University of Padova
Department of general psychology
Brain, Mind and Computer Science
Neuroscience, Technology, and Society
XXXV series

PhD Thesis

EXERCISE PROTOCOLS WITH UNSTABLE DEVICES TO ENHANCE THE EFFICIENCY OF NEUROMUSCULAR MECHANISMS IN POSTURAL CONTROL

Grant sponsor Ledragomma Original Pezzi S.r.l.

Director: Ch.mo Prof. Luciano Gamberini
Supervisor: Ch.mo Prof. Antonio Paoli
Co-Supervisor: Ch.mo Prof. Alessandro Beghi

PhD Student: Alex Rizzato

Academic year 2022/2023

Index

Chapter 1 9

Introduction 9

1.1 Posture and balance control 9

1.2 Unstable devices 11
1.2.1 Historical framework 11

1.3 State of the art of gymnastic balls in physical activity 13
1.3.1 Unstable devices in training programs 13

1.3.2 Unstable devices in everyday-living scenarios 14

1.4 Gaps in the current research 16
1.4.1 Objectifying the use of unstable devices in training protocols 16

1.4.2 Human-computer interaction and unstable devices 16

1.5 Project overall goals 17

Chapter 2 21

Different gymnastic balls affect postural balance rather than core-muscle activity 21

2.1 Introduction 21

2.2 Materials and methods 22
2.2.1 Subjects 22

2.2.2 Experimental design 23

2.2.3 Data Analysis 24

2.2.4 Statistical Analysis 25

2.3 Results 25
2.3.1 CoP-related parameters 25

2.3.2 EMG core-muscle activity 26

2.4 Discussion 28

2.5 Conclusions 30

Chapter 3 31

Balance control in young adults: relationship between the gymnastic ball size and subject's anthropometry 31

3.1 Introduction 31

3.2 Material and methods 32
3.2.1 Subjects 32

3.2.2 Unstable devices: gymnastic balls 33

3.2.3 Dynamometric platform 33

3.2.4 The optoelectronic system 34

3.2.5 Experimental protocol 34

3.3 Data analysis 36
3.3.1 Dynamic analysis 36

3.3.2 Kinematic analysis 36

3.3.3 Visual-Analog Scales 38

3.4 Statistical analysis 38

3.5 Results 39
3.5.1 Two-way ANOVA (3x2) for repeated measures 39

3.5.2 Independent T-test 48

3.6 Discussion 50

3.7 Conclusions 51

Chapter 4 53

Multimodal training protocols to face fall risk in older adults 53

4.1 Introduction 53
4.1.1 Physical activity protocols for fall-risk prevention 53

4.1.2 Aim of the study 54

4.2 Materials and method 55

4.2.1 Subjects 55

4.2.2 Experimental design 55

4.2.3 Assessments 56

4.2.4 Training protocol 59

4.3 Data analysis **63**

4.4 Statistical Analysis **64**

4.5 Results **65**

4.5.1 GPAQ *65*

4.5.2 Static balance test *65*

4.5.3 Dynamic balance test with RAMP perturbation *66*

4.5.4 Dynamic balance test with SINE-WAVE perturbation *68*

4.5.5 Maximal isometric lower-limb strength *69*

4.5.6 Handgrip test *70*

4.5.7 Timed up and go test *70*

4.5.8 10 meter-walking test *70*

4.6 Discussion **71**

4.7 Conclusions **73**

Chapter 5 75

Effectiveness and therapeutic compliance of digital therapy in shoulder rehabilitation: a randomized controlled trial 75

5.1 Introduction **75**

5.2 Methods **76**

5.2.1 Subjects *76*

5.2.2 Experimental design *76*

5.3 Functional assessments **77**

5.3.1 Mobility assessment *77*

5.3.2 Strength assessment *78*

5.4 Questionnaires **78**

5.4.1 Shoulder global health status *78*

5.4.2 Enjoyment *79*

5.4.3 Self-efficacy *79*

5.4.4 Attitude to train at home *79*

5.4.5 Intention to train at home *79*

5.4.6 Usability *80*

5.5 Therapeutic protocol **80**

5.5.1 Digital therapy *80*
4.5.2 Control therapy *81*

5.6 Statistic al analysis **82**

5.7 Results **82**

5.8 Discussion **84**

5.9 Conclusions **86**

Chapter 6 87

References 87

Appendix A 97

International visiting research project 97

Appendix B 105

Scopus indexed publications within the three-year PhD program 105

Abstract

Posture and balance control are essential to safely achieve daily living activities and motor tasks. Currently, gymnastic balls are the most used unstable devices to implement training and rehabilitation strategies in functional and proprioceptive training programs. Research supporting and objectifying the use of gymnastic balls or other unstable devices (e.g., balance discs, wobble boars) in training practice is few and contradictory. Hence, considering the state of the art and the variety of research regarding unstable devices and their use within the training programs, this three-year research project aimed to deepen the role of unstable devices in response to exercise by applying surface electromyography, kinematic, and kinetic analysis techniques. In detail, chapter 1 describes the current state of the art on the use of unstable devices in physical activity, summarizes their historical background and presents the aims of the three-year PhD project. Chapter 2 outlines the first experimental research that investigated the effect of three different gymnastic balls on balance and core-muscle activation while performing different physical exercises. Chapter 3 presents an anthropometric study on the sitting posture, to assess the manufacturer's guidelines rightness, based on the subject's height, for the choice of the most suitable gymnastic ball. Chapter 4 deepens the use of unstable devices on dynamic balance and lower limb strength exercises in older adults within a 3-month training protocol. In detail, we aimed to understand whether a training protocol with unstable devices could improve important indicators (i.e., strength and balance control) related to fall risk prevention compared to a training protocol with exercises performed on firm surfaces. Finally, chapter 5 deepens the application of a new-instrumented unstable device to understand whether a digital therapy gaming system could be more therapeutically relevant than traditional rehabilitation in shoulder pathology.

Chapter 1

Introduction

1.1 Posture and balance control

Posture and balance control are essential to safely achieve daily living activities and motor tasks in general (Paillard, 2017). Posture corresponds to the position of the different body segments in the space (Paillard, 2017). Namely, the habitual attitude of a person determined by the contraction of muscles interacting with the external environment. Balance is the ability to maintain the body's center of gravity (CoG), namely, the projection onto the ground of the center of mass (CoM) within the base of support to avoid falling (Paillard, 2017). The center of pressure (CoP) is the point where the total sum of a pressure field acts on a body, causing a force to act through that point. The CoP displacement, derived from force platforms, is a widely accepted measure to investigate static balance control. The displacement and the velocity of the CoP are the most-employed parameters to quantify the postural performance objectively.

Traditionally, literature differentiates between static and dynamic balance conditions. The static condition is referred to balance under unperturbed environments such as quiet standing (Macpherson and Horak, 2013), while the dynamic condition is connected to the ability of the subject to react efficiently to the base of support displacements or to external mechanical stimuli (Paillard, 2019). Therefore, automatic processes of postural control usually occur in static balance (i.e., balance under unperturbed environments such as quiet standing (Macpherson and Horak, 2013)), while cognitive processes are more connected to dynamic balance (i.e., the ability of the subject to react efficiently to the base of support displacements or external mechanical stimuli (Paillard, 2019)).

The human bipedal quiet stance has been modeled as a single inverted pendulum whose pivot is located at the ankles. In this model, the projection of the center of mass falls in front of the ankle (about 50-60 mm), creating a dorsiflexor moment around the ankle, which is continuously counteracted by the stabilizing effect of tonic muscles (Morasso et al., 2019). In addition, the less marked medio-lateral oscillations must be considered. Building up the upright body posture against gravity is an automatic process governed by the brainstem and spinal cord through postural reflexes with the person unaware of the muscular tone adjustments. These oscillations could be considered as a mostly automatic process of postural control since the subject is largely unaware of the adjustments of postural muscles (Takakusaki et al., 2017). Therefore, postural regulation mainly occurs at brainstem-spinal levels with neural circuits tuned by local loops of assistance or self-organized mechanisms due to the unperturbed and extremely predictable context (Lajoie et al., 1993). Conversely, adjusting body posture in goal-oriented tasks requires motor outputs arising from the cerebral cortex to the brainstem and spinal cord, thus calling into play cognition of self-body information (Takakusaki et al., 2017). Thus, a prevalence of the supra-spinal postural strategy is required due to the ongoing regulation of the movement for the adaptation to the new environment (Lajoie et al., 1993). Figure 1.1 shows that both automatic and cognitive processes of postural control are based on somatosensory, visual, and vestibular information that take action in different areas of the central nervous system, depending on the level of automatization of the motor process (Takakusaki et al., 2017).

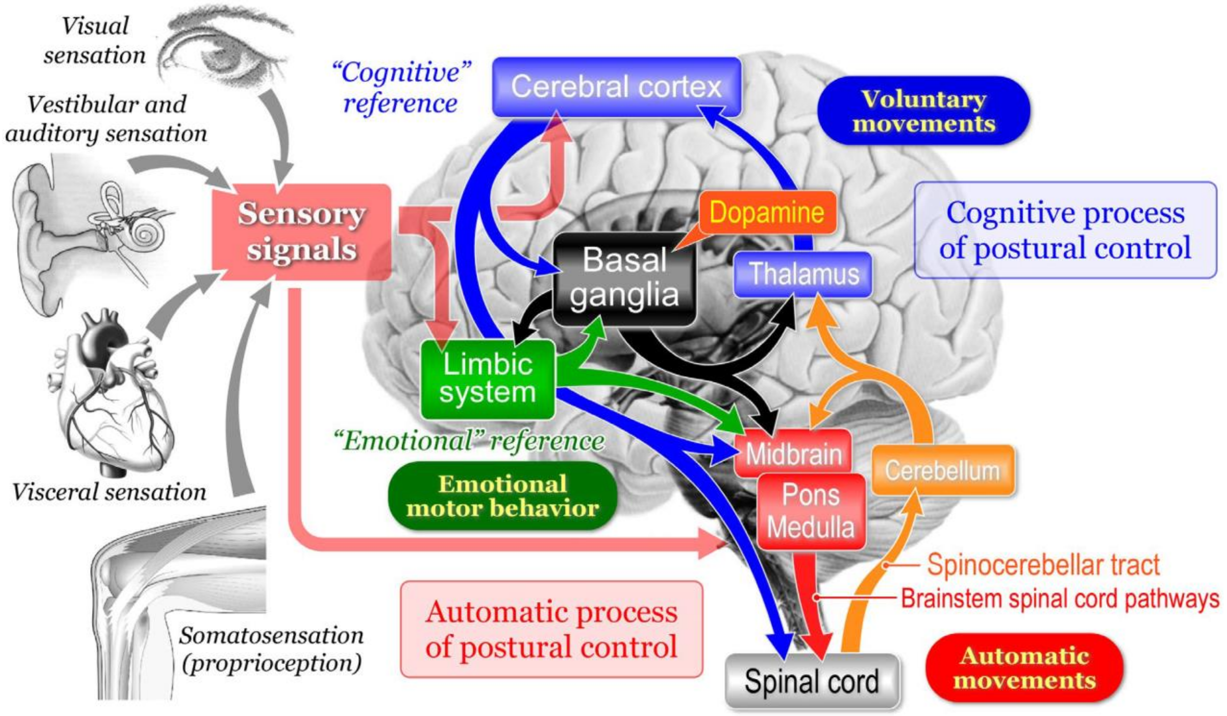


Figure 1.1. Basic signal flow involved in postural control (Takakusaki et al., 2017).

Multiple factors can influence postural balance control: aging, anthropometry, physiological, pathophysiological, and psychological status. In young and healthy subjects, physical activity is one of the main factors determining changes in balance ability. If acute sports activity can negatively influence postural control, a regular and long-term physical activity program may determine an increased balance performance (Paillard, 2017). Furthermore, the increase of balance performance could depend specifically on the type of physical activity practiced and the environment in which the activity is carried out. This can influence the plasticity of the brain areas that regulate postural functions, which undergo structural and functional adaptations that improve balance performance and postural control strategies (Paillard, 2017).

1.2 Unstable devices

Unstable devices have become a common tool in many physical activities, from athletic training to muscle strengthening, injury prevention to rehabilitation, and as an everyday comfortable chair to replace the standard office chair. In physiotherapy, unstable devices are used for injury rehabilitation and balance improvement. For instance, a recent review showed that physio balls, air cushions, balance pads, and wobble boards are appropriate supports to enhance balance during stroke rehabilitation (Van Criekinge et al., 2017). Indeed, while sitting on unstable devices, the injured patients can exercise slowly, simultaneously involving the nervous and musculoskeletal systems. Similarly, unstable devices are used in injury prevention programs. In detail, Willardson et al. showed that balance board and stability disc exercises, performed in conjunction with plyometric exercises, are recommended to improve proprioceptive and reactive capabilities, which may reduce the likelihood of lower extremity injuries (Willardson, 2007). Moreover, in specific holistic activities such as Yoga and Pilates, unstable devices are widely used as a base of support aimed at improving balance, strength, muscle flexibility, muscle tone, and coordination. Unstable devices are an excellent tool for stretching purposes, especially for people with specific necessities or difficulty lying on the floor (e.g., older adults or people with joint disorders). Additionally, unstable devices are used for general and personalized athletic training, and many coaches include unstable surfaces in their training routines in everyday and professional contexts. Indeed, compared with the control group, Behm and colleagues showed that unstable surface training improved muscle strength, power, and balance in adolescents, young adults, and old adults (Behm et al., 2015). Hence, unstable devices are considered ductile tools suitable for several application areas.

1.2.1 Historical framework

Gymnastic balls are unstable devices used to implement functional and proprioceptive training programs. Gymnastic ball's invention dates to 1968, when the Italian producers Aquilino Cosani and Domenico Dondé conceived a technique for producing large colored balls in vinyl instead of rubber, therefore more resistant to perforations and heavy loads. In 1971, the patent for the well-known exercise tool with a handle was filed, and the product was named Pon-Pon (figure 1.2).

Figure 1.2. Pon Pon on the title page of a 1969 catalogue *courtesy Ledragomma.*

The use of gymnastic balls for rehabilitation purposes began in Switzerland by Dr. Susanne Klein-Vogelbach. They were used as therapeutic complements to treatments for orthopedic and neurological disorders. Later, when the British physical therapist Mary Quinton discovered these devices while traveling in Bern - Switzerland, she included them in her pediatric care plans. She began to use gymnastic balls for rehabilitation of cerebral palsy in children to train their reflexes and balance ability (figure 1.3).

Figure 1.3. Mary Quinton during a rehabilitation session with gymnastic ball (Carrière, 1999).

Shortly after, these unstable devices began to be sold throughout Europe. The gymnastic balls spread more and more, even among the adult population suffering from orthopedic problems or other medical disorders, thanks to Dr. Susan Klein-Vogelbach, director of the Basel school of physiotherapy. In

1972, Maria Lucera, a professor at the physiotherapy school in Zurich from 1970 to 1988, expanded the technique after attending a course by Susan Vogelbach and published a book with 270 new exercises.

In the 1970s and 80s, gymnastic balls were rapidly introduced in the United States, where they were used to treat spinal cord injuries and other bone structure disorders. Over time, the gymnastic balls have been used in several fields: spinal stabilization, post-partum programs, or to refine somatic awareness in the Feldenkrais method. In 1991, with the great development of fitness in the sports field, the gymnastic ball was later adapted to this new activity and used in many different exercises for conditioning or prevention. Today it is more and more frequent to see them in gyms, rehabilitation centers, and hospitals. They are also employed in offices, and domestic settings, as surrogate of seats.

1.3 State of the art of gymnastic balls in physical activity

The presence of gymnastic balls or other unstable devices during training practice encompasses large sections of the population. Indeed, gymnastic balls are used for the improvement of athletic performance (Reed et al., 2012), recreational (Marshall and Murphy, 2005), and rehabilitation (Tsaklis et al., 2015) purposes, as well as for daily-living quality of life enhancement in people with specific necessities (Dunn et al., 2008; Marques et al., 2013a). Including gymnastic balls in strength and conditioning programs has become widespread among coaches and practitioners as well. More precisely, gymnastic balls have been proposed as an additional tool in conventional exercises to stimulate the neuro-muscular apparatus (Lehman et al., 2005b). The study of muscle activity through surface electromyography (EMG) during exercises performed on gymnastic balls is one of the most investigated topics in the scientific literature. Knowing the muscle activity during specific workouts is essential in the prescription and scheduling of training that aims to increase the intensity over time. Furthermore, performing exercises on unstable surfaces (i.e., gymnastic balls) may require a higher muscle activity.

1.3.1 Unstable devices in training programs

However, research supporting this assumption is few and contradictory. For instance, a significant higher muscle activity of trunk muscles was found when subjects performed crunches (Vera-Garcia et al., 2000) or upper body exercises (Behm et al., 2005) on a gymnastic ball and squats with feet on balance discs (Behm et al., 2002). Moreover, Lehman and colleagues studied the different muscle activity caused by the same exercise performed on the floor and an unstable surface (Lehman et al., 2005b). During the prone bridge exercise, the addition of a gymnastic ball resulted in increased myoelectric activity of the rectus abdominis and external oblique, with respect to its counterpart on the floor (Lehman et al., 2005b). A year later, the same research group investigated muscle activity in subjects during push-ups with feet or hands placed on a bench or on a Swiss ball. They found increased muscle activity of the triceps and rectus abdominis only when the hands were on the unstable surface (Lehman et al., 2006). However, some other studies showed inconsistency in EMG response with a non-statistically significant increase in muscle activity when comparing an exercise on or off an unstable surface (Lehman et al., 2005a; Chulvi-Medrano et al., 2010). In detail, there were non-statistically significant differences (i.e., rectus abdominus, external oblique, internal oblique, and erector spinae) when subjects performed upper body resistance exercises while seated on a stable and unstable surface (Lehman et al., 2005a). Chulvi-Medrano et al. observed a higher force production and muscle activity when deadlifts were performed on a stable surface (Chulvi-Medrano et al., 2010). These findings raise the question of whether these unstable devices may be helpful in strength and conditioning training protocols.

