoid System. *Eur J Transl Myol* **2017**, *27*, 6363, doi:10.4081/ejtm.2017.6363.
229. Petry, V.K.; Paletta, J.R.; El-Zayat, B.F.; Efe, T.; Michel, N.S.; Skwara, A. Influence of a Training Session on Postural Stability and Foot Loading Patterns in Soccer Players. *Orthop Rev (Pavia)* **2016**, *8*, 6360, doi:10.4081/or.2016.6360.
230. Mosteller, R.D. Simplified calculation of body-surface area. *N Engl J Med* **1987**, *317*, 1098, doi:10.1056/NEJM198710223171717.
231. Paillard, T.; Montoya, R.; Dupui, P. Postural adaptations specific to preferred throwing techniques practiced by competition-level judoists. *J Electromyogr Kinesiol* **2007**, *17*, 241-244, doi:10.1016/j.jelekin.2006.01.006.
232. Paillard, T.; Costes-Salon, C.; Lafont, C.; Dupui, P. Are there differences in postural regulation according to the level of competition in judoists? *Br J Sports Med* **2002**, *36*, 304-305, doi:10.1136/bjsm.36.4.304.
233. Pauk, J.; Ihnatouski, M.; Najafi, B. Assessing plantar pressure distribution in children with flatfoot arch: application of the Clarke angle. *J Am Podiatr Med Assoc* **2014**, *104*, 622-632, doi:10.7547/8750-7315-104.6.622.

234. Gobbi, G.; Galli, D.; Carubbi, C.; Pelosi, A.; Lillia, M.; Gatti, R.; Queirolo, V.; Costantino, C.; Vitale, M.; Saccavini, M., et al. Assessment of body plantar pressure in elite athletes: an observational study. *Sport Sciences for Health* **2013**, *9*, 13-18, doi:10.1007/s11332-013-0139-8.
235. Anjos, D.M.; Gomes, L.P.; Sampaio, L.M.; Correa, J.C.; Oliveira, C.S. Assessment of plantar pressure and balance in patients with diabetes. *Arch Med Sci* **2010**, *6*, 43-48, doi:10.5114/aoms.2010.13506.
236. Notarnicola, A.; Maccagnano, G.; Fiore, A.; Spinarelli, A.; Montenegro, L.; Paoloni, M.; Pastore, F.; Tafuri, S.; Moretti, B. Baropodometry on patients after total knee arthroplasty. *Musculoskelet Surg* **2018**, *102*, 129-137, doi:10.1007/s12306-017-0505-9.
237. Matsuda, S.; Fukubayashi, T.; Hirose, N. Characteristics of the Foot Static Alignment and the Plantar Pressure Associated with Fifth Metatarsal Stress Fracture History in Male Soccer Players: a Case-Control Study. *Sports Med Open* **2017**, *3*, 27, doi:10.1186/s40798-017-0095-y.
238. Teymouri, M.; Halabchi, F.; Mirshahi, M.; Mansournia, M.A.; Mousavi Ahranjani, A.; Sadeghi, A. Comparison of plantar pressure distribution between three different shoes and three common movements in futsal. *PLoS One* **2017**, *12*, e0187359, doi:10.1371/journal.pone.0187359.
239. Castillo-Lopez, J.M.; Vargas-Macias, A.; Dominguez-Maldonado, G.; Lafuente-Sotillos, G.; Ramos-Ortega, J.; Palomo-Toucedo, I.C.; Reina-Bueno, M.; Munuera-Martinez, P.V. Metatarsal pain and plantar hyperkeratosis in the forefeet of female professional flamenco dancers. *Med Probl Perform Art* **2014**, *29*, 193-197, doi:10.21091/mppa.2014.4040.
240. Hills, A.P.; Hennig, E.M.; McDonald, M.; Bar-Or, O. Plantar pressure differences between obese and non-obese adults: a biomechanical analysis. *Int J Obes Relat Metab Disord* **2001**, *25*, 1674-1679, doi:10.1038/sj.ijo.0801785.
241. Gravante, G.; Russo, G.; Pomara, F.; Ridola, C. Comparison of ground reaction forces between obese and control young adults during quiet standing on a baropodometric platform. *Clin Biomech (Bristol, Avon)* **2003**, *18*, 780-782, doi:10.1016/s0268-0033(03)00123-2.
242. Tribastone, F.; Tribastone, P. *Compendium of preventive and compensatory motor education [in Italian]*; Roma: Società Stampa Sportiva: 2001.
243. Magee, D.J. *Musculoskeletal evaluation [in Portuguese]*; São Paulo: Editora Manole: 2005.
244. Gerbino, P.G.; Griffin, E.D.; Zurakowski, D. Comparison of standing balance between female collegiate dancers and soccer players. *Gait Posture* **2007**, *26*, 501-507, doi:10.1016/j.gaitpost.2006.11.205.
245. Vieira, T.; Botter, A.; Gastaldi, L.; Sacco, I.C.N.; Martelli, F.; Giacomozzi, C. Textured insoles affect the plantar pressure distribution while elite rowers perform on an indoor rowing machine. *PLoS One* **2017**, *12*, e0187202, doi:10.1371/journal.pone.0187202.
246. Castropil, W.; Arnoni, C. Postural patterns and adaptations in judo athletes. *Archives of budo* **2014**, *10*, 23-28.
247. Guadagni, V.; Drogos, L.L.; Tyndall, A.V.; Davenport, M.H.; Anderson, T.J.; Eskes, G.A.; Longman, R.S.; Hill, M.D.; Hogan, D.B.; Poulin, M.J. Aerobic exercise improves cognition and cerebrovascular regulation in older adults. *Neurology* **2020**, *94*, e2245-e2257, doi:10.1212/WNL.0000000000009478.
248. Schapschroer, M.; Lemez, S.; Baker, J.; Schorer, J. Physical Load Affects Perceptual-Cognitive Performance of Skilled Athletes: a Systematic Review. *Sports Med Open* **2016**, *2*, 37, doi:10.1186/s40798-016-0061-0.