A different research line studied the application of these devices to increase dynamic balance and proprioception for injury treatment or prevention (Handoll et al., 2001; Kidgell et al., 2007; Behm and Colado, 2012a; Steinberg et al., 2019). Current research indicates that proprioceptive loss can occur with functional instability following an injury and may be the major factor in the high recurrence rate of an injury (Kidgell et al., 2007). For instance, Steinberg and colleagues showed that three weeks of balance board training improved the ankle discrimination ability of ballet dancers regardless of their reported chronic ankle instability. Moreover, following three weeks of balance board training, previously injured dancers significantly improved their ankle discrimination acuity scores (Steinberg et al., 2019). Similarly, Verhagen and colleagues found a significant reduction in ankle sprain risk only for volleyball players with a history of ankle sprains after a proprioceptive balance board program (Verhagen et al., 2004). Therefore, training the neuromuscular system through balance activities on unstable surfaces is a method highly integrative and demanding for injury treatment or prevention (Kidgell et al., 2007).

1.3.2 Unstable devices in everyday-living scenarios

Several information channels frequently suggest gymnastic ball sitting (at work, home, libraries, and in many other environments), not always with scientific awareness (Lowe et al., 2015). Sitting on gymnastic balls, does not provide a stable base of support and thus may require a higher commitment to maintaining the body posture on top (Hildenbrand and Noble, 2004). Subjects are constantly constrained to fine balance adjustments to maintain their posture (Rizzato et al., 2021). Thus, to preserve an adequate upright posture while sitting on the gymnastic ball, subjects should increase muscles' activity and experience increased heart rate, with a consequent higher metabolic rate (O'Sullivan et al., 2002; Haller et al., 2006). In this regard, Haller (Haller et al., 2006) demonstrated that energy expenditure (EE) was significantly higher (5.6%) while sitting on a gymnastic ball than on a standard chair. Similarly, in a later study it was found a higher EE (6%) when working on the gymnastic ball than sitting on the standard chair. EE registered in subjects seated on the gymnastic ball was also very similar to that observed during the standing position (Beers et al., 2008). These EE increments produced an estimated additional 32 kcal/day considering a full-time working day (Tudor-Locke et al., 2014). As aforementioned, even though small, this extra amount of EE could successfully influence weight gain prevention (Hill et al., 2012). Although gymnastic ball application needs further insights to deepen its role on EE, other aspects of "active sitting" must be acknowledged. For instance, workplace gymnastic ball employment could improve posture and muscle activity (Schult et al., 2013). However, there are still controversial results in the scientific literature on this topic.

Gregory and colleagues investigated trunk muscle activity and body posture, comparing a standard office chair to a gymnastic ball. Among the registered muscles (i.e., thoracic and lumbar erector spinae, rectus abdominis, and external oblique), only the thoracic erector spinae increased its activity (Gregory et al., 2006). Similarly, Kingma and colleagues (Kingma and van Dieën, 2009) found greater trunk motion (33%) and variation in lumbar electromyography activity (66%) in subjects seated on a gymnastic ball compared to an office chair. On the same topic, other authors showed no difference in trunk muscle activity when users sat on a gymnastic ball compared to a stable stool (McGill et al., 2006). Even though some authors showed an increased self-perceived posture (Schult et al., 2013), long-term use of gymnastic balls could be unproductive if accompanied by discomfort (Lehman et al., 2006; McGill et al., 2006; Kingma and van Dieën, 2009). Other researchers suggested that trunk muscle strength could positively influence the experienced discomfort, often related to low back pain (Lee et al., 1995; Ashmen et al., 1996). However, it is hard to infer if an increase in muscle strength could be due to the working use of the gymnastic ball. Finally, workers can quickly adopt gymnastic balls to obtain small behavioral changes and reduce negative sedentary behaviors. However, understanding whether the advantages of using a gymnastic ball may offset the disadvantages is still an open question, especially over long periods.

1.4 Gaps in the current research

1.4.1 Objectifying the use of unstable devices in training protocols

When prescribing exercise for any goal, one of the most important principles is the adaptation of the exercise programs to the individual. Thus, many companies projected exercise tools that can fit the needs of the individual and his/her level of ability. For instance, TheraBand® represents an example of this concept: the company produces multipurpose devices in which eight color-coded levels can be distinguished. Each color corresponds to a specific level of resistance. Exercise intensity is typically prescribed using this color code (Uchida et al., 2016). Similarly, gymnastic balls (as other unstable devices) exist with different shapes or diameters to respond to the subject's specific necessities. As aforementioned, most of the scientific literature studies focused on comparing muscle activity when an exercise is performed on or off an unstable surface. However, despite their employment in daily practice, no studies objectively quantified the effect of their shapes or diameter on core muscle activity, body posture, and Centre of pressure (CoP) trajectory. Indeed, a larger gymnastic ball has a higher bearing surface on the floor. Equally, the subject has a higher bearing surface while performing an exercise on it. An expected advance to the discipline is to objectify how different unstable devices (e.g., diameter or shapes) can influence the exercise execution, core muscle activity, or CoP displacements.

1.4.2 Human-computer interaction and unstable devices

Human activity recognition through wearable sensors (e.g., inertial movement units) has been extensively explored throughout the last twenty years (Bao and Intille, 2004; Ermes et al., 2008). Moreover, the latest mobile phones and ever-growing computing, networking, and sensing powers have changed people's habits (Xing Su et al., 2014). Nowadays, real-time user-independent human activity recognition is a growing technology that many companies support (Siirtola and Röning, 2012). It represents a focal core in most areas of society, including health and fitness monitoring. The application of interactive gaming and virtual reality is becoming progressively accepted to gain motivating and addictive settings that can increase the effectiveness of a therapeutic protocol (Dennett and Taylor, 2015). For instance, many medical centers in different countries chose Nintendo Wii as a rehabilitative device. In Australia, 61% of medical centers for urban stroke are registered to own a console (Taylor et al., 2011). However, since computer-based devices for rehabilitation are many, no one has ever applied sensors in existing tools such as gymnastic balls. Motion sensors, such as accelerometers, can represent a cheap technology easily associable with every person's devices, such as smartphones or tablets. Therefore, low-cost technologies associated to gymnastic balls (or other unstable devices) could represent the expected advance in the discipline when applied to rehabilitation or fitness. If it was the case, it could represent a valuable option or complement to improve training protocols making them more efficient and enjoyable.

1.5 Project overall goals

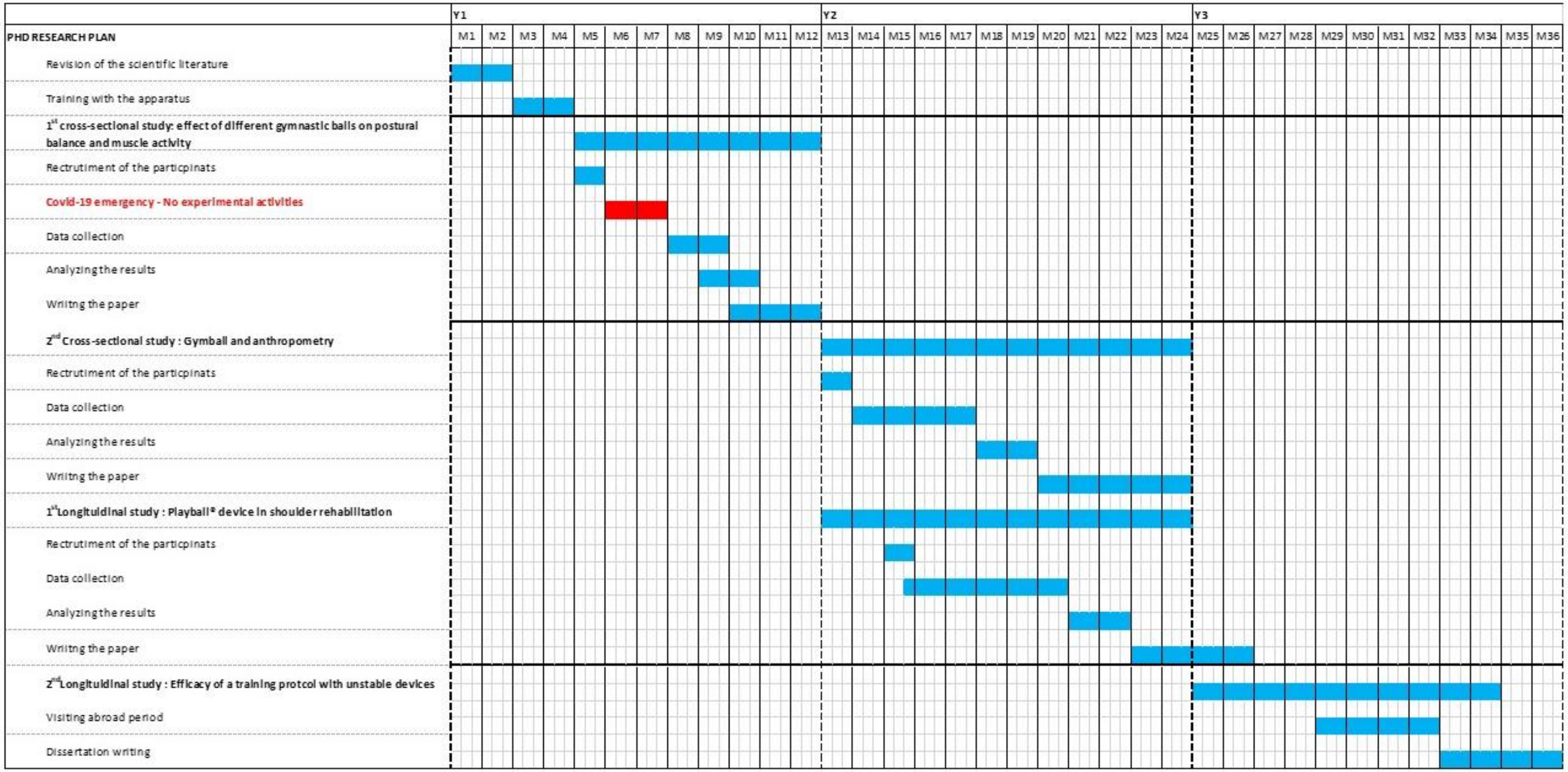
Hence, considering the state of the art and the variety of research regarding the unstable devices and their employment within the training programs, this project aimed to answer questions and gaps in the current research and to point out openings for future investigation in the field. In detail, by applying techniques such as surface EMG, kinematic and kinetic analysis, this project firstly aimed to deepen the role of the unstable devices in response to exercise considering postural and neuro-muscular parameters.

- In the first year, after revising the literature, this three-year project investigated whether three gymnastic balls different in size and shape could affect the CoP-related parameters (i.e., Area 95 and mean velocity) when the same exercise was performed. Moreover, we analyzed how core muscle activity responded to the destabilization of the different gymnastic balls during the same exercise execution.
- Later, in the second year, considering the guidelines for using the different gymnastic balls in relation to subjects' anthropometrics we studied whether: (i) subjects of the same height range could assume the same posture (i.e., kinematic parameters) while seated on the gymnastic ball; (ii) subjects could receive the same destabilization (i.e., CoP displacement) while seated on the gymnastic ball.
- Finally, in the third year, we investigated the efficacy of the unstable devices on dynamic balance and lower limb strength within a 3-month training protocol in older adults. We aimed to understand whether a training protocol with unstable devices, compared to training in stable conditions, could improve important indicators (i.e., strength and balance) for fall risk prevention.

Then, considering the growing number of technological tools in fitness and rehabilitation, we deepened the application of instrumented unstable devices in human-computer interaction contexts. Therefore, across the second year of the PhD program, this study aimed to evaluate an existing physiotherapy tool (PlayBall$^{®}$ Playwork, Alon 10, Ness Ziona, Israel) as a sensorized exercise ball that allows patients to complete rehabilitation games and receive real-time visual feedback.

- The objectives of this study were: (i) to evaluate whether a novel digital therapy gaming system was therapeutically relevant during shoulder rehabilitation; (ii) to understand whether PlayBall® was effective in improving patients' engagement in comparison to a control non-gaming rehabilitation program.

On next page, figure 1.4 summarizes the detailed three-year timeline research plan of the PhD program.



	Y1												Y2												Y3											
PHD RESEARCH PLAN	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36
Revision of the scientific literature	🟦	🟦																																		
Training with the apparatus			🟦	🟦																																
1st cross-sectional study: effect of different gymnastic balls on postural balance and muscle activity					🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																								
Rectrutiment of the particpinats					🟦																															
Covid-19 emergency - No experimental activities						🟥	🟥																													
Data collection								🟦	🟦																											
Analyzing the results									🟦	🟦																										
Writng the paper										🟦	🟦	🟦																								
2nd Cross-sectional study : Gymball and anthropometry													🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦												
Rectrutiment of the particpinats													🟦																							
Data collection														🟦	🟦	🟦	🟦																			
Analyzing the results																		🟦	🟦																	
Writng the paper																				🟦	🟦	🟦	🟦	🟦												
1st Longituidinal study : Playball® device in shoulder rehabilitation													🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦												
Rectrutiment of the particpinats															🟦																					
Data collection															🟦	🟦	🟦	🟦	🟦	🟦																
Analyzing the results																					🟦	🟦														
Writng the paper																							🟦	🟦	🟦	🟦										
2nd Longituidinal study : Efficacy of a training protcol with unstable devices																									🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
Visiting abroad period																													🟦	🟦	🟦	🟦				
Dissertation writing																																	🟦	🟦	🟦	🟦

Figure 1.4. Three-year research plan.

Chapter 2

Different gymnastic balls affect postural balance rather than core-muscle activity

Research n. 1. Rizzato, A., Paoli, A., and Marcolin, G. (2021). Different gymnastic balls affect postural balance rather than core-muscle activation: A preliminary study. *Appl. Sci.* 11. doi:10.3390/app11031337.

2.1 Introduction

Visual, vestibular, and somatosensory systems interact together to control human postural stability by sending information that is subsequently processed by the central nervous system. Response messages are then sent to the skeletal muscle system, guaranteeing the efficiency of both static and dynamic postural balance (Nardone et al., 2010; Paillard, 2017). In the static condition, balance performance is related to minimizing body sway while assuming conventional body postures (Paillard, 2019), with or without a reduced base of support (Paillard and Noé, 2015). Conversely, dynamic balance is defined as the subject's ability to react efficiently to the base of support displacements (Paillard, 2019). Both in static and dynamic conditions, the goal is to avoid postural imbalance and a potential fall. Likewise, in sport, a reduced postural balance control is one of the limiting factors of the performance, and it is associated with the risk of injuries (Zemková, 2014). Therefore, all strategies aiming to maximize the sensory-motor systems' efficiency or reduce their age-dependent deterioration induce positive functional adaptations to the postural balance control both in daily-living and sport context (Paillard, 2017). Among these strategies, proprioceptive and functional training with the employment of unstable devices such as gymnastic balls is a widespread practice in professional (Reed et al., 2012), recreational (Marshall and Murphy 2005), and rehabilitation (Marques et al., 2013; Tsaklis et al., 2015) contexts. The rationale of this training modality is to increase the postural control systems' commitment and muscle activity to counterbalance the multidirectional perturbations caused by unstable devices. Methodologically, to assess the amount of destabilization during this kind of exercises, available scientific literature identified two instruments: the force platform that quantifies the center of pressure (COP) displacements (Dunn et al., 2008; Vera-Garcia et al., 2020) and the surface electromyography to assess the core-muscle activity (Lehman et al., 2005b, 2005a). More in detail, Vera-Garcia and colleagues studied different core stability-exercises measuring the COP mean velocity during their execution. Their study gave useful information for the prescription of exercises of increasing difficulty based on the assumption that the higher the COP mean velocity, the more destabilizing the exercise (Vera-Garcia et al., 2020). Similarly, Dunn and colleagues documented significant improvements in seniors' COP-related parameter scores after running a Fitball exercise program (Dunn et al., 2008). Also, Ogaya and colleagues found in a group of 23 older adults an improvement of COP-related parameters after attending a balance training program using wobble boards (Ogaya et al., 2011). Unlike the COP-related parameters, core-muscle activity seems to show controversial responses to the destabilizing exercises. For instance, no effects on core-muscle activity were detected performing upper body strength exercises while sitting on a labile rather than stable surface (Lehman et al., 2005a). Even, Chulvi-Medrano and colleagues observed higher paraspinal muscle activity performing deadlifts with feet on a stable surface with respect to the unstable counterpart (Chulvi-Medrano et al., 2010). Conversely, it was observed an increased activity of the rectus abdominis and external oblique muscles during prone bridge with feet on a Swiss ball compared to a stable surface (Lehman et al., 2005b). These previous investigations focused on the destabilization produced by unstable devices compared to stable conditions. Nevertheless, this approach lacks to consider two variables that could modulate the amount of destabilization induced by an exercise: the size and the shape of the unstable devices employed. Indeed, the surface of the ball in contact with the ground could depend on these two variables influencing the destabilization level. Therefore, the aim of the present study was twofold. Firstly, we aimed to investigate whether three gymnastic balls different in size and shape could affect the COP-related parameters of the same exercise. Secondly, we investigated how specific muscles involved in core stabilization responded to the destabilization produced by the gymnastic balls.

2.2 Materials and methods

2.2.1 Subjects

Eleven active and healthy subjects volunteered for the study (all males; mean ± SD: 22 ± 1.09 years; 77.36 ± 10.63 kg; 1.81 ± 0.052 m). Subjects with no history of (i) orthopedic injuries in the last year, (ii) neurological diseases, and (iii) sight, hearing, or vestibular disorders were eligible for inclusion. All the subjects gave their written informed consent and were free to renounce the study at any time. Data collection started in January but due to the COVID-19 emergency, it was suspended until May 2020. Data collection ended in July 2020.

2.2.2 Experimental design

The experimental protocol adhered to the Declaration of Helsinki principles and was approved by the department institutional review board. All the subjects were informed about the aims of the study and the methods adopted.

We outlined a cross-sectional design (figure 2.1) in which three different gymnastic balls were tested (Ledragomma Srl, Osoppo, Italy). Two out of three gymnastic balls were spherical with a diameter of 53 (Gym 53) and 65 (Gym 65) centimeters, respectively (Fig. 1A). The third one had an ovoid shape with a diameter of 65 centimeters (Eggball, Fig. 1A). All the gymnastic balls have been inflated until they reached the circumference reported in the manufacturer's guidelines. All the gymnastic balls were employed in three different experimental conditions: bipedal seated (BS), unipedal seated (US), and during a dynamic exercise involving both upper and lower limbs (EX).

The postural balance control was assessed through a computerized force platform (AMTI BP400600, USA), recording the CoP trajectory at a sampling frequency of 100Hz (Fig. 1B). The force platform systems had the following characteristics: average COP accuracy of just a fraction of a millimeter (typically less than 0.2); crosstalk values typically ± 0.05% of applied load; measurement accuracy typically ± 0.1% of applied load (minimum applied load of 22.6 kg). Then, the signal was analyzed with the software Balance Clinic 1.4.2. Core-muscle activity was recorded with a BTS FREEEMG (BTS Bioengineering, Milan, Italy). Device resolution was 16 bit and the sampling frequency was set to 1 kHz. Muscles analyzed were the rectus abdominis (RA), the abdominal external oblique (EO), and erector spinae (ES) of both the right and left sides of each participant (Fig. 1B). Ag/AgCl pre-gelled electrodes were applied with an inter-electrode distance of 24 mm. Skin preparation, sensor location, and orientation on the muscle bellies following previous studies (Ng et al., 1998; Boccia and Rainoldi, 2014). The three experimental conditions are sketched in Fig. 1C. Before recording the trials all the subjects familiarized with the tasks to perform on the gymnastic balls. In the BS condition, the barefooted subjects were instructed to sit on the gymnastic ball with hands naturally resting on their knees and the trunk in an upright position. Both feet were placed on the force platform. In the US condition, the barefooted subjects were instructed to sit on the gymnastic ball with hands naturally resting on their knees and the trunk in an upright position. The non-dominant lower limb was raised parallel to the ground with the knee fully extended. In the EX condition, the barefooted subjects, starting from a seated position, were asked to perform alternate leg extensions and sidearm lateral raises gripping two 1-kg kettlebells. The velocity of both leg extensions and arm lateral raises was standardized setting a metronome at 50 beats per minute. The support surface on the force platform has been enlarged using a wooden board (1.5 x 0.8 m) to allow both the feet and the gymnastic ball allocation. The distance between the feet and the gymnastic balls' posterior margin was standardized to the length of the right lower limb of the subjects measured from the anterior superior iliac spine and the ankle's medial malleolus. Subjects were instructed to gaze at a thin line vertically placed on a white wall in front of them, at 0.8 m. For each experimental condition, three trials lasting 30 seconds were performed with opened eyes.

Figure 2.1. Experimental design of the cross-sectional study. (A) Gymnastic balls employed in the experimental trials; (B) details of the force platform and sensor location on the left and experimental setup on the right; (C) visual representation of the tasks performed by subjects. From left to right: bipedal seated (BS), unipedal seated (US), and dynamic exercise (EX).

2.2.3 Data Analysis

For all the experimental conditions, we calculated the following parameters derived from the CoP trajectory: Area95 (the area of the 95th percentile ellipse measured in cm^2) and Unit Path (the path length per unit time, i.e., the average velocity measured in cm/s). The platform was calibrated according to the manufacturer's guidelines before the recording of each trial. In each condition, CoP parameters were averaged among the three trials. For what concerns the core-muscle activity, the root mean square (RMS) of the EMG interference signals was calculated for each muscle (both sides) and averaged among the three trials. A mean between the left and right mean activity of each muscle was then computed, and finally, a global index of the level of core muscle activity was calculated by summing the means of the three muscles' EMG signals.

2.2.4 Statistical Analysis

Data collected passed the D'Agostino-Pearson test for normality distribution check. Thus, the possible main effect of the device (i.e. Gym 53, Gym 65, and Eggball) or body posture (i.e. BS and US) were investigated performing a two-way ANOVA for repeated measures for both COP and EMG variables. When F-value showed main effects or interactions, a Bonferroni post-hoc analysis was carried out for pair-wise comparisons. Moreover, one-way ANOVA for repeated measures was performed to investigate the effect of the three different gymnastic balls on COP and EMG variables in the EX condition. Data were processed with the software packages JASP for Windows (Version 0.11.1, Amsterdam) and presented as mean ± standard deviation (SD). The significant level for differences was set to $p < 0.05$.

2.3 Results

2.3.1 CoP-related parameters

Figures 2.2A and 2.2B show the Unit Path and Area95 results, respectively. The two-way ANOVA analysis showed a significant main effect of the device ($p<0.001$; $\eta_p^2 = 0.621$) and body posture ($p<0.001$; $\eta_p^2 = 0.816$) for the Unit Path parameter. Bonferroni post-hoc analysis revealed significantly lower ($p< 0.01$) values for the Eggball (BS: 3.097 ± 0.527 cm/s; US: 4.313 ± 0.843 cm/s) with respect to Gym53 (BS: 3.678 ± 0.457 cm/s; US: 5.247 ± 0.732 cm/s) and Gym65 (BS: 3.122 ± 0.418 cm/s; US: 5.340 ± 0.896 cm/s). Furthermore, the two-way ANOVA analysis showed a significant main effect of the device ($p<0.001$; $\eta_p^2 = 0.652$) and body posture ($p<0.001$; $\eta_p^2 = 0.887$) for the Area95 parameter. Bonferroni post-hoc analysis revealed significantly lower ($p< 0.001$) values for the Eggball (BS: 0.473 ± 0.189 cm^2; US: 3.049 ± 1.329 cm^2) with respect to Gym53 (BS: 0.674 ± 0.180 cm^2; US: 4.857 ± 1.938 cm^2) and Gym65 (BS: 0.682 ± 0.280 cm^2; US: 5.695 ± 1.964 cm^2). Table 1 shows the one-way ANOVA results for the Area95 ($p<0.001$; $\eta_p^2 = 0.494$), Unit Path ($p<0.001$; $\eta_p^2 = 0.516$) in the EX condition. Post-hoc analysis showed a statistically significant difference ($p < 0.001$) between Gym53 and Gym65 for the Area95. Moreover, significant higher values of the Unit Path were detected in the Gym65 condition with respect to Eggball ($p< 0.01$) and Gym53 ($p< 0.01$).

	Gym53	Gym65	Eggball
Area95 (cm^2)	31.86 ± 13.24	45.86 ± 15.47 #	37.68 ± 17.43
Unit Path (cm/s)	10.44 ± 1.58 §	11.91 ± 1.91	10.68 ± 2.24 $
EMG (μV)	61.77 ± 45.41	60.76 ± 48.41	54.11 ± 31.89

Table 2.1. One-way ANOVA results of the postural balance and EMG parameters for Gym53, Gym65 and Eggball during the EX condition. Data are presented as mean ± standard deviation. # Significantly different from Gym65 ($p < 0.001$); $ significantly different from Gym65 ($p < 0.01$); § significantly different from Gym65 ($p < 0.01$).

2.3.2 EMG core-muscle activity

Figure 2.2C shows the results of core-muscle activity. A significant main effect was found for the body posture ($p<0.01$; $\eta_p^2 = 0.561$). Namely, significantly higher EMG values were observed for US (gym53: 38.485 ± 12.853 μV; gym65: 36.310 ± 10.611 μV; Eggball: 38.635 ± 12.599 μV) with respect to BS (gym53: 29.749 ± 10.552 μV; gym65: 28.875 ± 9.320 μV; Eggball: 28.969 ± 6.492 μV). No differences were detected comparing the different gymnastic balls. In the EX condition no statistically significant differences were detected for the core-muscle activity ($p>0.05$).

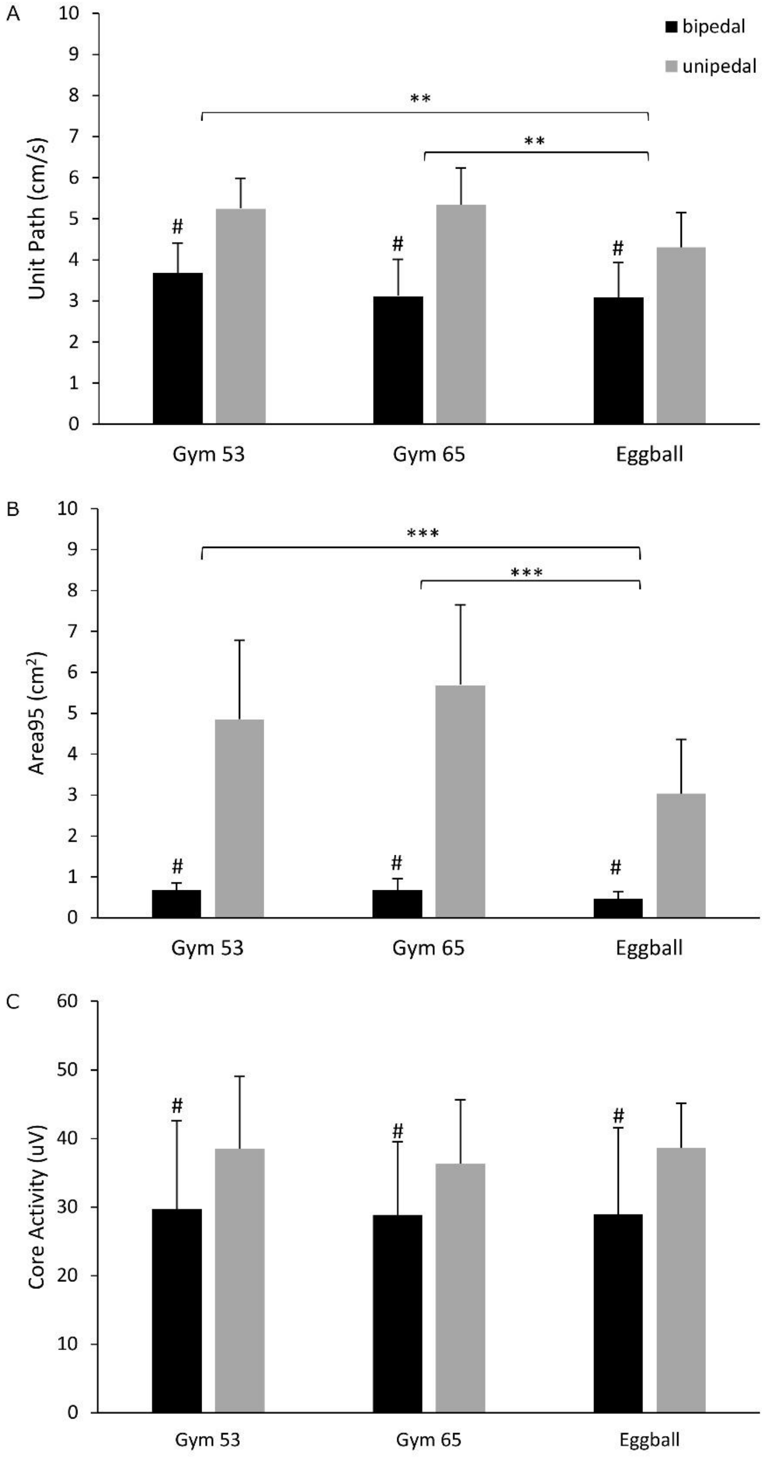


Figure 2.2. Two-way ANOVA results comparing the different gymnastic balls under BS and US posture. Data are presented as mean ± standard deviation. (A) Unit Path results; ** significantly different from Eggball ($p < 0.01$), #significantly different from US posture ($p < 0.001$). (B) Area95 results; *** significantly different from Eggball ($p < 0.01$), #significantly different from US posture ($p < 0.001$). (C) Muscle-core activity results; #significantly different from US posture ($p < 0.01$).

2.4 Discussion

With the current interest in core-stability and postural balance, a broad of unstable devices and exercises are emerging in the field of functional training (Behm and Colado, 2012b; Powell and Williams, 2015). However, the destabilizing effect produced by different unstable devices on the same exercise is lacking objectivation. Therefore, the main purpose of this study was to investigate whether three gymnastic balls different in shape and size could influence CoP-related parameters and core-muscle activity under the same postural condition or exercise. Indeed, understanding the effects of different unstable devices on the same postural condition allows modulating better training progression over time.

COP-related parameters resulted in being more sensitive than core-muscle activity to assess the destabilization level induced by the three gymnastic balls. Both Unit Path and Area95 highlighted a significantly higher instability when the postural task was performed on the Gym53 and Gym65 with respect to the Eggball. We suppose that the ovoid shape of the Eggball could have minimized the multidirectional displacements that subjects suffered while maintaining postures in Gym53 and Gym65. Basing on the assumption that the higher the COP mean velocity, the more destabilizing the exercise (Vera-Garcia et al., 2020), our findings gave practical information for the development of training protocols of increasing difficulty focusing not only on the type of exercise but also on the device to employ. Namely, in our case, the employment of the Eggball in the early stages of a rehabilitation training rather than the Gym53 or the Gym65.

Also, the postural balance control showed greater CoP displacements and velocity under the US with respect to the BS posture. A widely accepted assumption is that biomechanically the degree of stability is proportional to the size of the base of support, and it is maximized in any direction when the line of gravity is furthest inside the edge of the base of support (Riach and Starkes, 1993). In our case, the feet on the ground and the ball on which the subject was seated established the base of support. During US posture, the non-dominant lower limb was raised, leading to the base of support restriction. Thus, Unit Path and Area95 results confirmed the abovementioned assumption when unstable devices contributed to determining the base of support.

Our results showed non-significant differences between the three gymnastic balls (i.e., Gym53, Gym65, and Eggball) on the core-muscle activity under the same body posture (i.e., BS and US). Thus, core-muscle activity was independent from the shape and size of the gymnastic ball used. The easy postural task proposed with a foothold always on the stable ground could have accounted for the unchanged core-muscle activity. Otherwise, we can speculate that core muscles equally contributed to the trunk stabilization while concurrent muscle co-activations could have happened to face the different perturbations induced by the balls. Specifically, global and local muscles (e.g., lower limbs and spinal muscles) could have counterbalanced the body sway induced by the gymnastic balls. Researchers contended that data on activity of core muscles during tasks performed on unstable surfaces (Vera-Garcia et al., 2000) or in the seated position in addition to standing (Saeterbakken and Fimland, 2012) are needed. As far as we are concerned, our study is the first to investigate muscle activity while performing the same exercise with different gymnastic balls. Indeed, previous studies focused on the effect of core-muscle activity in different exercises or comparing labile versus stable surfaces (Vera-Garcia et al., 2000; Chulvi-Medrano et al., 2010). The significantly different activity of core-muscle between BS and US condition we found is in line with previous findings (Calatayud et al., 2015). Even though the muscles assessed were different (lumbar multifidus spinae, thoracic multifidus spinae, lumbar erector spinae, thoracic erector spinae, and gluteus maximus), Calatayud et al. found a greater global mean muscle activity in single-leg stance vs. two-leg stance, while subjects were sitting on an exercise ball (Calatayud et al., 2015). This suggested that progressive postural control disruption might involve an increment amount of core muscle activity rather than the employment of gymnastic balls of different shapes and sizes.

Finally, the EX condition deserves to be discussed separately because of the voluntary and ongoing movements performed on the gymnastic balls with upper and lower limbs. If the core-muscle activity reflected the behavior detected in the body postures from one side, the COP-related parameters did not totally confirm the same trend. Indeed, in the EX condition, the Eggball presented similar Unit Path and Area95 values compared to Gym53 and Gym65. An explanation of these differences could be that in the EX condition, the balance response was more influenced by the subjects' active movements rather than by the device itself. In this regard, it has been suggested that rhythmic ongoing movements could induce a delay or an attenuated balance response reflecting a limitation of the central nervous system in processing multiple sensory stimuli (Quant et al., 2001). Similarly, the sensory discharge from lower-limb activity could attenuate sensory stimuli (visual, somatosensory, or vestibular inputs) that convey sensations of whole-body instability (Brooke et al., 1997). A further explanation could be the higher competition in cognitive processes due to continuous changes in the surrounding environments, acting forces, and sensory inputs (Takakusaki et al., 2017). In the EX condition, subjects had to simultaneously perform voluntary movements to maintain balance on the gymnastic balls. Indeed, these two actions competed for the same control mechanisms (Takakusaki et al., 2017). These abovementioned theories could explain the different behavior observed under the EX condition, where the continuous changes imposed by the voluntary movements could have unpredictably affected the postural balance control. This preliminary study has some potential limitations to be acknowledged. Certainly, a larger and more heterogeneous sample size, is needed to test the extendibility of our findings to a vaster population. Then, we only considered core-muscle activity. The inclusion of thigh and shank muscles could have contributed to the understanding of the whole body mechanisms adopted to counteract the different destabilizations imposed by the three gymnastic balls.

2.5 Conclusions

The COP-related parameters demonstrated that the shapes and sizes of the three gymnastic balls produced a different degree of destabilization under the same body posture but let unaltered the core-muscle activity. Thus, besides the exercise prescription, trainers and therapists should objectively focus on choosing the most suitable device to modulate the difficulty of the postural exercises. Conversely, the employment of unstable devices in a dynamic exercise was not determinant in producing specific destabilizing effects. Although further investigations are needed, distinct shapes and sizes of gymnastic balls seem to be more effective in generating different destabilizing stimuli assuming static body postures rather than performing dynamic exercises.

Chapter 3

Balance control in young adults: relationship between the gymnastic ball size and subject's anthropometry

3.1 Introduction

Balance training is part of several different rehabilitation and sports contexts. To this purpose, many tools (e.g., gymnastic balls, balance discs) are used within training programs to induce unexpected multidirectional perturbations. Indeed, subjects, while exercising, must counterbalance the random-induced perturbations through their postural control system and, more precisely, activating their core and lower limb muscles (Borghuis et al.; Gouttebarge and Zuidema, 2018; Khaiyat and Norris, 2018; Słomka et al., 2018). Core stability exercises stimulate the ability of the motor system to maintain or restore the trunk position under internal or external perturbations such those induced by the unstable devices (Zazulak et al., 2008; Vera-Garcia et al., 2015). Moreover, core muscle activity contributes to safeguard the spine from possible compressive forces and wrong postures (Axler and McGill, 1997; Kavcic et al., 2004). However, the most common core stability exercises are usually administered on personal criteria rather than objective parameters.