249. Niedermeier, M.; Weiss, E.M.; Steidl-Muller, L.; Burtscher, M.; Kopp, M. Acute Effects of a Short Bout of Physical Activity on Cognitive Function in Sport Students. *Int J Environ Res Public Health* **2020**, *17*, doi:10.3390/ijerph17103678.
250. Slimani, M.; Bragazzi, N.L.; Tod, D.; Dellal, A.; Hue, O.; Cheour, F.; Taylor, L.; Chamari, K. Do cognitive training strategies improve motor and positive psychological skills development in soccer players? Insights from a systematic review. *J Sports Sci* **2016**, *34*, 2338-2349, doi:10.1080/02640414.2016.1254809.
251. Harris, D.J.; Wilson, M.R.; Vine, S.J. A Systematic Review of Commercial Cognitive Training Devices: Implications for Use in Sport. *Front Psychol* **2018**, *9*, 709, doi:10.3389/fpsyg.2018.00709.
252. Papaioannou, A.; Ballon, F.; Theodorakis, Y.; Auwelle, Y.V. Combined effect of goal setting and self-talk in performance of a soccer-shooting task. *Percept Mot Skills* **2004**, *98*, 89-99, doi:10.2466/pms.98.1.89-99.
253. Perrey, S.; Besson, P. Studying brain activity in sports performance: Contributions and issues. *Prog Brain Res* **2018**, *240*, 247-267, doi:10.1016/bs.pbr.2018.07.004.
254. Sexton, C.E.; Betts, J.F.; Demnitz, N.; Dawes, H.; Ebmeier, K.P.; Johansen-Berg, H. A systematic review of MRI studies examining the relationship between physical fitness and activity and the white matter of the ageing brain. *Neuroimage* **2016**, *131*, 81-90, doi:10.1016/j.neuroimage.2015.09.071.
255. Thompson, T.; Steffert, T.; Ros, T.; Leach, J.; Gruzelier, J. EEG applications for sport and performance. *Methods* **2008**, *45*, 279-288, doi:10.1016/j.ymeth.2008.07.006.
256. Angius, L.; Pascual-Leone, A.; Santarnecchi, E. Brain stimulation and physical performance. *Prog Brain Res* **2018**, *240*, 317-339, doi:10.1016/bs.pbr.2018.07.010.
257. Mendez-Villanueva, A.; Suarez-Arrones, L.; Rodas, G.; Fernandez-Gonzalo, R.; Tesch, P.; Linnehan, R.; Kreider, R.; Di Salvo, V. MRI-Based Regional Muscle Use during Hamstring Strengthening Exercises in Elite Soccer Players. *PLoS One* **2016**, *11*, e0161356, doi:10.1371/journal.pone.0161356.
258. Machado, D.; Unal, G.; Andrade, S.M.; Moreira, A.; Altimari, L.R.; Brunoni, A.R.; Perrey, S.; Mauger, A.R.; Bikson, M.; Okano, A.H. Effect of transcranial direct current stimulation on exercise performance: A systematic review and meta-analysis. *Brain Stimul* **2019**, *12*, 593-605, doi:10.1016/j.brs.2018.12.227.
259. da Silva Machado, D.G.; Bikson, M.; Datta, A.; Caparelli-Daquer, E.; Unal, G.; Baptista, A.F.; Cyrino, E.S.; Li, L.M.; Morya, E.; Moreira, A., et al. Acute effect of high-definition and conventional tDCS on exercise performance and psychophysiological responses in endurance athletes: a randomized controlled trial. *Sci Rep* **2021**, *11*, 13911, doi:10.1038/s41598-021-92670-6.
260. Giustiniani, A.; Battaglia, G.; Messina, G.; Morello, H.; Guastella, S.; Iovane, A.; Oliveri, M.; Palma, A.; Proia, P. Transcranial Alternating Current Stimulation (tACS) Does Not Affect Sports People's Explosive Power: A Pilot Study. *Front Hum Neurosci* **2021**, *15*, 640609, doi:10.3389/fnhum.2021.640609.
261. Clarke, S.; Crottaz-Herbette, S. Modulation of visual attention by prismatic adaptation. *Neuropsychologia* **2016**, *92*, 31-41, doi:10.1016/j.neuropsychologia.2016.06.022.
262. Magnani, B.; Caltagirone, C.; Oliveri, M. Prismatic adaptation as a novel tool to directionally modulate motor cortex excitability: evidence from paired-pulse TMS. *Brain Stimul* **2014**, *7*, 573-579, doi:10.1016/j.brs.2014.03.005.
263. Rossetti, Y.; Rode, G.; Pisella, L.; Farne, A.; Li, L.; Boisson, D.; Perenin, M.T. Prism adaptation to a rightward optical deviation rehabilitates left hemispatial neglect. *Nature* **1998**, *395*, 166-169, doi:10.1038/25988.
264. Tsujimoto, K.; Mizuno, K.; Nishida, D.; Tahara, M.; Yamada, E.; Shindo, S.; Kasuga, S.; Liu, M. Prism adaptation changes resting-state functional connectivity in the dorsal

stream of visual attention networks in healthy adults: A fMRI study. *Cortex* **2019**, *119*, 594-605, doi:10.1016/j.cortex.2018.10.018.