For instance, a study by Vera-Garcia and colleagues (Vera-Garcia et al., 2020) suggested an intensity progression of the most common core stability exercises: front bridge, back bridge, side-bridge, and bird-dog. In detail, seventy-six participants (M= 48; F= 28) performed the established core-stability exercises, while the COP displacement was measured to determine the exercise intensity and the consequent difficulty progression. The results showed a greater CoP trajectory, and thus higher oscillation, in exercises where the body was in total length position (i.e., long-bridge vs. short- bridge exercise). Moreover, one-supporting leg exercises resulted more difficult compared to two-supporting legs on the ground. Finally, the presence of an unstable device led to greater difficulty in both monopodalic and bipodalic exercises compared to the same exercise performed on a firm surface. Therefore, the unstable surface compared to a firm surface increased the difficulty in maintaining balance while performing a core-stability exercise. Moreover, performing exercise on the unstable device could increase the muscle activity (Lehman et al., 2005b; Imai et al., 2010; Vera-Garcia et al., 2015). For instance, Marshall and Murphy showed how performing exercises on an unstable surface (i.e., Swiss ball) led to a greater muscle activity compared to the stable surface in four different exercises: roll-out, inclined press-up, contralateral single-leg hold, and quadruped exercise (Marshall and Murphy, 2005). In particular, the use of the Swiss ball led to a 30% increase in rectus abdominis activity in the single-leg hold exercise and during the “top” phase of the press-up compared to the stable surface. Similarly, Imai and colleagues studied the muscle activity of five exercises performed on the floor and on an unstable surface: elbow-toe, hand-knee, curl-up, side bridge, and back bridge (Imai et al., 2010). This study indicates that lumbar stabilization exercises on an unstable surface enhanced the activities of trunk muscles, except for the back bridge exercise.

However, people with different anthropometrics mostly use unstable devices, and, to the best of our knowledge, no scientific guidelines considered whether different heights could respond to unstable stimuli in similar ways. For this purpose, the manufacturer usually provides guidelines to choose the proper size of unstable devices such as gymnastic balls. For instance, the Company Ledragomma Original Pezzi recommends the choice of the gymnastic ball according to specific anthropometric parameters:

- subjects up to 1.40 m tall should use a 42 cm diameter ball;
- subjects up to 1.55 m tall should use a 53 cm diameter ball;
- subjects up to 1.75 m tall should use a 65 cm diameter ball;
- subjects over 1.75 m tall should use a 75 cm diameter ball.

However, if these device choice criteria are followed, do all subjects of the same height range assume the same posture sitting on the device? Do all subjects of the same height range receive the same destabilization? Thus, even though the seated posture does not represent a challenging task to subjects, the choice of the gymnastic balls is based on the seated position as a reference. Thus, this study aimed to assess the manufacturer’s guidelines, based on the subject’s height, for the choice of gymnastic ball most suitable for subject’s anthropometrics. In detail, it evaluated whether the size of the device (i.e., gymnastic balls with a diameter of 53 cm, 65 cm, and 75 cm) compared to the subjects’ height could influence: the level of induced destabilization (i.e., CoP displacement) and body posture (i.e., joint angles).

3.2 Material and methods

3.2.1 Subjects

Twenty-nine subjects aged between 19 and 26 (M = 15 and F= 14; Height range: 1.55 m and 1.95 m; mass range: 51 kg and 87 kg) volunteered for the study. Subjects had no vestibular, visual, or neurological disorders. All participants signed their informed consent to the study and were free to withdraw from the study at any time.

3.2.2 Unstable devices: gymnastic balls

The company LEDRAGOMMA srl supplied for three Gymnastik Ball Original PEZZI® of different diameters: 53 cm, 65 cm, and 75 cm (figure 3.1).

Figure 3.1. From left to right, Gymnastik Ball of Ø 53 cm, Ø 65cm, and Ø 75cm.

3.2.3 Dynamometric platform

A dynamometric platform (AMTI BP400600© - Advanced Mechanichal Tecnology, Inc.) was used to derive the center of pressure trajectory, an objective indicator of the postural balance control system (figure 3.2). The dynamometric platform had the following characteristics: average COP measurement accuracy typically lower than 0.22 mm; measurement accuracy typically ± 0.1% of applied load (minimum applied load of 22.6 kg). The COP signal was analyzed with Balance Clinic 1.4.2 software.

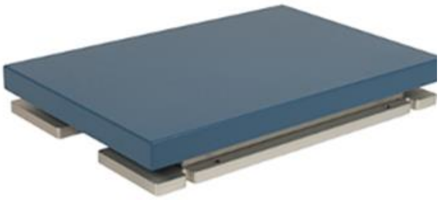


Figure 3.2. Dynamometric platform AMTI BP400600©

To place the different gymnastic balls over the dynamometric platform, the support surface was expanded by a wooden board (length 1.50 m; width 0.80 m; thickness 0.03 m), fixed with screws to the dynamometric platform (figure 3.3).

Figure 3.3. Dynamometric platform expanded with the wooden board.

3.2.4 The optoelectronic system

To accurately investigate the body posture assumed by the subjects sitting on the gymnastic balls, an optoelectronic system was used for kinematic analysis. The 10-cameras optoelectronic system (figure 3.4) determined the coordinates of the marker position through the Motive 2.0 software (Optitrack, Corvallis). The marker position was displayed within the previously calibrated and three-dimensionally recorded acquisition volume.

Figure 3.4. Cameras and marker of the Motion Capture System.

3.2.5 Experimental protocol

First, a specific marker set (figure 3.5) that allowed the identification of the anatomical segment was identified for the acquisition of the subject's posture. The following joint angles were then analyzed: the angle at the ankle, knee, hip, pelvis, and trunk.

The markers were applied to the following 19 anatomical landmarks:

1. The seventh cervical vertebra.
2. The right and left acromion.
3. The midpoint of the axillary line, at the height of the thoracic vertebrae.
4. The midpoint of the postero-superior iliac spines.
5. The right and left anterior superior iliac spine.
6. The greater trochanter of the right and left femur.

7. The right and left femoral condyle.
8. The head of the right and the left fibula.
9. The right and left medial malleolus.
10. The right and left heel.
11. The right and left fifth metatarsal.

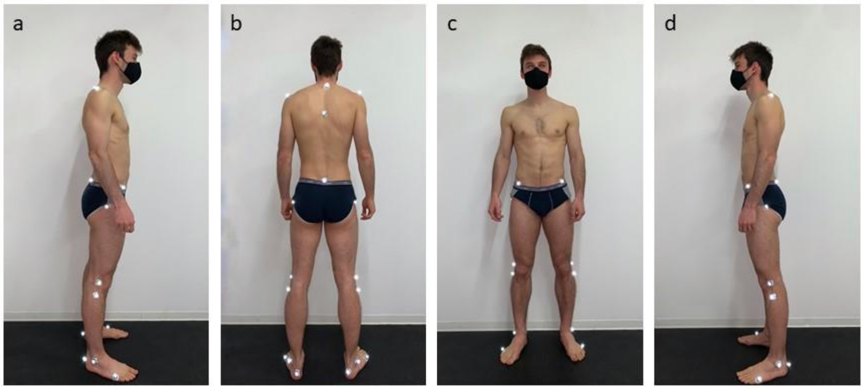


Figure 3.5. Marker-set used: (a) right lateral view; (b) posterior view; (c) anterior view; (d) left lateral view.

Once the application of the marker-set was completed, the subject was positioned over the dynamometric platform for the experimental trials. First, a test in the quiet standing position was performed as reference. The test consisted of holding the same static upright position for three trials of 30 s each, according to the recommendations of Scoppa et al. (Scoppa et al., 2013). Specifically, barefooted subjects were instructed to stand with extended legs, place the arms along their sides naturally and to gaze at a thin line vertically placed on a white wall in front of them at a distance of 80 cm. The feet' position on the force platform was standardized using a V-shaped layout, keeping a 7-cm distance between the heels and a wide open position of the tips of 30° between them, according to the international society of posturography recommendations (Kapteyn et al., 1983). Subsequently, each participant performed three static tests sitting on the gymnastic balls of different diameters. The subject, seated on the ball, with both feet on the ground, was asked not to move them for the entire test duration and to place the hands on his thighs. A vertical wooden board with two additional markers was placed behind the ball to measure the anterior-posterior distance between the subject's feet (i.e., heel marker) and the posterior margin of the ball. A 5-second kinematic recording was performed to register the subjects' position. Three trials (30 seconds each) were performed for all the experimental conditions in which the posterior vertical board was removed. The experimental trials (figure 3.6) were randomized among the participants.

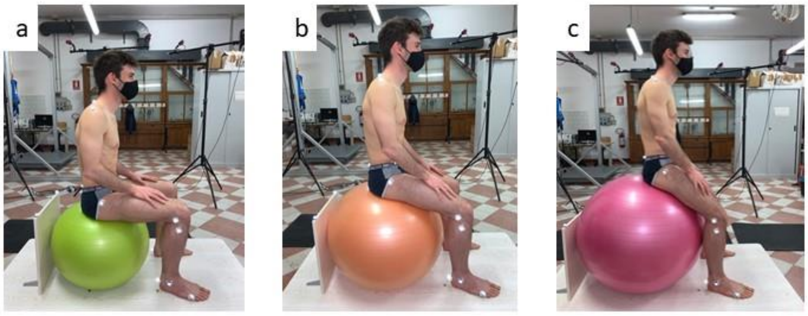


Figure 3.6. Three experimental conditions: subject sitting on the gymnastic ball with the diameter of (a) 53 cm, (b) 65 cm, and (c) 75 cm.

3.3 Data analysis

3.3.1 Dynamic analysis

The dynamometric platform provided data on the CoP trajectory. In particular, the CoP real-time displacement represented the subject's anteroposterior and mediolateral oscillations on the Cartesian plane. In detail, the coordinates along the abscissa axis represent the mediolateral component, while the coordinates along ordinate axis represent the anterior-posterior component. From the CoP trajectory, two parameters were calculated:

- Unit path (cm/s): it represents the mean velocity of the CoP. It is calculated by dividing the distance by the time taken. The higher the CoP mean velocity (i.e., higher Unit Path values), the more corrections are needed in the unit of time to counter the destabilization produced.
- Area95 (cm²): it represents the elliptical area calculated from the barycenter of the CoP trajectory. It has a 95% probability of keeping the CoP trajectory inside it. The greater the area of the ellipse, the higher the oscillations recorded.
- CoP percentage distance: it represents the CoP mean position expressed as a percentage distance between the subject's heels and the posterior board.

For each parameter, results among the three trials were averaged and considered for statistical analysis.

3.3.2 Kinematic analysis

The Optitrack optoelectronic system provided the three-dimensional coordinates of each marker.
The analysis of the kinematic data was performed by using the following software:

- Motive 2.0 (Optitrack, Corvallis): used during data collection to display and record the 3D position of the markers (100 Hz acquisition frequency; accuracy less than 1 mm).
- Smart Tracker (Bts Bioengineering, Milan): used for the tracking procedure. It allows assigning the anatomical landmark to the corresponding marker position (Fig. 3.7).

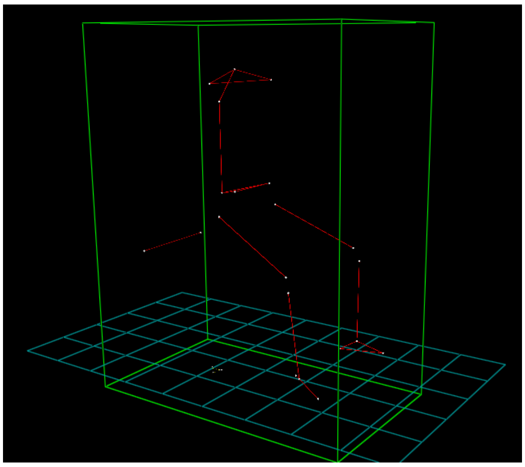


Figure 3.7. Smart Tracker, tracking procedure.

- Smart Analyzer (Bts Bioengineering, Milan): used for the biomechanical analysis of the joint angles. In detail, the following angles on the sagittal plane were analyzed:
  - ankle plantar- and dorsi-flexion;
  - knee flexion and extension;
  - hip flexion and extension;
  - pelvis anti-retroversion;
  - trunk flexion and extension.

- Joint angle kinematics convention follow (Perry and Burnfield, 1992):
  - Ankle joint kinematics
    - Positive values = dorsiflexion; negative values = plantarflexion.
  - Knee joint kinematics:
    - Positive values = flexion; negative values = extension.
  - Hip joint kinematics:
    - Positive values = flexion; negative values = extension.
  - Pelvis kinematics:
    - Positive values = anteversion; negative values = retroversion.

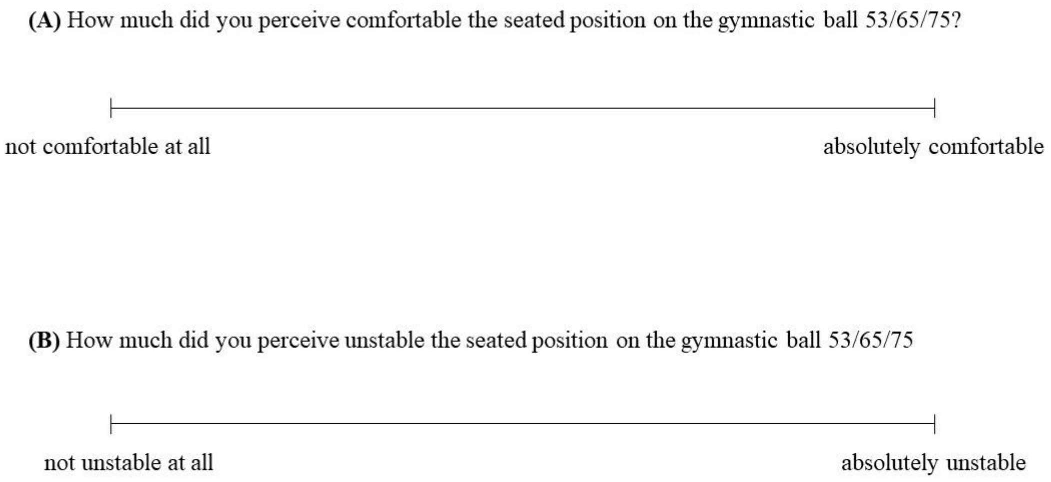
Trunk angle was considered equal to 0 deg. when the trunk was parallel to the vertical axis. Forward and backward trunk bending corresponds to positive and negative angle values, respectively.

3.3.3 Visual-Analog Scales

Each subject rated the perceived comfort and destabilization of each gymnastic ball. Two separate questions (figure 3.7) were submitted to the participants:

- "How much did you perceive comfortable the seated position on the gymnastic ball 53/65/75?" answer ranging from "*not comfortable at all*" to "*absolutely comfortable*"
- "How much did you perceive unstable the seated position on the gymnastic ball 53/65/75?" answer ranging from "not unstable at all" to "absolutely unstable".

The subjects were required to answer with a dash marked along the visual analog scale. The obtained value was converted into a score from zero to ten.



(A) How much did you perceive comfortable the seated position on the gymnastic ball 53/65/75?

not comfortable at all

absolutely comfortable

(B) How much did you perceive unstable the seated position on the gymnastic ball 53/65/75

not unstable at all

absolutely unstable

Figure 3.7. Visual-analog scales administered to subjects to rate perceived comfort (a) and destabilization (b) of each gymnastic ball.

3.4 Statistical analysis

All data collected successfully passed Levene's test for checking the normality distribution. The significant main effect of the device (i.e., gymnastic Ball 53, gymnastic ball 65, or gymnastic ball 75) or height (i.e., ≤ 1.75 m and > 1.75 m), or any interaction between them was investigated with a two-way ANOVA (3x2) for repeated measures, both for the CoP (i.e., Unit Path and Area95), and the kinematic parameters. When the Fisher F value showed significant main effects or any interaction, a post-hoc Bonferroni analysis was performed for multiple comparisons. Subsequently, the subjects of the two height groups (i.e., ≤ 1.75 m and > 1.75 m) were analyzed by assigning them the most appropriate ball according to the manufacturer's guidelines. Specifically, for subjects ≤ 1.75 m, the 65 cm diameter gymnastic ball, while for subjects > 1.75 m, the 75 cm diameter gymnastic ball. Therefore, a t-test for independent samples analyzed the differences between the two groups. All analysis were performed using the statistical software "Statistical Package for Social Science (SPSS) version 27" (IBM, Armonk, New York, USA). The significance level was set at $p < 0.05$.

3.5 Results

The twenty-nine healthy subjects included in the study all completed the tests. For both CoP and kinematic parameters, the mean was calculated over the three trials for each experimental condition.

3.5.1 Two-way ANOVA (3x2) for repeated measures

Firstly, subjects were divided into two groups (i.e., ≤ 1.75 m and > 1.75 m) and tested on all three gymnastic balls. The two-way ANOVA investigated whether, in the observed differences, a significant main effect of height, gymnastic ball, or any interaction between them could be observed.

Dynamic parameters. The Area95 and Unit Path means with their standard deviations are summarized in table 3.1 and graphically represented in figures 3.9 and 3.10, respectively. Results showed a significant main effect of the height for the Area95 ($p < 0.01$) and the Unit Path ($p < 0.001$). Conversely, the gymnastic ball did not show any significant main effect on the observed differences ($p > 0.05$).

	GYMBALL 53		GYMBALL 65		GYMBALL 75	
	UNIT PATH (cm/s)	AREA95 (cm^2)	UNIT PATH (cm/s)	AREA95 (cm^2)	UNIT PATH (cm/s)	AREA95 (cm^2)
≤ 1.75 m	3.75 ± 0.50	0.53 ± 0.33	3.67 ± 0.54	0.45 ± 0.34	4.13 ± 0.56	0.40 ± 0.42
> 1.75 m	3.39 ± 0.57	0.93 ± 0.72	3.18 ± 0.43	0.79 ± 0.61	3.26 ± 0.48	0.58 ± 0.53

Table 3.1. Mean and standard deviation of Area95 and Unit Path parameters.

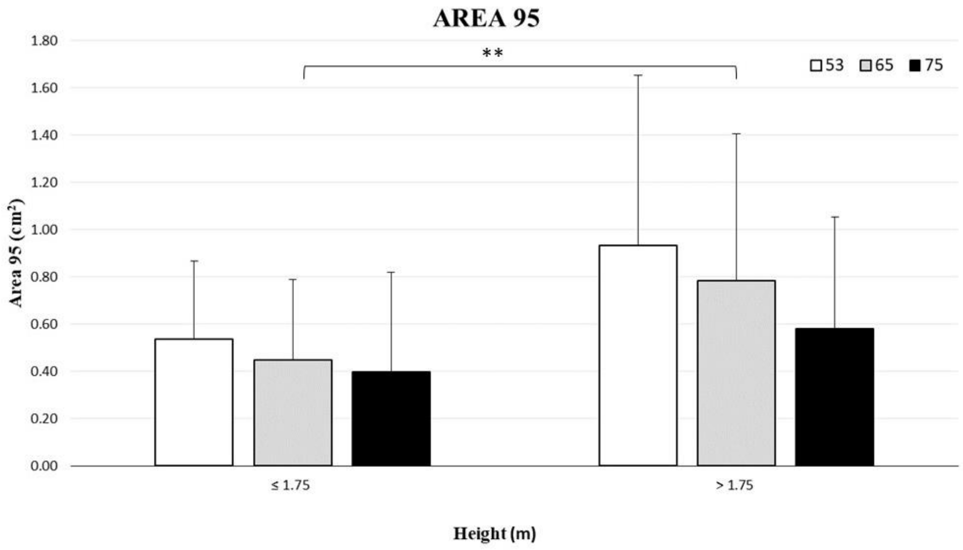


Figure 3.9. Results of the Area95 parameter. **significantly different $p < 0.01$.