265. Revol, P.; Touil, N.; Have, L.; Rode, G.; Jacquin-Courtois, S.; Rossetti, Y. Prisms adaptation improves haptic object discrimination in hemispatial neglect. *Cortex* **2020**, *123*, 152-161, doi:10.1016/j.cortex.2019.10.004.
266. Rode, G.; Klos, T.; Courtois-Jacquin, S.; Rossetti, Y.; Pisella, L. Neglect and prism adaptation: a new therapeutic tool for spatial cognition disorders. *Restor Neurol Neurosci* **2006**, *24*, 347-356.
267. Barrett, A.M.; Goedert, K.M.; Basso, J.C. Prism adaptation for spatial neglect after stroke: translational practice gaps. *Nat Rev Neurol* **2012**, *8*, 567-577, doi:10.1038/nrneurol.2012.170.
268. Sarri, M.; Greenwood, R.; Kalra, L.; Papps, B.; Husain, M.; Driver, J. Prism adaptation aftereffects in stroke patients with spatial neglect: pathological effects on subjective straight ahead but not visual open-loop pointing. *Neuropsychologia* **2008**, *46*, 1069-1080, doi:10.1016/j.neuropsychologia.2007.11.005.
269. Vatanparasti, S.; Kazemnejad, A.; Yoonessi, A.; Oveisgharan, S. The Effect of Continuous Theta-Burst Transcranial Magnetic Stimulation Combined with Prism Adaptation on the Neglect Recovery in Stroke Patients. *J Stroke Cerebrovasc Dis* **2019**, *28*, 104296, doi:10.1016/j.jstrokecerebrovasdis.2019.07.012.
270. Michel, C.; Rossetti, Y.; Rode, G.; Tilikete, C. After-effects of visuo-manual adaptation to prisms on body posture in normal subjects. *Exp Brain Res* **2003**, *148*, 219-226, doi:10.1007/s00221-002-1294-3.
271. Girardi, M.; McIntosh, R.D.; Michel, C.; Vallar, G.; Rossetti, Y. Sensorimotor effects on central space representation: prism adaptation influences haptic and visual representations in normal subjects. *Neuropsychologia* **2004**, *42*, 1477-1487, doi:10.1016/j.neuropsychologia.2004.03.008.
272. Guinet, M.; Michel, C. Prism adaptation and neck muscle vibration in healthy individuals: are two methods better than one? *Neuroscience* **2013**, *254*, 443-451, doi:10.1016/j.neuroscience.2013.08.067.
273. Bultitude, J.H.; Farne, A.; Salemme, R.; Ibarrola, D.; Urquizar, C.; O'Shea, J.; Luaute, J. Studying the neural bases of prism adaptation using fMRI: A technical and design challenge. *Behav Res Methods* **2017**, *49*, 2031-2043, doi:10.3758/s13428-016-0840-z.
274. Tsujimoto, K.; Mizuno, K.; Nishida, D.; Tahara, M.; Yamada, E.; Shindo, S.; Watanabe, Y.; Kasuga, S.; Liu, M. Correlation between changes in functional connectivity in the dorsal attention network and the after-effects induced by prism adaptation in healthy humans: A dataset of resting-state fMRI and pointing after prism adaptation. *Data Brief* **2019**, *22*, 583-589, doi:10.1016/j.dib.2018.12.053.
275. Kuper, M.; Wunnemann, M.J.; Thurling, M.; Stefanescu, R.M.; Maderwald, S.; Elles, H.G.; Goricke, S.; Ladd, M.E.; Timmann, D. Activation of the cerebellar cortex and the dentate nucleus in a prism adaptation fMRI study. *Hum Brain Mapp* **2014**, *35*, 1574-1586, doi:10.1002/hbm.22274.
276. Michel, C. Beyond the Sensorimotor Plasticity: Cognitive Expansion of Prism Adaptation in Healthy Individuals. *Front Psychol* **2015**, *6*, 1979, doi:10.3389/fpsyg.2015.01979.
277. Schintu, S.; Pisella, L.; Jacobs, S.; Salemme, R.; Reilly, K.T.; Farne, A. Prism adaptation in the healthy brain: the shift in line bisection judgments is long lasting and fluctuates. *Neuropsychologia* **2014**, *53*, 165-170, doi:10.1016/j.neuropsychologia.2013.11.013.
278. Cho, S.; Kim, W.S.; Park, S.H.; Park, J.; Paik, N.J. Virtual Prism Adaptation Therapy: Protocol for Validation in Healthy Adults. *J Vis Exp* **2020**, 10.3791/60639, doi:10.3791/60639.