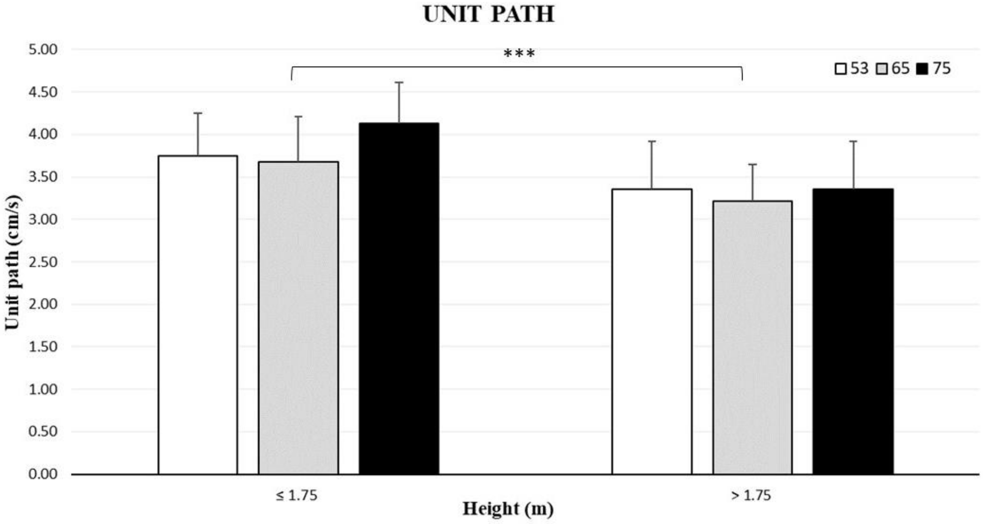


Figure 3.10. Results of the Unit Path parameter. ***significantly different $p < 0.001$.

Kinematic parameters. Figure 3.11 and table 3.2 report the results of the ankle plantar- and dorsi-flexion. Statistical analysis revealed a significant main effect of both the height ($p < 0.05$) and gymnastic ball ($p < 0.001$). Post-hoc comparisons showed that the ankle dorsi-flexion was higher ($p < 0.001$) in the gymnastic ball 53 compared to the gymnastic ball 65 and 75.

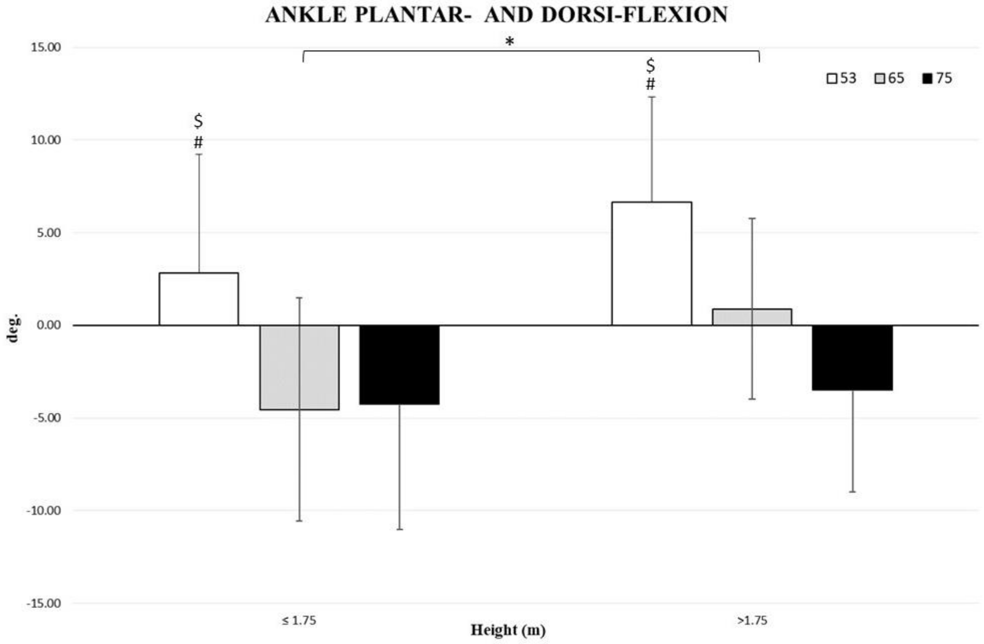


Figure 3.11. Results of the ankle plantar- and dorsi-flexion parameter. * Significantly different $p < 0.05$. $^{\$}$ Significantly different $p < 0.001$, 53 vs 65. $^{\#}$ Significantly different $p < 0.001$, 53 vs 75.

	ANKLE PLANTAR- AND DORSI-FLEXION (deg.)		
	GYMBALL 53	GYMBALL 65	GYMBALL 75
≤ 1.75 m	2.83 ± 6.40	– 4.54 ± 6.03	– 4.24 ± 6.78
> 1.75 m	6.64 ± 5.70	0.90 ± 4.88	– 3.49 ± 5.48

Table 3.2. Mean and standard deviation of ankle plantar- and dorsi-flexion.

Figure 3.12 and table 3.3 report the results of the knee flexion and extension. Statistical analysis revealed a significant main effect of both the height ($p < 0.001$) and gymnastic ball ($p < 0.001$). Post-hoc comparisons showed that the knee flexion was significantly higher ($p < 0.001$) in the gymnastic ball 53 compared to the gymnastic ball 65 and 75. Similarly, the knee flexion was significantly higher ($p < 0.001$) in gymnastic ball 65 than in gymnastic ball 75.

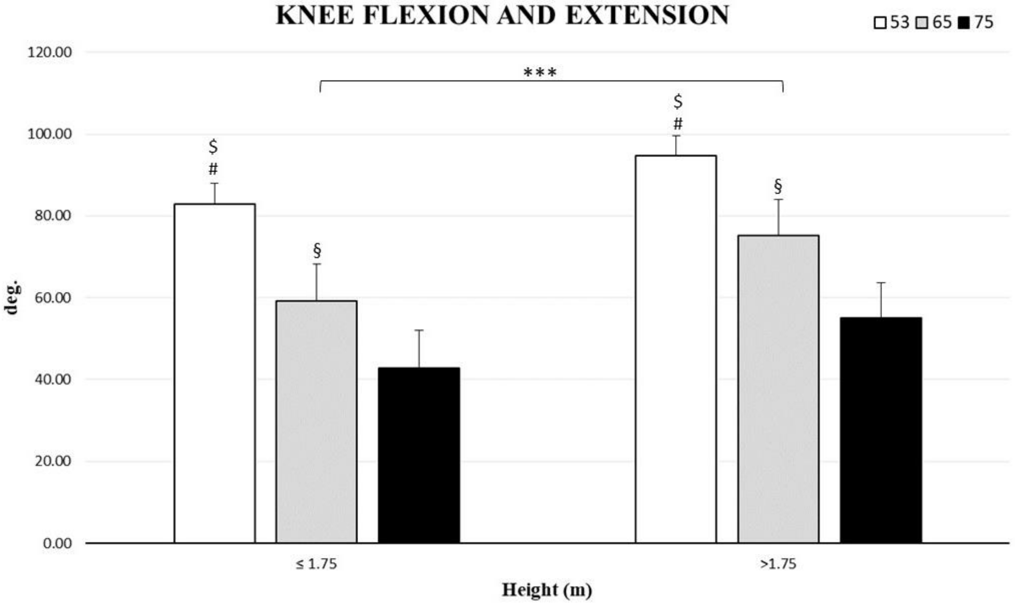


Figure 3.12. Results of the knee flexion and extension angle parameter. *** Significantly different $p < 0.001$. $^{\$}$ Significantly different $p < 0.001$, 53 vs 65. $^{\#}$ Significantly different $p < 0.001$, 53 vs 75. § Significantly different $p < 0.001$, 65 vs 75.

	KNEE FLEXION AND EXTENSION (deg.)		
	GYMBALL 53	GYMBALL 65	GYMBALL 75
≤ 1.75 m	83.94 ± 8.20	59.10 ± 9.00	42.87 ± 9.08
> 1.75 m	94.67 ± 8.63	75.28 ± 8.70	54.95 ± 8.78

Table 3.3. Mean and standard deviation for knee flexion and extension angle.

Figure 3.13 and table 3.4 report the results of the hip flexion and extension. Statistical analysis revealed a significant main effect of both the height ($p < 0.05$) and gymnastic ball ($p < 0.001$). Post-hoc comparisons showed that the hip flexion was significantly higher ($p < 0.001$) in the gymnastic ball 53 compared to the gymnastic ball 65 and 75. Similarly, the hip angle was less flexed ($p < 0.001$) in gymnastic ball 65 than in gymnastic ball 75.

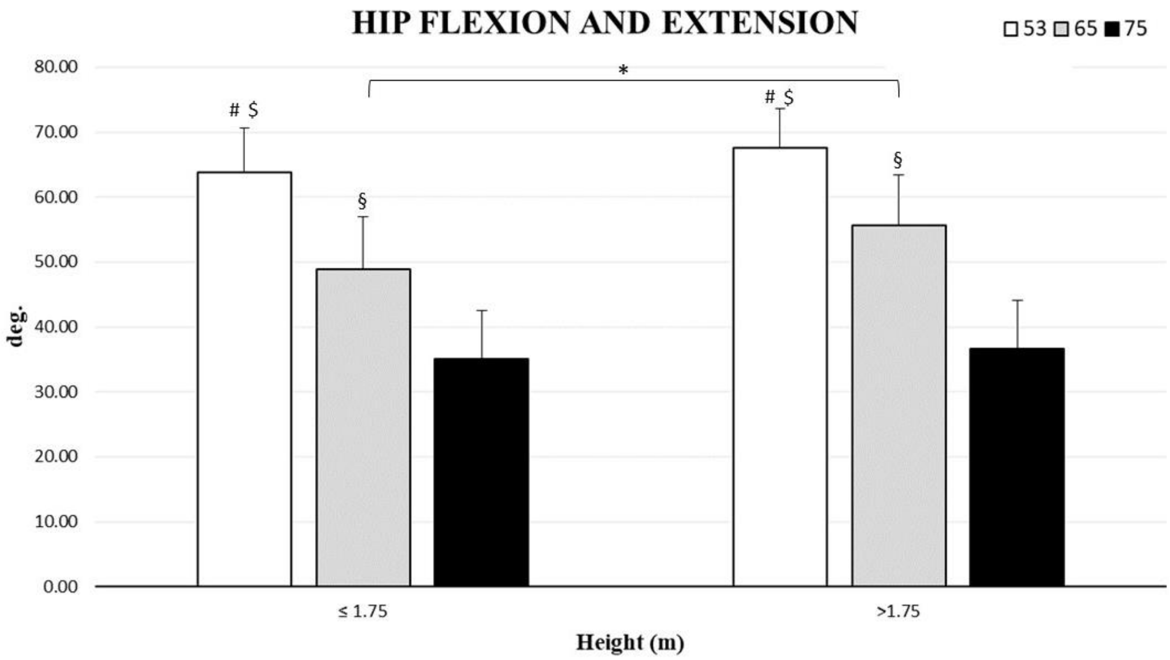


Figure 3.13. Results of the hip flexion and extension angle parameter. * Significantly different $p < 0.05$. $ Significantly different $p < 0.001$, 53 vs 65. # Significantly different $p < 0.001$, 53 vs 75. § Significantly different $p < 0.001$, 65 vs 75.

	HIP FLEXION AND EXTENSION (deg.)		
	GYMBALL 53	GYMBALL 65	GYMBALL 75
≤ 1.75 m	63.73 ± 6.89	48.95 ± 7.97	35.08 ± 13.87
> 1.75 m	67.53 ± 6.09	55.67 ± 7.78	36.65 ± 7.48

Table 3.4. Mean and standard deviation for hip flexion and extension angle.

Figure 3.14 and table 3.5 report the results of the angle in pelvis anti-retroversion. Statistical analysis showed a significant main effect of the height. Overall, the pelvis retroversion was higher in subjects taller less than 1.75 m ($p < 0.05$).

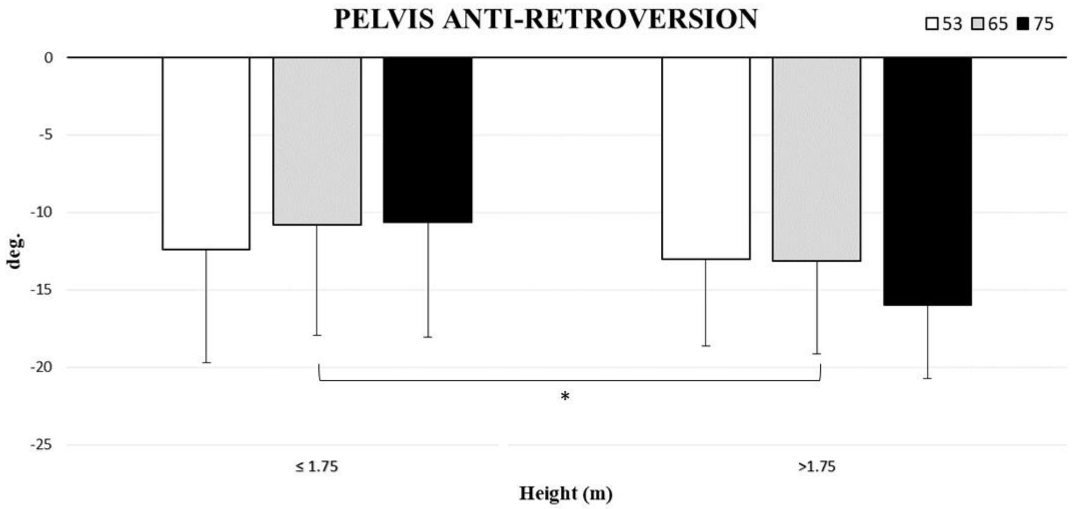


Figure 3.14. Results of the pelvis anti-retroversion angle parameter. * Significantly different $p < 0.05$.

	PELVIS ANTI-RETROVERSION (deg.)		
	GYMBALL 53	GYMBALL 65	GYMBALL 75
≤ 1.75 m	–12.41 ± 7.28	–10.81 ± 7.14	– 8.69 ± 7.43
> 1.75 m	–13.05 ± 5.55	–13.11 ± 6.04	–15.99 ± 4.74

Table 3.5. Mean and standard deviation for the pelvis anti-retroversion angle.

Figure 3.15 and table 3.6 report the results of the angle in the trunk flexion and extension. Statistical analysis showed a significant main effect of the gymnastic ball ($p < 0.001$). Post-hoc comparisons showed that the trunk forward flexion was significantly higher ($p < 0.001$) in the gymnastic ball 53 compared to the gymnastic ball 75. Similarly, the trunk flexion was significantly higher ($p < 0.05$) in gymnastic ball 65 than in gymnastic ball 75.

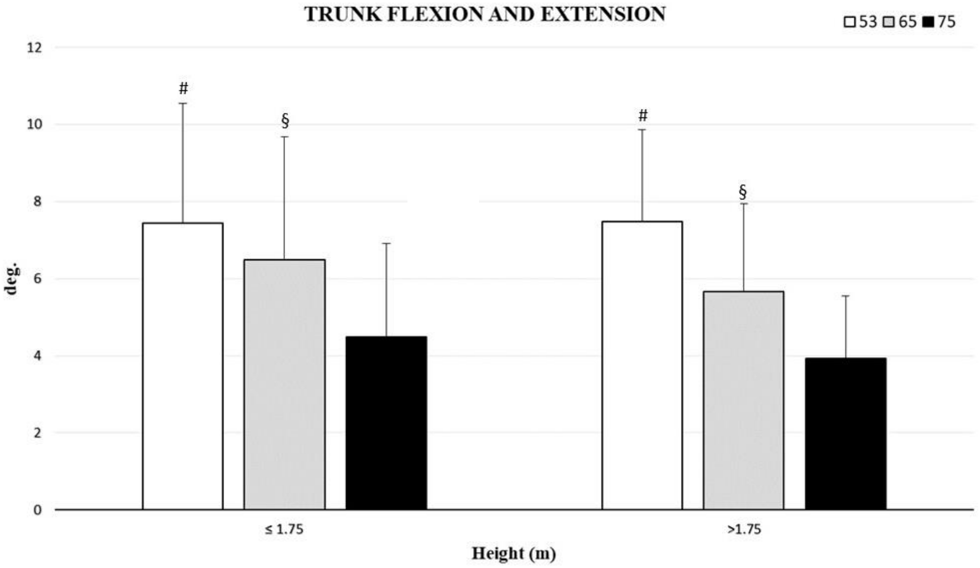


Figure 3.15. Results of the trunk flexion and extension angle parameter. $^{\#}$ Significantly different $p < 0.001$, 53 vs 75. § Significantly different $p < 0.05$, 65 vs 75.

	TRUNK FLEXION AND EXTENSION (deg.)		
	GYMBALL 53	GYMBALL 65	GYMBALL 75
≤ 1.75 m	7.43 ± 3.11	6.49 ± 3.19	4.48 ± 2.43
> 1.75 m	7.47 ± 2.39	5.67 ± 2.27	3.93 ± 1.62

Table 3.6. Mean and standard deviation for trunk flexion and extension angle.

Vas scores. Figure 3.16 and table 3.7 report the results of the perceived comfort obtained from the VAS scores. Statistical analysis revealed a significant main effect of the gymnastic ball ($p < 0.001$). Post-hoc comparisons showed that the perceived comfort was significantly higher in the gymnastic ball 53 vs. 75 ($p < 0.001$) and in the gymnastic ball 65 vs. 75 ($p < 0.001$).