279. Bracco, M.; Mangano, G.R.; Turriziani, P.; Smirni, D.; Oliveri, M. Combining tDCS with prismatic adaptation for non-invasive neuromodulation of the motor cortex. *Neuropsychologia* **2017**, *101*, 30-38, doi:10.1016/j.neuropsychologia.2017.05.006.
280. Martin, T.A.; Greger, B.E.; Norris, S.A.; Thach, W.T. Throwing accuracy in the vertical direction during prism adaptation: not simply timing of ball release. *J Neurophysiol* **2001**, *85*, 2298-2302, doi:10.1152/jn.2001.85.5.2298.
281. Morton, S.M.; Bastian, A.J. Prism adaptation during walking generalizes to reaching and requires the cerebellum. *J Neurophysiol* **2004**, *92*, 2497-2509, doi:10.1152/jn.00129.2004.
282. Dotov, D.G.; Frank, T.D.; Turvey, M.T. Balance affects prism adaptation: evidence from the latent aftereffect. *Exp Brain Res* **2013**, *231*, 425-432, doi:10.1007/s00221-013-3707-x.
283. Formenti, D.; Duca, M.; Trecroci, A.; Ansaldi, L.; Bonfanti, L.; Alberti, G.; Iodice, P. Perceptual vision training in non-sport-specific context: effect on performance skills and cognition in young females. *Sci Rep* **2019**, *9*, 18671, doi:10.1038/s41598-019-55252-1.
284. Hulsdunker, T.; Gunasekara, N.; Mierau, A. Short- and Long-Term Stroboscopic Training Effects on Visuomotor Performance in Elite Youth Sports. Part 1: Reaction and Behavior. *Med Sci Sports Exerc* **2021**, *53*, 960-972, doi:10.1249/MSS.0000000000002541.
285. Hulsdunker, T.; Gunasekara, N.; Mierau, A. Short- and Long-Term Stroboscopic Training Effects on Visuomotor Performance in Elite Youth Sports. Part 2: Brain-Behavior Mechanisms. *Med Sci Sports Exerc* **2021**, *53*, 973-985, doi:10.1249/MSS.0000000000002543.
286. Zhou, Y.; Chen, C.T.; Muggleton, N.G. The effects of visual training on sports skill in volleyball players. *Prog Brain Res* **2020**, *253*, 201-227, doi:10.1016/bs.pbr.2020.04.002.
287. Ellison, P.; Jones, C.; Sparks, S.A.; Murphy, P.N.; Page, R.M.; Carnegie, E.; Marchant, D.C. The effect of stroboscopic visual training on eye–hand coordination. *Sport Sciences for Health* **2020**, *16*, 401-410, doi:10.1007/s11332-019-00615-4.
288. Wilkins, L.; Nelson, C.; Tweddle, S. Stroboscopic Visual Training: a Pilot Study with Three Elite Youth Football Goalkeepers. *Journal of Cognitive Enhancement* **2018**, *2*, 3-11, doi:10.1007/s41465-017-0038-z.
289. Bonaventura, R.E.; Giustino, V.; Chiaramonte, G.; Giustiniani, A.; Smirni, D.; Battaglia, G.; Messina, G.; Oliveri, M. Investigating prismatic adaptation effects in handgrip strength and in plantar pressure in healthy subjects. *Gait Posture* **2020**, *76*, 264-269, doi:10.1016/j.gaitpost.2019.12.022.
290. Danckert, J.; Ferber, S.; Goodale, M.A. Direct effects of prismatic lenses on visuomotor control: an event-related functional MRI study. *Eur J Neurosci* **2008**, *28*, 1696-1704, doi:10.1111/j.1460-9568.2008.06460.x.
291. Magnani, B.; Mangano, G.R.; Frassinetti, F.; Oliveri, M. The role of posterior parietal cortices on prismatic adaptation effects on the representation of time intervals. *Neuropsychologia* **2013**, *51*, 2825-2832, doi:10.1016/j.neuropsychologia.2013.08.006.
292. Tilikete, C.; Rode, G.; Rossetti, Y.; Pichon, J.; Li, L.; Boisson, D. Prism adaptation to rightward optical deviation improves postural imbalance in left-hemiparetic patients. *Curr Biol* **2001**, *11*, 524-528, doi:10.1016/s0960-9822(01)00151-8.
293. Padula, W.V.; Nelson, C.A.; Padula, W.V.; Benabib, R.; Yilmaz, T.; Krevisky, S. Modifying postural adaptation following a CVA through prismatic shift of visuo-spatial egocenter. *Brain Inj* **2009**, *23*, 566-576, doi:10.1080/02699050902926283.
294. Vianna, D.; Greve, J. Relationship between ankle and foot mobility and the magnitude of the vertical fueza in relation to the ground. *(Relação entre a mobilidade do*

tornozelo e pé ea magnitude da forçã vertical de relação do solo). Rev. Bras. Fisioter. **2006**, *10*, 339-345.

295. Orlin, M.N.; McPoil, T.G. Plantar pressure assessment. *Phys Ther* **2000**, *80*, 399-409, doi:10.1093/ptj/80.4.399.
296. Kolb, F.P.; Lachauer, S.; Diener, H.C.; Timmann, D. Changes in conditioned postural responses. Comparison between cerebellar patients and healthy subjects. *Acta Physiol Pharmacol Bulg* **2001**, *26*, 143-146.
297. Massion, J. Movement, posture and equilibrium: interaction and coordination. *Prog Neurobiol* **1992**, *38*, 35-56, doi:10.1016/0301-0082(92)90034-c.
298. Gurfinkel, V.; Levick, Y.S. Perceptual and automatic aspects of the postural body scheme. **1991**.
299. Woollacott, M.; Shumway-Cook, A. Attention and the control of posture and gait: a review of an emerging area of research. *Gait Posture* **2002**, *16*, 1-14, doi:10.1016/s0966-6362(01)00156-4.
300. Filimon, F. Human cortical control of hand movements: parietofrontal networks for reaching, grasping, and pointing. *Neuroscientist* **2010**, *16*, 388-407, doi:10.1177/1073858410375468.
301. Ehrsson, H.H.; Fagergren, A.; Jonsson, T.; Westling, G.; Johansson, R.S.; Forssberg, H. Cortical activity in precision- versus power-grip tasks: an fMRI study. *J Neurophysiol* **2000**, *83*, 528-536, doi:10.1152/jn.2000.83.1.528.
302. Takebayashi, H.; Yagi, F.; Miyamoto, K.; Morioka, S.; Miyamoto, S.; Takuma, Y.; Inoue, Y.; Okabe, T.; Takimoto, K. Interaction interference between arm and leg: division of attention through muscle force regulation. *Hum Mov Sci* **2009**, *28*, 752-759, doi:10.1016/j.humov.2009.04.005.
303. Siemionow, V.; Yue, G.H.; Ranganathan, V.K.; Liu, J.Z.; Sahgal, V. Relationship between motor activity-related cortical potential and voluntary muscle activation. *Exp Brain Res* **2000**, *133*, 303-311, doi:10.1007/s002210000382.
304. Slobounov, S.; Hallett, M.; Stanhope, S.; Shibasaki, H. Role of cerebral cortex in human postural control: an EEG study. *Clin Neurophysiol* **2005**, *116*, 315-323, doi:10.1016/j.clinph.2004.09.007.
305. Fernandes, C.A.; Coelho, D.B.; Martinelli, A.R.; Teixeira, L.A. Right cerebral hemisphere specialization for quiet and perturbed body balance control: Evidence from unilateral stroke. *Hum Mov Sci* **2018**, *57*, 374-387, doi:10.1016/j.humov.2017.09.015.
306. Ishii, F.; Matsukawa, N.; Horiba, M.; Yamanaka, T.; Hattori, M.; Wada, I.; Ojika, K. Impaired ability to shift weight onto the non-paretic leg in right-cortical brain-damaged patients. *Clin Neurol Neurosurg* **2010**, *112*, 406-412, doi:10.1016/j.clineuro.2010.02.006.
307. Zhavoronkova, L.A.; Zharikova, A.V.; Kushnir, E.M.; Mikhalkova, A.A. EEG markers of upright posture in healthy individuals. *Human Physiology* **2012**, *38*, 604-612, doi:10.1134/S0362119712050131.
308. Cioncoloni, D.; Rosignoli, D.; Feurra, M.; Rossi, S.; Bonifazi, M.; Rossi, A.; Mazzocchio, R. Role of brain hemispheric dominance in anticipatory postural control strategies. *Exp Brain Res* **2016**, *234*, 1997-2005, doi:10.1007/s00221-016-4603-y.
309. Ferbert, A.; Priori, A.; Rothwell, J.C.; Day, B.L.; Colebatch, J.G.; Marsden, C.D. Interhemispheric inhibition of the human motor cortex. *J Physiol* **1992**, *453*, 525-546, doi:10.1113/jphysiol.1992.sp019243.
310. Shiraishi, H.; Yamakawa, Y.; Itou, A.; Muraki, T.; Asada, T. Long-term effects of prism adaptation on chronic neglect after stroke. *NeuroRehabilitation* **2008**, *23*, 137-151.