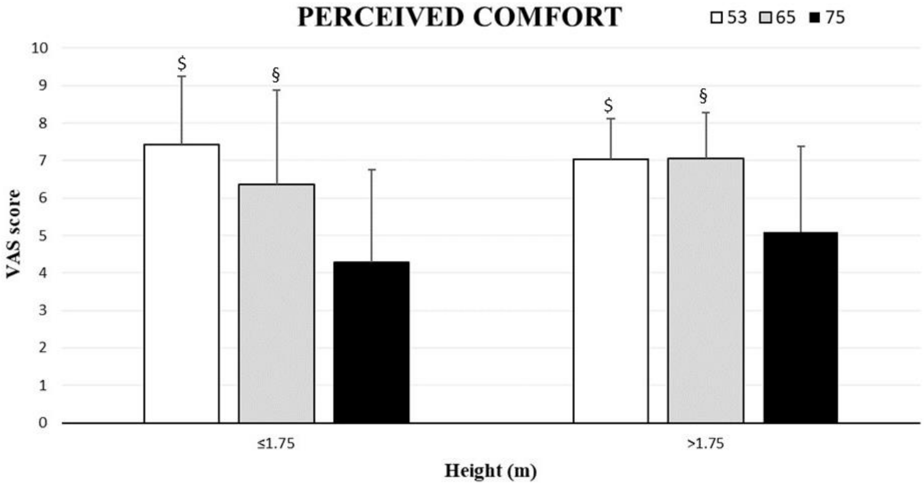


Figure 3.16. Results of the VAS score obtained related to the perceived comfort. $^{\$}$ Significantly different $p < 0.001$, 53 vs 75. § Significantly different $p < 0.05$, 65 vs 75.

	PERCEIVED COMFORT		
	GYMBALL 53	GYMBALL 65	GYMBALL 75
≤ 1.75 m	7.43 ± 1.81	6.35 ± 2.52	4.28 ± 2.47
> 1.75 m	7.03 ± 1.08	7.05 ± 1.23	5.09 ± 2.29

Table 3.7. Mean and standard deviation for perceived comfort parameter.

Figure 3.17 and table 3.8 report the results of the perceived destabilization obtained from the VAS scores. Statistical analysis did not show any statistically significant main effect of the height and gymnastic ball, or any interaction between them.

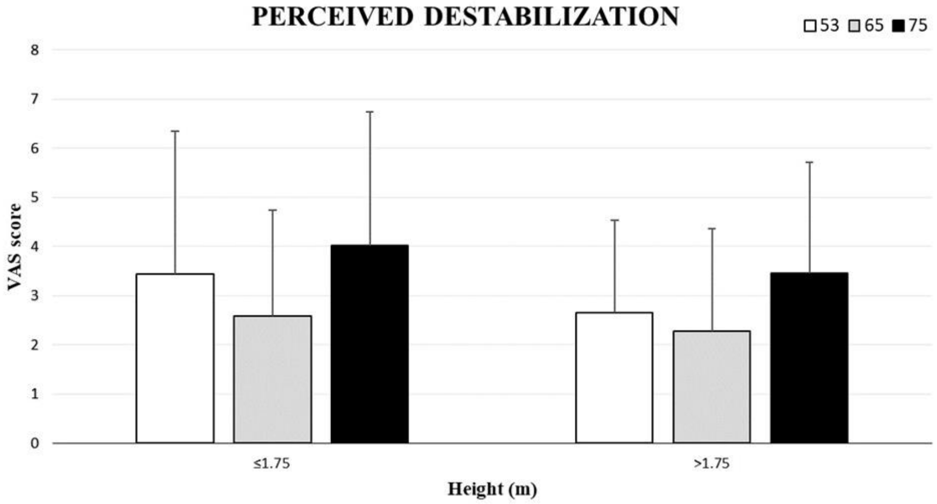


Figure 3.17. Results of the VAS score obtained related to the perceived destabilization. $^{\$}$ Significantly different $p < 0.001$, 53 vs 75. § Significantly different $p < 0.05$, 65 vs 75.

	PERCEIVED DESTABILIZATION		
	GYMBALL 53	GYMBALL 65	GYMBALL 75
≤ 1.75 m	3.43 ± 2.92	2.59 ± 2.15	4.02 ± 2.09
> 1.75 m	2.65 ± 1.88	2.26 ± 2.09	3.45 ± 2.27

Table 3.8. Mean and standard deviation for perceived destabilization parameter.

CoP percentage distance. Table 3.9 reports the results of the CoP percentage distance. Statistical analysis showed statistically significant main effect of the height ($p < 0.05$) and gymnastic ball ($p < 0.001$). Post-hoc comparisons are reported in table 3.9.

	COP PERCENTAGE DISTANCE		
	GYMBALL 53	GYMBALL 65	GYMBALL 75
≤ 1.75 m	0.84 ± 0.20 (#; $)	0.72 ± 0.12 (§)	0.61 ± 0.11
> 1.75 m	0.90 ± 0.15 (#; $)	0.80 ± 0.11 (§)	0.68 ± 0.10

Table 3.9. Mean and standard deviation for perceived destabilization parameter. $^{\$}$ Significantly different from gymball 65 ($p < 0.01$); $^{\#}$ Significantly different from gymball 75 ($p < 0.001$); § Significantly different from gymball 75 ($p < 0.05$).

3.5.2 Independent T-test

In this analysis, the recruited subjects were assigned to a specific gymnastic ball according to the manufacturer's guidelines (Ledragomma Original PEZZI®). In detail, subjects ≤ 1.75 m tall were measured while using the Ø 65 cm gymnastic ball and subjects > 1.75 m tall while using the Ø 75 cm gymnastic ball. The two groups (≤ 1.75 and > 1.75 m) were compared to understand whether the same ergonomic responses could be observed when assigned to the most suitable gymnastic ball according to the manufacturer. As before, the same parameters were considered: dynamics (i.e., Area95 and Unit Path), kinematics (i.e., ankle, knee, hip, pelvis, and trunk joint angles), and subjective scores (i.e., comfort and destabilization).

Dynamic parameters. Table 3.10 reports the results of the Unit path and Area95 parameters. The independent t-test showed a significant difference between the two groups for the Unit Path ($p < 0.05$) but any significant difference for the Area 95.

	≤ 1.75 m	> 1.75 m
Unit Path (cm/s)	3.67 ± 0.54*	3.21 ± 0.48
Area95 (cm²)	0.45 ± 0.34	0.58 ± 0.53

Table 3.10. Mean and standard deviation for Area95 and Unit Path parameter.
*significantly different ($p < 0.05$).

Kinematic parameters. Table 3.11 reports the results of the ankle, knee, hip, pelvis, and trunk joint angles. The independent t-test showed statistically significant difference between the two groups for hip ($p < 0.001$), pelvis ($p < 0.05$) and trunk ($p < 0.05$) joint angle. Conversely, ankle and knee joint angle did not show any statistically significant difference between the two groups.

	≤ 1.75 m	> 1.75 m
Ankle plantar- and dorsi-flexion (deg.)	– 4.54 ± 6.03	– 3.49 ± 5.48
Knee flexion and extension (deg.)	59.16 ± 9.00	54.95 ± 8.78
Hip flexion and extension (deg.)	48.95 ± 7.97	36.65 ± 7.48***
Pelvis anti- and retro-version (deg.)	–10.81 ± 7.14	–15.99 ± 4.74*
Trunk flexion and extension (deg.)	6.49 ± 3.19	3.93 ± 1.62*

Table 3.11. Mean and standard deviation for the joint angle parameter.

VAS scores. Table 3.12 reports the results of the VAS score for the perceived comfort and destabilization scales. The independent t-test did not show any statistically significant difference between the two groups for both the parameters.

	≤ 1.75 m	> 1.75 m
Perceived Comfort	6.35 ± 2.52	5.09 ± 2.29
Perceived Destabilization	2.59 ± 2.15	5.07 ± 2.26

Table 3.12. Mean and standard deviation for the perceived comfort and destabilization scales.

CoP percentage distance. The independent t-test did not show any statistically significant difference between the two groups (≤ 1.75 m: 0.72 ± 0.12; > 1.75 m: 0.68 ± 0.10) for the CoP percentage distance.

3.6 Discussion

In the scientific literature, several studies investigated the use of unstable devices aimed at postural control training. In particular, it has been demonstrated that a specific exercise task performed on an unstable surface required a greater balance commitment than on a stable surface (Vera-Garcia et al., 2020). Similarly, in the first part of this PhD project I investigated the effect on core muscle activity and postural control of different unstable devices while subjects performed the same exercise on them (Rizzato et al., 2021). However, in that analysis, the subject's anthropometrics was not included as a variable. Thus, the present study deepened the effect of the device's size (i.e., gymnastic ball diameter) on the CoP-related and kinematic parameters, considering the subjects' anthropometrics.

The first part of the analysis investigated whether, in a static sitting posture with bipodalic stance, there was a greater effect on the parameters studied of the participants' height or the size of the gymnastic ball. For the dynamic parameters, a significant main effect of the subject's height occurred, indicating that subjects < 1.75 m required greater balance adjustments (i.e., higher Unit Path) than subjects >1.75 m tall. Indeed, the Unit Path reflects the efficiency of the postural control system characterizing the net neuromuscular activity necessary to maintain the balance (Paillard and Noé, 2006). Nonetheless, Area95 was significantly higher in subjects taller than 1.75 m. Area95 is considered an index to objectively quantify an individual's overall dynamic postural performance (Paillard and Noé, 2015). Indeed, despite subjects < 1.75 required greater balance adjustments, they elicited a better balance performance. However, gymnastic ball size did not influence these outcomes. The lack of a significant main effect of the gymnastic ball over Area95 and Unit Path means that the different gymnastic balls (i.e., diameters 53, 65, and 75 cm) gave all subjects the same amount of destabilization. Finally, the subjects' anthropometrics or the gymnastic ball diameter did not significantly affect the perceived destabilization. Conversely, the perceived comfort was influenced by the gymnastic ball diameter, highlighting how all the subjects reported the Ø 53 and Ø 65 gymnastic balls as the more comfortable.

As expected, in a seated posture the joint angles reflected the subjects' height. Indeed, subjects taller less than 1.75 m presented a more dorsi-flexed ankle, knee and hip flexion compared to subjects taller less than 1.75 m in a seated posture regardless of the gymnastic ball. Similarly, observing the gymnastic ball effect on the joint angles was more interesting. In particular, the post-hoc comparisons showed greater dorsiflexion, knee flexion, and hip flexion angle in the Ø 53 ball compared to Ø 65 and Ø 75 ball. Therefore, the three just-mentioned joint angles vary according to the diameter of the gymnastic balls regardless of the height, with a progressive order: the smaller the diameter, the more flexed the joint angle.

The second analysis deepened whether the guidelines provided by the company (Ledragomma Original Pezzi srl) rightly considered the subjects' anthropometrics to choose the most suitable gymnastic ball. Thus, following the company's guidelines, the two groups were assigned the gymnastic ball they should use: namely, 65 cm diameter to height group ≤ 1.75 m; 75 cm diameter to height group > 1.75 m. Regarding the CoP-related parameters, the Area95 did not differ between the two groups. Conversely, the Unit Path was statistically higher in subjects ≤ 1.75 m on gymball 65 compared to the subjects > 1.75 m on gymball 75. Area95 is considered an index to objectively quantify an individual's overall dynamic postural performance (Paillard, 2015), while the Unit Path reflects the efficiency of the postural control system characterizing the net neuromuscular activity necessary to maintain the balance (Paillard, 2006). Therefore, the two height groups on the suggested gymnastic ball reached the same balance performance with a different efficiency.

The ankle and knee angles did not show significant differences between the groups. Therefore, the company's guidelines were correct in suggesting the most suitable device for different subjects' anthropometrics, if the goal is to let unchanged the lower limb angles. Instead, the hip, pelvis and trunk angle showed significant differences between the two groups; in particular, subjects ≤ 1.75 m had a more flexed hip angle than subjects > 1.75 m on the respectively assigned ball. Moreover, the pelvis retroversion was higher in the group > 1.75 m than ≤ 1.75 m; conversely, trunk forward flexion was higher in subjects ≤ 1.75 m. Finally, VAS scores of perceived comfort and destabilization were the same between the two groups. Thus, when subjects were assigned to the gymnastic ball following the company's guidelines, each group was equally comforted and destabilized with respect to the other. In our case, the company's guidelines suggested specific gymnastic ball sizes to optimize the subjects' posture during exercise and to give them the same amount of destabilization regardless of their height. Our results demonstrated that also sample's subjective feelings strengthen the company's guidelines.

3.7 Conclusions

As expected, the smaller the size of gymnastic ball, the more flexed the joint angles during the seated posture independently of the subject's height. Overall, the manufacturer's guidelines, based on the subject's height, for the choice of gymnastic ball are suitable for subject's anthropometrics. Moreover, subjects different in height, had the same destabilization and a similar CoP position distance in a seated posture, when assigned to the corresponding ball. Nonetheless, the proper ball should be chosen according to the population's specific needs (e.g., the exercise to be performed). For instance, older adults can perform an exercise on the larger diameter gymnastic ball, bringing them closer to an upright posture and making them safer while exercising. Thus, a larger diameter of the gymnastic ball facilitates older adults to stand up, considering the higher extension of the knee during the seated posture.

Chapter 4

Multimodal training protocols to face fall risk in older adults

4.1 Introduction

It is estimated that the percentage of older adults who fall every year ranges between 20% and 33% (Peel, 2011), with an even greater frequency for institutionalized people (Rubenstein, 2006). Above all, the possible injuries and adverse effects of falling represent the main issue in the health of older adults. Mainly, sarcopenia and reduced balance ability affect the risk of falling. Sarcopenia is a progressive and generalized loss of skeletal muscle mass and function consequent to adverse events such as falls, cognitive decline, frailty, and increased mortality (Cruz-Jentoft and Sayer, 2019). The decrease in muscle mass and function affects the expression of strength in older adults and can lead to the inability to perform activities of daily living (ADLs) where a level of strength is required.

Loss of postural balance control derives from the impairment of visual (Saftari and Kwon, 2018), vestibular (Agrawal et al., 2020), and proprioceptive (Henry and Baudry, 2019) systems. Specifically, the decline in visual acuity, contrast sensitivity, and visual field width is associated with an increased risk of falling (Saftari and Kwon, 2018). In the vestibular system, an alteration of the vestibulo-ocular reflexes and a reduction of the peripheral and central cell population leads to problems such as disorientation, vertigo, and instability (Agrawal et al., 2020). For the proprioceptive system, neuromuscular spindles undergo a reduction in the number and size of fibers, increased wall thickness, and decreased conduction velocity (Henry and Baudry, 2019). Thus, a fall can occur when the lower-limb strength cannot compensate for the compromised function of the postural control system, which is often responsible for the loss of balance.

4.1.1 Physical activity protocols for fall-risk prevention

A recent meta-analysis (Sherrington et al., 2017) considered 88 randomized controlled trials that studied physical activity as the only intervention on older adults (aged > 65) in community settings. The authors found that physical activity practice of at least 3 hours a week reduced up to 39% of the fall risk. Moreover, Cadore and colleagues showed that when the interventions were multi-component (i.e., strength, aerobic, and balance exercises), the fall risk varied from 22% to 40% in frail older adults (Cadore et al., 2013). However, a systematic review (De Labra et al., 2015) suggested that frail older adults seemed mostly to benefit from exercise interventions, although the optimal program remains unclear. This issue is due to the great intrinsic variability of the type of training (e.g., functional training protocols can include several different motor stimuli) and to the difficulty of finding detailed protocols published in the literature. Given the importance of the accessibility of physical activity to everyone, involving the participants, especially the older ones, in activities that require just a few simple devices could be a winning option. Indeed, due to their physiological and practical benefits, there has recently been growing interest in using unstable devices in training protocols. These devices (e.g., gymnastic balls, Bosu, half discs) can be used in different contexts: athletic (Reed et al., 2012), recreational (Marshall and Murphy, 2005), or rehabilitative (Tsaklis et al., 2015). These tools continuously stimulate the postural tonic system since they do not provide a stable support base and force the user to continuous adaptations to maintain balance (Rizzato et al., 2021), resulting in increased muscle activity and heart rate (O'Sullivan et al., 2002; Haller et al., 2006). Unstable devices can combine strength and balance training in tailored protocols; however, it is not yet clear whether their use can provide a sufficient stimulus to improve the lower-limb strength or whether they are limited to the proprioceptive component.

4.1.2 Aim of the study

The study aimed to evaluate the effect of two different types of training on lower-limb strength and dynamic balance. The first training always used stable surfaces, which better stimulated the strength component, while the other training used unstable devices, which required greater postural balance control. Therefore, a 3-month longitudinal interventional study was structured (two sessions per week), with assessments performed at the beginning, after six weeks, and at the end of the training program.

4.2 Materials and method

4.2.1 Subjects

After an online advertisement on the official website of the city of Padova, thirty-seven elderly subjects over the age of 65 voluntarily participated in the study (F=21; M= 16; age: 72.9±5.3 yrs, height 1.62.3 ± 0.17 m, and weight 69.6 ± 12.5 kg). The form for treating personal data and informed consent was signed at the first meeting. For subject eligibility, the following inclusion and exclusion criteria were observed.

Inclusion criteria:

- Older than 65 years;
- Maximum one structured physical activity per week;
- Completion of at least 22 out of 24 training sessions.

Exclusion criteria:

- Vision problems not corrected by glasses or contact lenses;
- Psychiatric and neurological disorders;
- Regular assumption of drugs that can interfere with normal cognitive functioning (e.g., antidepressants, antipsychotics, anxiolytics);
- Assumption of psychotropic drugs;
- Any other pathologies for which the physical activity practice was contraindicated.

4.2.2 Experimental design

Subjects were then randomized into two intervention groups, namely STABLE (ST) and UNSTABLE (UNST), which performed the physical activity program detailed in section 3.2.4, and a CONTROL group (CTRL). In detail, two subjects from the UNST group were excluded for health reasons unrelated to the study. Moreover, one subject from the CTRL group encountered technical problems with the instrumentation. Below, table 4.1 reports the characteristics of the three groups.

	SUBJECTS	AGE (yrs)	HEIGHT (m)	MASS (kg)
CTRL	9 (M=5)	74.22 ± 6.33	1.66 ± 0.09	67.16 ± 12.45
ST	13 (M=5)	74.53 ± 5.12	1.64 ± 0.08	70.19 ± 11.88
UNST	12 (M=6)	70.08 ± 4.35	1.64 ± 0.09	71.33 ± 13.77

Table 4.1. Characteristics of the subjects. Data presented as mean ± standard deviation.