311. Magnani, B.; Oliveri, M.; Mangano, G.R.; Frassinetti, F. The role of Posterior Parietal Cortex in spatial representation of time: a TMS study. *Behav Neurol* **2010**, *23*, 213-215, doi:10.3233/BEN-2010-0298.
312. Bracco, M.; Veniero, D.; Oliveri, M.; Thut, G. Prismatic Adaptation Modulates Oscillatory EEG Correlates of Motor Preparation but Not Visual Attention in Healthy Participants. *J Neurosci* **2018**, *38*, 1189-1201, doi:10.1523/JNEUROSCI.1422-17.2017.
313. Rogers, G.; Smith, D.; Schenk, T. Immediate and delayed actions share a common visuomotor transformation mechanism: a prism adaptation study. *Neuropsychologia* **2009**, *47*, 1546-1552, doi:10.1016/j.neuropsychologia.2008.12.022.
314. Clower, D.M.; Hoffman, J.M.; Votaw, J.R.; Faber, T.L.; Woods, R.P.; Alexander, G.E. Role of posterior parietal cortex in the recalibration of visually guided reaching. *Nature* **1996**, *383*, 618-621, doi:10.1038/383618a0.
315. Parkinson, A.; Condon, L.; Jackson, S.R. Parietal cortex coding of limb posture: in search of the body-schema. *Neuropsychologia* **2010**, *48*, 3228-3234, doi:10.1016/j.neuropsychologia.2010.06.039.
316. Fan, J.; Voisin, J.; Milot, M.H.; Higgins, J.; Boudrias, M.H. Transcranial direct current stimulation over multiple days enhances motor performance of a grip task. *Ann Phys Rehabil Med* **2017**, *60*, 329-333, doi:10.1016/j.rehab.2017.07.001.
317. Oldfield, R.C. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* **1971**, *9*, 97-113, doi:10.1016/0028-3932(71)90067-4.
318. McIntosh, R.D.; Brown, B.M.A.; Young, L. Meta-analysis of the visuospatial aftereffects of prism adaptation, with two novel experiments. *Cortex* **2019**, *111*, 256-273, doi:10.1016/j.cortex.2018.11.013.
319. Spijkerman, D.C.; Snijders, C.J.; Stijnen, T.; Lankhorst, G.J. Standardization of grip strength measurements. Effects on repeatability and peak force. *Scand J Rehabil Med* **1991**, *23*, 203-206.
320. Martin-Arevalo, E.; Schintu, S.; Farne, A.; Pisella, L.; Reilly, K.T. Adaptation to Leftward Shifting Prisms Alters Motor Interhemispheric Inhibition. *Cereb Cortex* **2018**, *28*, 528-537, doi:10.1093/cercor/bhw386.
321. Naccarato, M.; Calautti, C.; Jones, P.S.; Day, D.J.; Carpenter, T.A.; Baron, J.C. Does healthy aging affect the hemispheric activation balance during paced index-to-thumb opposition task? An fMRI study. *Neuroimage* **2006**, *32*, 1250-1256, doi:10.1016/j.neuroimage.2006.05.003.
322. Ward, N.S.; Newton, J.M.; Swayne, O.B.; Lee, L.; Frackowiak, R.S.; Thompson, A.J.; Greenwood, R.J.; Rothwell, J.C. The relationship between brain activity and peak grip force is modulated by corticospinal system integrity after subcortical stroke. *Eur J Neurosci* **2007**, *25*, 1865-1873, doi:10.1111/j.1460-9568.2007.05434.x.
323. Shibuya, K. The activity of the primary motor cortex ipsilateral to the exercising hand decreases during repetitive handgrip exercise. *Physiol Meas* **2011**, *32*, 1929-1939, doi:10.1088/0967-3334/32/12/004.
324. Shibuya, K.; Kuboyama, N.; Tanaka, J. Changes in ipsilateral motor cortex activity during a unilateral isometric finger task are dependent on the muscle contraction force. *Physiol Meas* **2014**, *35*, 417-428, doi:10.1088/0967-3334/35/3/417.
325. Tien, N.W.; Kerschensteiner, D. Homeostatic plasticity in neural development. *Neural Dev* **2018**, *13*, 9, doi:10.1186/s13064-018-0105-x.
326. Turrigiano, G.G.; Nelson, S.B. Homeostatic plasticity in the developing nervous system. *Nat Rev Neurosci* **2004**, *5*, 97-107, doi:10.1038/nrn1327.
327. Welch, R.B. Speculations on a model of prism adaptation. *Perception* **1974**, *3*, 451-460, doi:10.1068/p030451.

328. Longo, M.R.; Haggard, P. An implicit body representation underlying human position sense. *Proc Natl Acad Sci U S A* **2010**, *107*, 11727-11732, doi:10.1073/pnas.1003483107.

APPENDIX – PhD academic career

Metrics and Research achievements

- During the PhD Program, the candidate Valerio Giustino obtained 26 publications indexed on Scopus (5 in the first year, 11 in the second year, 10 in the third year) mainly focused on biomechanics and neuroscience in sports, posturology in athletes and special populations, motor coordination in children, and physical activity in elderly.
- Scopus metrics show that the PhD candidate Valerio Giustino currently is 8 H-index with 230 citations by 174 documents. The most cited article reached 69 citations in just a year and a half (Giustino, V.; Parroco, A.M.; Gennaro, A.; Musumeci, G.; Palma, A.; Battaglia, G. Physical Activity Levels and Related Energy Expenditure during COVID-19 Quarantine among the Sicilian Active Population: A Cross-Sectional Online Survey Study. *Sustainability* **2020**, 12, 4356).
- The PhD candidate participated in 17 National and International Congresses presenting both posters and oral presentations.
- The PhD candidate obtained the Best Award Poster 2021 at the XVII National Congress of the Italian Association of Psychology – Section of Social Psychology.
- Valerio Giustino was co-supervisor of 16 thesis of degree and master's students.
- He was invited reviewer for the following international scientific journals indexed on Scopus: Heliyon, Frontiers in Psychology, Journal of Psychosomatic Research, BioMed Research International, SAGE Open.

International mobility

During the PhD Program, the candidate Valerio Giustino carried out three research periods abroad in three different destinations.

- He spent 1-week of research stay (from 4 March 2019 to 9 March 2019) in the Faculty of Kinesiology of the University of Split (Croatia), under the supervision of Prof. Damir Sekulic.
- He spent a 7-months research period (from 13 November 2019 to 12 June 2020) at the Neurophysiology of Movement Laboratory of the University of Colorado Boulder, under the supervision of Prof. Roger M. Enoka.
- He spent a 6-months period (from 16 November 2020 to 17 May 2021) as visiting research/student at the Lithuanian Sports University, under the supervision of Prof. Simona Pajaujiene.

Other academic activities

- During the PhD Program, the candidate Valerio Giustino was Tutor for didactic-integrative, preparatory and recovery activities in the biomechanics area (2020-2021).
- Furthermore, he was a classroom Tutor of the National TECO project for the evaluation of the Italian university system and research (2020-2021).
- Moreover, he was a member of the electoral commission for the election of the representatives of students enrolled in specialization courses and research doctorates for the academic two-year period 2021-2022.
- He participated at the European Researchers' Night (Sharper 2021).
- The PhD candidate participated at the Business Plan Competition 2020 of the Department of Psychology, Educational Science and Human Movement of the University of Palermo presenting the business project entitled “SIA: Sports Investment Agency. Winning business projects in sports”.