The intervention groups (i.e., ST and UNST) participated at two weekly physical activity sessions held at the physiological institute of the University of Padua, with continuous supervision by experts. Each physical activity session lasted 45 minutes and the training days were not consecutive. Each subject (CTRL, ST, and UNST groups) performed the assessment sessions at the beginning of the experimental period (T_0), after six weeks (T_1), and after twelve weeks (T_2).

4.2.3 Assessments

Global physical activity questionnaire (GPAQ). At the beginning of the study (T_0), each subject was administered the GPAQ questionnaire for estimating the daily levels of physical activity (Bull, 2009). GPAQ covers several components of physical activity, such as intensity, duration, and frequency, and it assesses three domains in which physical activity is performed (occupational physical activity, transport-related physical activity, and physical activity during discretionary or leisure time). The daily estimation allowed classifying the subjects into three categories of physical activity: Low, Moderate, and High.

Handgrip test. The grip strength of the dominant hand was measured using a handgrip dynamometer (Saehan Corp®, SH5001, South Korea). Indeed, the strength of a person's handgrip has been recognized as a valid measure of the overall muscle function and strength from age 50 onward (Steiber, 2016). Three consecutive measurements were made with subjects seated upright and with the elbow flexed at 90° (Bohannon et al., 2006).

Static Balance test. Static postural balance was assessed on a force platform (AMTI BP400600, Watertown, MA, USA), where subjects had to hold the same static upright posture. They were instructed to stand with extended legs and place their arms naturally along their sides. The feet position on the force platform was standardized using a V-shaped frame, keeping a 7-cm distance between the heels and a wide-open position of the tips with 30° between them, according to the international society of posturography recommendations (Kapteyn et al., 1983). Three static balance tests were performed, lasting one minute each (figure 4.1 C).

Dynamic Balance test. The force platform was placed over an electrically driven movable platform (Shaker Table - EnginLAB s.r.l.) controlled by Real Time Test Controller RTC-9000 software (figure 4.1 B). For each trial subjects were asked to stand over the movable system with arms along their sides and knees extended, looking at a reference placed in front of them at the eye level. All subjects wore a safety harness attached to an overhead frame to prevent falling in case of loss of balance due to the unexpected plate shifting (figure 4.1 A). The software allows programming the ramp rate (mm/sec) and displacement (mm) to control the platform movement (figure 4.1 D). Dynamic balance tests used two functions: RAMP (i.e., sudden perturbations) and SINE-WAVE (i.e., a continuous sinusoidal perturbation of constant amplitude). In the RAMP perturbation the table displacement was set at a 50 mm in posterior-anterior direction and its speed at 100 mm/s. Each trial lasted 60 s, and between seconds 20 and 40, the operator randomly applied the unexpected perturbation. Of the five trials, two no-perturbation trials were randomly administered as well to prevent the subject from thinking that the perturbation would have always occurred. Moreover, three trials with the SINE-WAVE perturbation (frequency: 1 Hz; Amplitude 50 mm; sinusoidal onset: 2 s) lasting 60 seconds each were performed. The sinusoidal perturbation started at the second 20 and ended at the second 40. This perturbation was not unexpected, and the subjects were informed that it would have occurred from second 20 to 40.

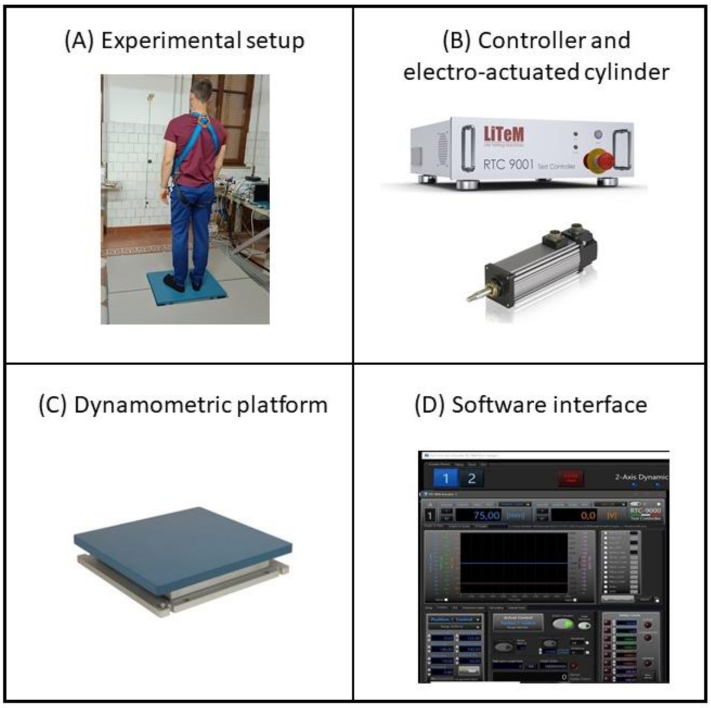


Figure 4.1. Dynamic balance test.

Maximal isometric strength. The dominant lower limb strength was evaluated through the isometric maximum voluntary contraction (MVC) of the quadriceps. The experimental setup (figure 4.2 A) consisted of a custom-built chair (figure 4.2 B) instrumented with a uni-axial load cell (MuscleLab - Ergotest Technology). Before the test, ten sub-maximal warm-up contractions were performed with visual feedback. After the warm-up, three trials were performed with 30 seconds of recovery in between. The duration of each MVC was 3 seconds (figure 4.2 C), during which the experimenter verbally prompted the subject.

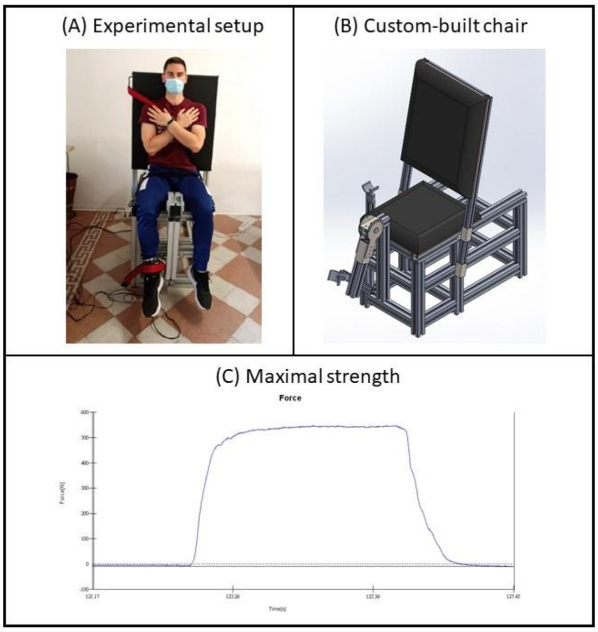


Figure 4.2. Maximal quadriceps lower-limb strength test.

Timed-up and go Test. The test measured the time the subject needed to (i) stand up from the chair, (ii) walk to the line 3-meters away on the floor at the preferred pace, (iii) walk back to the chair at the same pace, and (iv) sit down again. Subjects wore their regular footwear; the timing started with the word "Go" and stopped after the bottom of the subject touched the chair. Three trials were performed.

10-meter walking Test. The subject was instructed to walk a set distance (i.e., 20 meters) at his/her preferred speed. The timing started when the subject walked the 5-meter line and stopped when the subject crossed the 15-meter line away on the floor from the starting position. Indeed, a 5-meter space was set at the beginning and the end of the track to let the subject accelerate/decelerate to the preferred speed.

4.2.4 Training protocol

Each physical activity session was regularly composed of warm-up, core combining strength and balance (tables 4.2 and 4.3), and a cool-down. Warm and cool-down phases were standardized for both experimental groups, while the core phase was differentiated between the ST and UNST groups. Following, figure 4.3 summarizes the devices, both stable and unstable, used during the training protocol.

Figure 4.3. Stable and unstable devices used during both the training protocols.

The training table that includes the progressions made over the three months is presented below (tables 4.4 and 4.5). The goal was to increase the difficulty over time for both balance and strength. These progressions considered the subject's starting level, the level of perceived fatigue, and individual progresses.

Warm-up:

- Joint mobility exercises of the lower and upper limbs (e.g., twisting/tilting of the trunk);
- Walking gaits (e.g., on toes, on heels, tandem walking);
- Preliminary strength exercises (e.g., throwing, lifting, or moving with light weights).

Core part:

TRAINING A	SETS AND REPS	RECOVERY
Standing hip abduction	3 x (12+12)	30 s
Seated hip flexion	3 x (12+12)	30 s
Monopodalic balance	3 x (30 s+30 s)	30 s
Crunches	3x12	30 s
Exercise added after the 4th week		
Half Squat	3 x 12	30 s

Table 4.2. Training program to be performed in the first session of the week.

TRAINING B	SETS AND REPS	RECOVERY
Leg press	3 x 12	30 s
Hip adduction	3 x 12	30 s
Hip Extension	3 x 12	30 s
Calf	3 x 12	30 s
Exercise added after the 4th week		
Isometric supine bridge	20 s	30 s

Table 4.3. Training program to be performed in the second session of the week.

STABLE GROUP (ST)			
START	PROGRESSION 1	PROGRESSION 2	PROGRESSION 3
Hip abductions holding a support	elastic band	One hand on the support	Increase the elastic band load
Seated hip flexion	Ankle brace (1/2 kg)	One hand on the support	Increase the ankle brace load (2/3 kg)
Monopodalic balance	Increase stay time	Arms abducted holding a ball	Combining movement of upper limbs
Crunch hands extended forward	Crunch hands to the head	Increase reps	Increase reps
Half squat	Box squat	Squat	Increase reps
Leg press	Increase load	Increase load	Increase load
Hip adductions holding a support	elastic band	One hand on the support	Increase the elastic band load
Hip extensions holding a support	Ankle brace (1/2 kg)	One hand on the support	Increase the ankle brace load (2/3 kg)
Bipodalic calf	One hand on the support	Bipodalic calf on the forefoot	Monopodalic Calf
Isometric supine bridge	Increase stay time	Dynamic supine bridge	Increase reps

Table 4.4. Training progression determined for the stable group.

UNSTABLE GROUP (UNST)			
START	PROGRESSION 1	PROGRESSION 2	PROGRESSION 3
Hip abductions on the foam pad holding a support	Elastic band	One hand on the support	Balance Disc substitutes Foam pad
Seated hip flexion on gymnastic ball holding a support	One hand on the support	Ankle brace (1/2 kg)	Ankle brace (2/3 kg)
Monopodalic balance on the active disc	One hand on the support	Increase stay time	Combining movement of upper limbs
Crunch on gymnastic ball hands on the chest	Crunch on gymnastic ball hand to the head	Increase reps	Increase reps
Half squat on foam pad	Box squat on foam pad	Box squat on balance disc	Squat on balance disc
Leg press on foam pad	Increase load	Leg press on balance disc	Increase load
Hip adduction on foam pad	Elastic band	One hand on the support	Balance disc substitutes foam pad
Hip extension on foam pad	Ankle brace (1/2 kg)	One hand on the support	Hip extension on balance disc
Bipodalico calf on foam pad	One hand on the support	Bipodalico calf on balance disc	Monopodalic Calf on balance disc
Isometric supine bridge on foam pad	Increase stay time	Dynamic supine bridge on foam pad	Dynamic supine bridge on balance disc

Table 4.5. Training progression determined for the unstable group.

Cool-down:

- Static stretching exercises for the main muscle groups involved;
- Breathing and relaxation exercises.

4.3 Data analysis

The handgrip test measured the isometric grip strength of the dominant hand in kilograms. On the other hand, the maximum strength of the dominant lower limb was expressed in Newton and normalized with respect to the subject's body mass (% Body Weight). The best performance in the three tests was considered as outcome. In the static balance test, the area of the confidence ellipse (i.e., Area 95), and the Mean velocity (i.e., Unit path) calculated from the CoP trajectory were considered for statistical analysis. Both variables were averaged over the three trials.

Data analysis for the RAMP perturbation condition is sketched in figure 4.4. The perturbation point (PP) was identified as the anterior-posterior CoP value corresponding to the instant the plate started to move. The first peak (FP) was calculated as the difference between the peak reached by the CoP displacement after the external perturbation and the mean value of the anterior-posterior CoP displacement before the PP. This parameter reflected the first reflex reaction of the body to the plate shifting. The maximal oscillation of the CoP was calculated as the sum of the absolute values of FP and the subsequent peak (second peak, SP) following the external perturbation. Moreover, the standard deviation of the CoP signal over a 2.5-second time window from the PP was defined as the post-perturbation variability (PPV). PPV is an index of the efficiency of the subject in controlling the body oscillations immediately after the external perturbation to reach a new quiet condition.

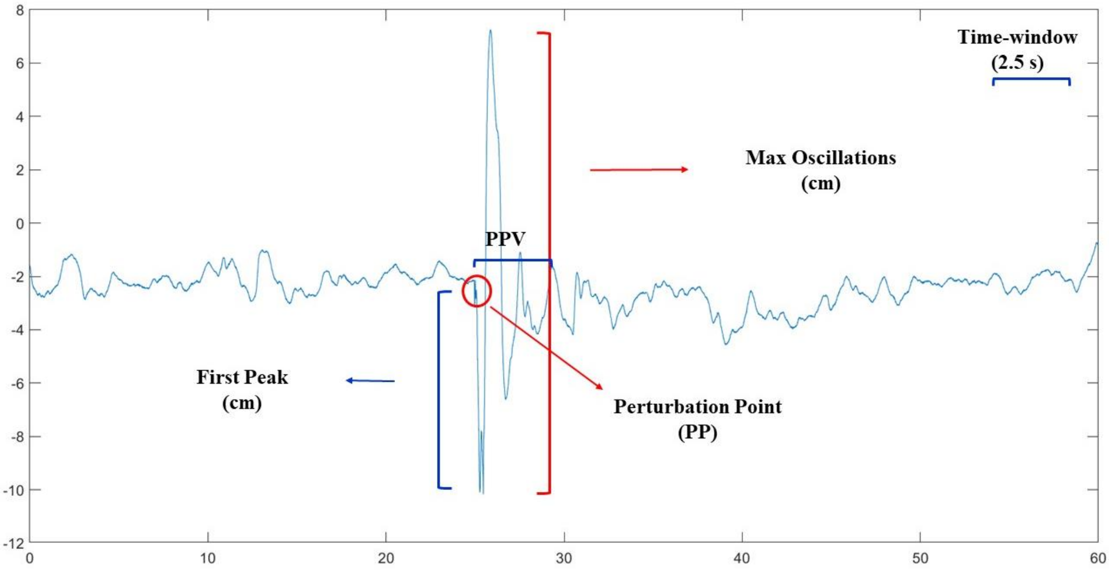


Figure 4.4. Parameters (i.e., First peak, Max Oscillations and Post-perturbation Variability) calculated in the RAMP perturbation in the dynamic balance test.

In the SINE-WAVE test, the Area 95 and the Unit Path parameters were calculated within 20 seconds of the perturbation time (Figure 4.5). Each parameter was averaged over the three trials.

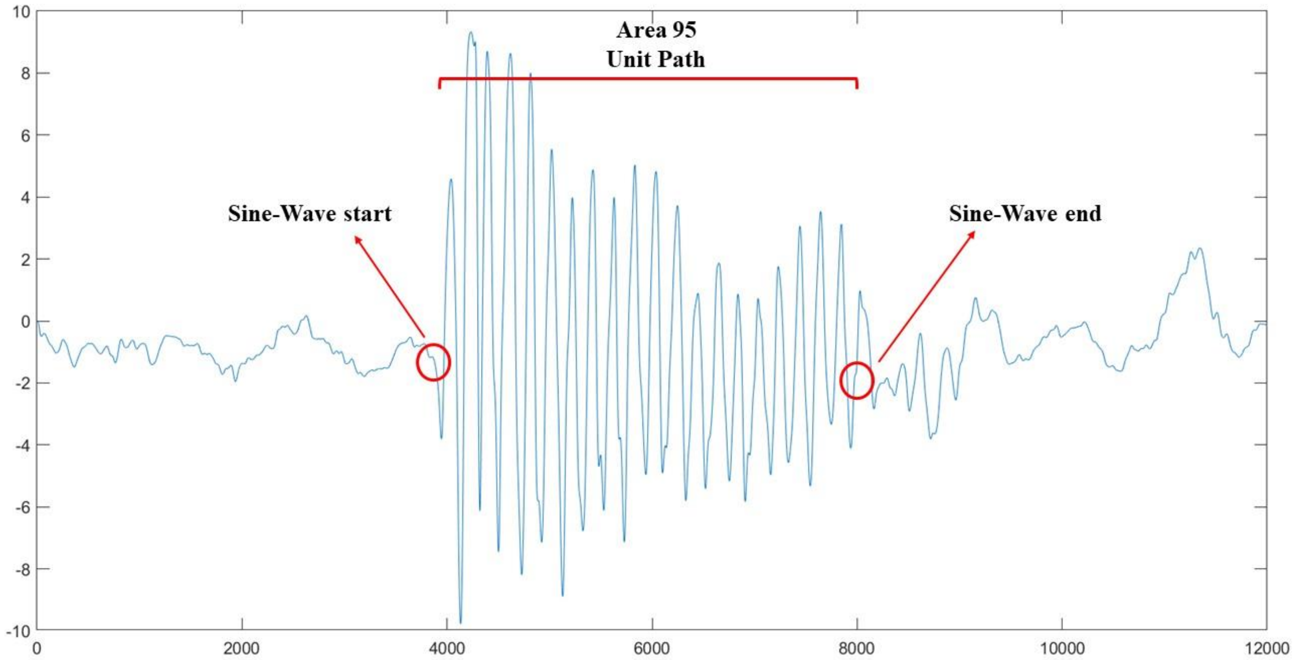


Figure 4.5. Area95 and Unit Path parameters calculated in the 20-second SINE-WAVE perturbation in the dynamic balance test.

All parameters related to dynamic postural control were calculated with MATLAB Software, version R2021b. Finally, the average between the three trials in the "Timed-up and go" and the "10-meter walking" test was considered.