List of published articles

- Battaglia, G., Giustino, V., Tabacchi, G., Lanza, M., Schena, F., Biino, V., Giuriato, M., Gallotta, M.C., Guidetti, L., Baldari, C., Gennaro, A., Palma, A., Bellafiore, M. Interrelationship Between Age, Gender, and Weight Status on Motor Coordination in Italian Children and Early Adolescents Aged 6–13 Years Old (2021) Frontiers in Pediatrics, 9, 738294. DOI: 10.3389/fped.2021.738294

- Mazzo, M.R., Weinman, L.E., Giustino, V., Mclagan, B., Maldonado, J., Enoka, R.M. Changes in neural drive to calf muscles during steady submaximal contractions after repeated static stretches (2021) Journal of Physiology, 599 (18), pp. 4321-4336. DOI: 10.1113/JP281875

- Sanfilippo, V., Giustino, V., Mauro, G.L., Martines, F., Messina, G., Rizzo, S. Assessment and rehabilitation program in dizziness patients presenting vertebral fractures (2021) Dizziness: Prevalence, Risk Factors and Management, pp. 263-288.

- Messina, G., Giustino, V., Corrao, A., Rizzo, S., Salvago, P., Martines, F. Postural disorders in patients with dizziness: From postural analysis to vestibular rehabilitation programs (2021) Dizziness: Prevalence, Risk Factors and Management, pp. 229-245.

- Martines, F., Giustino, V., Dispenza, F., Galletti, F., Rizzo, S., Salvago, P., Messina, G. Body balance and postural control in patients with dizziness (2021) Dizziness: Prevalence, Risk Factors and Management, pp. 173-193.

- Amato, A., Messina, G., Giustino, V., Brusa, J., Brighina, F., Proia, P. A pilot study on non-invasive treatment of migraine: The self-myofascial release (2021) European Journal of Translational Myology, 31 (1), 9249. DOI: 10.4081/ejtm.2021.9646

- Scaturro, D., Rizzo, S., Sanfilippo, V., Giustino, V., Messina, G., Martines, F., Falco, V., Cuntrera, D., Moretti, A., Iolascon, G., Mauro, G.L. Effectiveness of rehabilitative intervention on pain, postural balance, and quality of life in women with multiple vertebral fragility fractures: A prospective cohort study (2021) Journal of Functional Morphology and Kinesiology, 6 (1), 24. DOI: 10.3390/jfmk6010024

- Gjaka, M., Feka, K., Bianco, A., Tishukaj, F., Giustino, V., Parroco, A.M., Palma, A., Battaglia, G. The effect of covid-19 lockdown measures on physical activity levels and sedentary behaviour in a relatively young population living in Kosovo (2021) Journal of Clinical Medicine, 10 (4), 763, pp. 1-15. DOI: 10.3390/jcm10040763

- Giustino, V., Messina, G., Alesi, M., La Mantia, L., Palma, A., Battaglia, G. Study of postural control and body balance in subjects with Down syndrome (2021) Human Movement, 22 (1), pp. 66-71. DOI: 10.5114/hm.2021.98466

- Di Stefano, V., Battaglia, G., Giustino, V., Gagliardo, A., D’Aleo, M., Giannini, O., Palma, A., Brighina, F. Significant reduction of physical activity in patients with neuromuscular disease during COVID-19 pandemic: the long-term consequences of quarantine (2021) Journal of Neurology, 268 (1), pp. 20-26. DOI: 10.1007/s00415-020-10064-6

- Petrigna, L., Giustino, V., Zangla, D., Aurea, S., Palma, R., Palma, A., Battaglia, G. Physical fitness assessment in Goalball: A scoping review of the literature (2020)

Heliyon, 6 (7), e04407. DOI: 10.1016/j.heliyon.2020.e04407

- Brusa, J., Maggio, M.C., Giustino, V., Thomas, E., Zangla, D., Iovane, A., Palma, A., Corsello, G., Messina, G., Bellafiore, M. Upper and lower limb strength and body posture in children with congenital hypothyroidism: An observational case-control study (2020) International Journal of Environmental Research and Public Health, 17 (13), 4830, pp. 1-10. DOI: 10.3390/ijerph17134830

- Giustino, V., Parroco, A.M., Gennaro, A., Musumeci, G., Palma, A., Battaglia, G. Physical activity levels and related energy expenditure during COVID-19 quarantine among the sicilian active population: A cross-sectional online survey study (2020) Sustainability (Switzerland), 12 (11), 4356. DOI: 10.3390/su12114356

- Brusa, J., Maggio, M.C., Zangla, D., Giustino, V., Thomas, E., Palma, R., Messina, G., Palma, A., Corsello, G., Bellafiore, M. Comparison of postural features and muscle strength between children with idiopathic short stature and healthy peers in relation to physical exercise (2020) Sustainability (Switzerland), 12 (9), 3639. DOI: 10.3390/su12093639

- Battaglia, G., Giustino, V., Messina, G., Faraone, M., Brusa, J., Bordonali, A., Barbagallo, M., Palma, A., Dominguez, L.-J. Walking in natural environments as geriatrician's recommendation for fall prevention: Preliminary outcomes from the 'passiata day' model (2020) Sustainability (Switzerland), 12 (7), 2684. DOI: 10.3390/su12072684

- Bonaventura, R.E., Giustino, V., Chiaramonte, G., Giustiniani, A., Smirni, D., Battaglia, G., Messina, G., Oliveri, M. Investigating prismatic adaptation effects in handgrip strength and in plantar pressure in healthy subjects (2020) Gait and Posture, 76, pp. 264-269. DOI: 10.1016/j.gaitpost.2019.12.022

- Russo, L., Giustino, V., Toscano, R.E., Secolo, G., Secolo, I., Iovane, A., Messina, G. Can tongue position and cervical ROM affect postural oscillations? A pilot and preliminary study (2020) Journal of Human Sport and Exercise, 15, pp. S840-S847. DOI: 10.14198/jhse.2020.15.Proc3.35

- Giustino, V., Russo, L., Toscano, R.E., Secolo, G., Secolo, I., Battaglia, G., Messina, G. A novel global postural alteration? Qualitative assessment of hallux valgus and swallowing disorder in human posture: A preliminary investigation on the incidence during age span for promoting psycho-physical and postural well-being (2020) Journal of Human Sport and Exercise, 15 (Proc3), pp. S833-S839. DOI: 10.14198/jhse.2020.15.Proc3.34

- Feka, K., Brusa, J., Cannata, R., Giustino, V., Bianco, A., Gjaka, M., Iovane, A., Palma, A., Messina, G. Is bodyweight affecting plantar pressure distribution in children? An observational study (2020) Medicine (United States), 99 (36), e21968. DOI: 10.1097/MD.0000000000021968

- Francavilla, V.C., Mingrino, O., Giustino, V., Iovane, A., Messina, G. Application of T-Thesys Therapy in post-operative recovery in knee-surgical interventions: A case study (2020) Journal of Human Sport and Exercise, 15 (Proc2), pp. S299-S307. DOI: 10.14198/jhse.2020.15.Proc2.21

- Messina, G., Francavilla, V.C., Giustino, V., Mingrino, O., Genovesi, F., Amato, A., Proia, P. Use of nutritional supplement to improve performance in professional soccer players: A case report (2020) Journal of Human Sport and Exercise, 15 (Proc2), pp. S289-S298. DOI: 10.14198/jhse.2020.15.Proc2.20

- Bianco, A., Ravalli, S., Maugeri, G., D'Agata, V., Vecchio, M., D'Amico, A.G., Pavone, V., Lucenti, L., Amato, A., Gentile, A., Giustino, V., Feka, K., Thomas, E., Musumeci, G. The "journal of Functional Morphology and Kinesiology" Journal club series: Highlights on recent papers in overtraining and exercise addiction (2019) Journal of Functional Morphology and Kinesiology, 4 (4). DOI: 10.3390/jfmk4040068

- Messina, G., Giustino, V., Martines, F., Rizzo, S., Pirino, A., Scoppa, F. Orofacial muscles activity in children with swallowing dysfunction and removable functional appliances (2019) European Journal of Translational Myology, 29 (3), pp. 246-250. DOI: 10.4081/ejtm.2019.8267

- Giustino, V., Lorusso, F., Rizzo, S., Salvago, P., Martines, F. Sudden sensorineural hearing loss (2019) Sensorineural Hearing Loss: Pathophysiology, Diagnosis and Treatment, pp. 207-216.

- Messina, G., Amato, A., Brighina, F., Monaco, A.L., Giustino, V., Brusa, J., Iovane, A., Proia, P. Lactate level and handgrip test in migraine and fibromyalgia after self-myofascial release treatment (2019) Journal of Human Sport and Exercise, 14 (Proc5), pp. S2019-S2025. DOI: 10.14198/jhse.2019.14.Proc5.23

- Feka, K., Pomara, F., Russo, G., Piccione, M.C., Petrucci, M., Giustino, V., Messina, G., Iovane, A., Palma, A., Bianco, A. How do sports affect static baropodometry? An observational study among women living in southern Italy (2019) Human Movement, 20 (1), pp. 9-16. DOI: 10.5114/hm.2019.78091

ACKNOWLEDGEMENTS

At the conclusion of this dissertation, and of this course, I would like to thank some people who are very dear to me.

To my beloved son, Giuseppe, who has brought immense happiness and joy into our lives. I dedicate this dissertation to you.

To my wife, Jessica, for always being there and constantly believing in me, more than I believed in myself.

To my parents, Giuseppe and Giovanna, for passing on tenacious principles of life such as commitment, dedication and the importance of knowledge.

To my brother, Giulio, with whom, bound by the principles that our parents have passed on to us, we give each other strength and courage.

To my colleague and friend Dr. Rosario Emanuele Bonaventura, with whom we shared the common interest of research by combining two different fields of research, sports science and neuroscience.

To all my PhD colleagues and to all the researchers I have collaborated with.

To the coordinator of the PhD Program, Prof. Massimiliano Oliveri, for allowing me to share relevant research experiences with him.

To my tutor, Prof. Giuseppe Battaglia, who gave me the opportunity to conduct numerous scientific researches.

To my co-tutor, Prof. Simona Pajaujiene, who provided me with useful advice for my academic growth.

To Prof. Roger Maro Enoka, who admitted me to his prestigious laboratory, a formative experience that I will carry throughout my life.

To a my academic reference point, Prof. Antonino Bianco, who has constantly transmitted

me new knowledge and clear academic advice for personal and research group growth.

To my mentor, Prof. Antonio Palma, the person who has always believed in me from the beginning.