4.4 Statistical Analysis

A two-way ANOVA test for repeated measures was used to investigate any significant main effect of the training (i.e., T_0: 0 weeks, T_1: 6weeks, and T_2: 12 weeks) vs. the group (i.e., ST, UNST, CTRL) in the mean differences for all variables. The significance level was set at $p<0.05$. In case of any statistically significant main effect or interaction, the Bonferroni post-hoc test was performed. JASP Software, version 0.16.3.0 was used for statistical analysis.

4.5 Results

4.5.1 GPAQ

Of the thirty-seven subjects, thirty-four subjects regularly completed the study. The GPAQ questionnaire divided the subjects into three categories (Low, Moderate, and High) based on daily physical activity. Table 4.6 shows the results obtained.

	Subjects (n)		
	High	Moderate	Low
ST	3	7	3
UNST	4	8	0
CTRL	2	5	2

Table 4.6. GPAQ results for UNST, ST and CTRL groups.

4.5.2 Static balance test

Table 4.7 reports the results for the Area95 parameter in the static balance test, presented as mean and standard deviation. The two-way ANOVA did not show any statistically significant main effect of groups, training, or interaction between them.

	Area95 (cm^2)		
	T_0	T_1	T_2
CTRL	1.45 ± 0.47	1.80 ± 0.62	1.79 ± 1.13
ST	1.26 ± 0.32	1.50 ± 0.54	1.61 ± 0.64
UNST	1.26 ± 0.52	1.30 ± 0.56	1.58 ± 1.24

Table 4.7. Area95 parameter in the static balance test for UNST, ST and CTRL group; results are presented as mean ± standard deviation.

Table 4.8 reports the results for the unit Path parameter in the static balance test, presented as mean and standard deviation. The two-way ANOVA did not show any statistically significant main effect of groups, training, or interaction between them.

	Unit Path (cm/s)		
	T_0	T_1	T_2
CTRL	5.99 ± 0.91	6.12 ± 0.97	6.19 ± 0.91
ST	6.02 ± 1.15	6.20 ± 1.17	6.11 ± 1.18
UNST	5.96 ± 1.12	6.02 ± 1.10	6.08 ± 1.08

Table 4.8. Unit Path parameter in the static balance test for UNST, ST and CTRL group; results are presented as mean ± standard deviation.

4.5.3 Dynamic balance test with RAMP perturbation

First Peak. Figure 4.6 reports the results for the First peak in dynamic balance test with the RAMP perturbation. The two-way ANOVA did not show a statistically significant main effect of training, group, and interaction training vs. group: CTRL (T_0: 7.33 ± 1.11, T_1: 7.49 ± 0.80, T_2: 7.62 ± 0.98); ST (T_0: 6.88 ± 0.64, T_1: 6.83 ± 0.66, T_2: 7.02 ± 0.85); UNST (T_0: 7.35 ± 0.58, T_1: 7.10 ± 0.94, T_2: 6.71 ± 0.76).

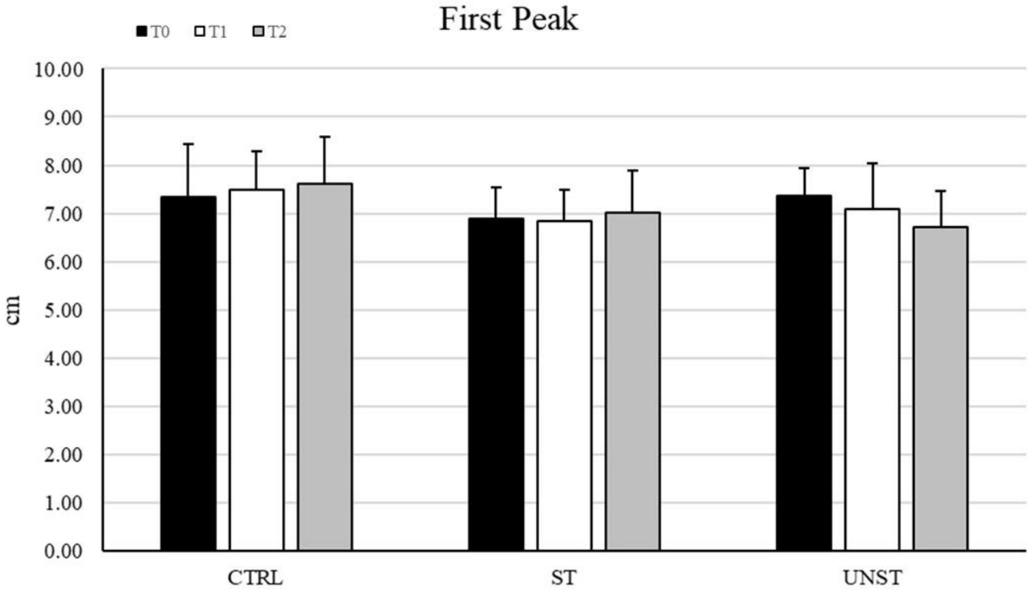


Figure 4.6. First peak parameter in the RAMP dynamic balance test for UNST, ST and CTRL group; results are presented as mean ± standard deviation.

Max Oscillations. Figure 4.7 reports the results for the max oscillations parameter in dynamic balance test with the RAMP perturbation. The two-way ANOVA showed a statistically significant main effect of training ($p < 0.001$), and interaction training vs. group ($p < 0.05$): CTRL (T_0: 11.70 ± 2.55, T_1: 11.33 ± 2.49, T_2: 10.79 ± 2.71); ST (T_0: 12.14 ± 2.37, T_1: 10.01 ± 1.82, T_2: 10.43 ± 2.45); UNST (T_0: 12.77 ± 2.27, T_1: 10.86 ± 2.48, T_2: 9.67 ± 2.29). In detail, the Bonferroni post-hoc comparisons showed significantly higher values in T_0 compared to T_1 ($p < 0.01$) and T_2 ($p < 0.05$) in the ST group. Similarly, significant higher values were observed in the T_0 compared to T_1 ($p < 0.05$) and T_2 ($p < 0.001$) in the UNST group.

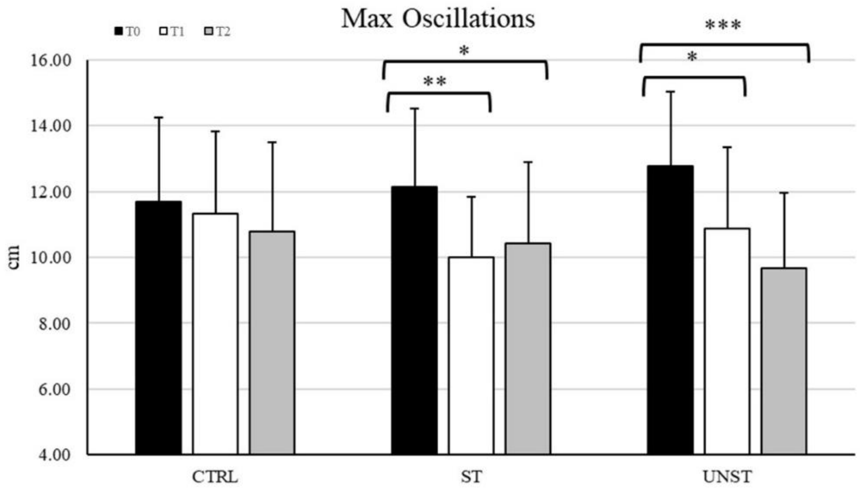


Figure 4.7. Max Oscillations parameter in the RAMP dynamic balance test for UNST, ST and CTRL group; results are presented as mean ± standard deviation. Significantly different *(p< 0.05); ** (p< 0.01); *** (p< 0.001).

Post-perturbation variability. Figure 4.8 reports the results for the post-perturbation variability parameter in dynamic balance test with the RAMP perturbation. The two-way ANOVA showed a statistically significant main effect of training ($p < 0.001$): CTRL (T_0: 2.70 ± 0.66, T_1: 2.48 ± 0.56, T_2: 2.40 ± 0.57); ST (T_0: 2.93 ± 0.55, T_1: 2.25 ± 0.33, T_2: 2.30 ± 0.51); UNST (T_0: 3.19 ± 0.72, T_1: 2.57 ± 0.83, T_2: 2.27 ±0.56). In detail, the Bonferroni post-hoc comparisons showed significantly higher values in T_0 compared to T_1 ($p < 0.01$) and T_2 ($p < 0.01$) in the ST group. Similarly, significantly higher values were observed in the T_0 compared to T_1 ($p < 0.01$) and T_2 ($p < 0.001$) in the UNST group.

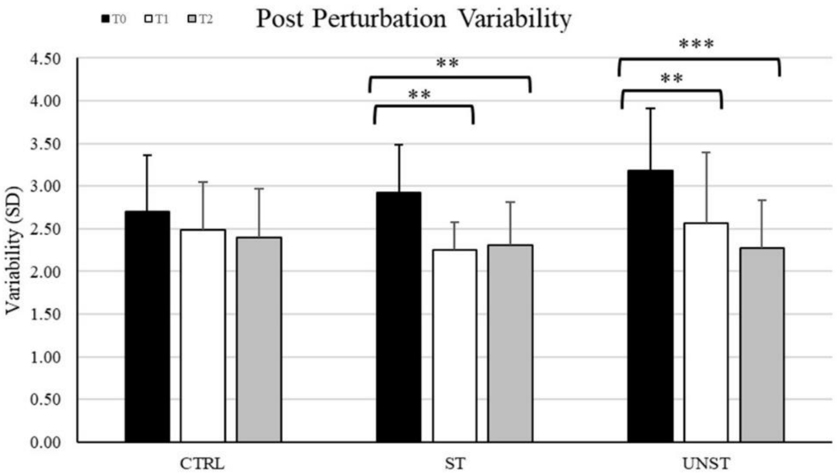


Figure 4.8. Post-perturbation variability parameter in the RAMP dynamic balance test for UNST, ST and CTRL group; results are presented as mean ± standard deviation. Significantly different ** (p< 0.01); *** (p< 0.001).

4.5.4 Dynamic balance test with SINE-WAVE perturbation

Area95. Figure 4.9 reports the results for the Area95 parameter in dynamic balance test with the SINE-WAVE perturbation. The two-way ANOVA showed a statistically significant main effect of training ($p < 0.001$) and interaction training vs group ($p< 0.001$): CTRL (T_0: 29.89 ± 10.09, T_1: 20.56 ± 6.67, T_2: 18.27 ± 7.25); ST (T_0: 31.86 ± 20.13, T_1: 20.16 ± 8.64, T_2: 16.39 ± 6.37); UNST (T_0: 31.84 ± 20.63, T_1: 20.33 ± 8.80, T_2: 17.48 ± 6.46). In detail, the Bonferroni post-hoc comparisons showed significantly higher values in T_0 compared to T_2 ($p < 0.05$) in the ST group. Similarly, significantly higher values were observed in the T_0 compared to T_2 ($p < 0.01$) in the UNST group.

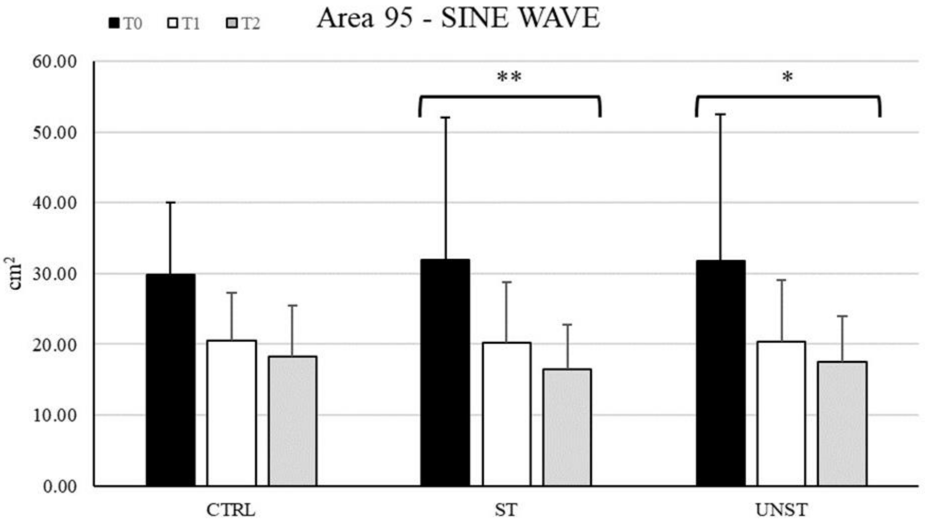


Figure 4.9. Area95 parameter in the SINE-WAVE dynamic balance test for UNST, ST and CTRL group; results are presented as mean ± standard deviation. Significantly different *($p< 0.05$); ** ($p< 0.01$).

Unit Path. Figure 4.10 reports the results for the Unit Path parameter in dynamic balance test with the SINE-WAVE perturbation. The two-way ANOVA showed a statistically significant main effect of training ($p < 0.001$): CTRL (T_0: 15.07 ± 3.65, T_1: 11.80 ± 3.37, T_2: 10.57 ± 4.11); ST (T_0: 14.96 ± 6.25, T_1: 11.35 ± 4.36, T_2: 9.72 ± 3.71); UNST (T_0: 15.08 ± 6.14, T_1: 12.20 ± 4.28, T_2: 10.72 ± 3.59). In detail, the Bonferroni post-hoc comparisons showed significantly higher values in T_0 compared to T_1 ($p < 0.05$) and T_2 ($p < 0.001$) in the ST group. Moreover, significantly higher values were observed in the T_0 compared to T_2 in the CTRL ($p < 0.01$) and UNST ($p < 0.01$) group.

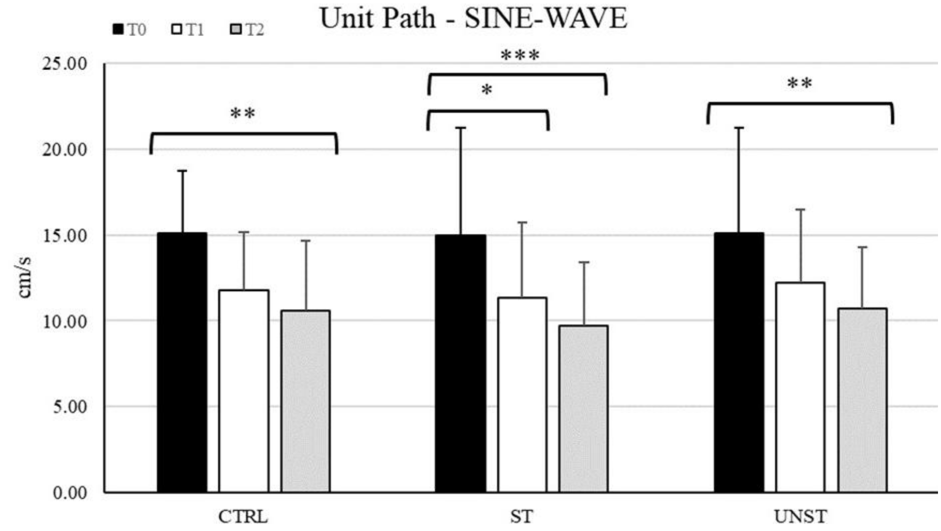


Figure 4.10. Unit Path parameter in the SINE-WAVE dynamic balance test for UNST, ST and CTRL group; results are presented as mean ± standard deviation. Significantly different *(p< 0.05); ** (p< 0.01); *** (p< 0.001).

4.5.5 Maximal isometric lower-limb strength

Figure 4.11 reports the results for the maximal isometric strength of the dominant lower limb. The two-way ANOVA showed a statistically significant main effect of training ($p < 0.001$), and interaction training vs. group ($p < 0.01$): CTRL (T_0: 5.78 ± 0.16, T_1: 5.77 ± 0.12, T_2: 5.50 ± 0.14); ST (T_0: 5.52 ± 0.15, T_1: 7.04 ± 0.13, T_2: 6.99 ± 0.14); UNST (T_0: 6.23 ± 0.13, T_1: 6.93 ± 0.22, T_2: 7.08 ± 0.22). In detail, the Bonferroni post-hoc comparisons showed significantly lower values in the T_0 compared to T_1 ($p < 0.001$) and T_2 ($p < 0.001$) in the ST group.

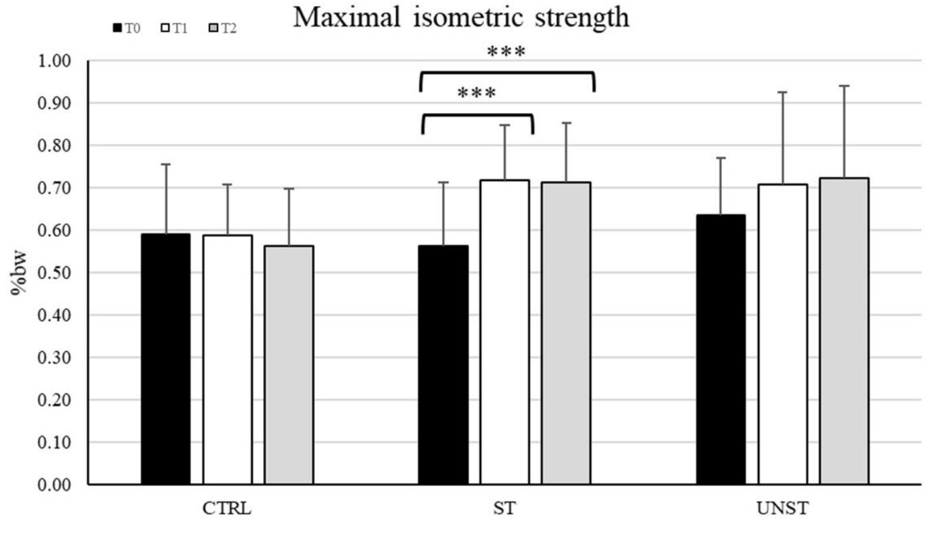


Figure 4.11. Maximal isometric strength of the dominant lower limb. Results for UNST, ST and CTRL group presented as mean ± standard deviation. significantly different *** ($p < 0.001$).

4.5.6 Handgrip test

Table 4.9 reports the results for the handgrip test presented as mean and standard deviation. The two-way ANOVA did not show any statistically significant main effect of groups, training, or any interaction between them.

	Handgrip (kg)		
	T_0	T_1	T_2
CTRL	34.24 ± 10.40	32.89 ± 10.07	33.38 ± 8.49
ST	30.95 ± 6.67	30.93 ± 7.45	31.82 ± 6.81
UNST	33.20 ± 8.96	32.93 ± 9.65	34.82 ± 9.32

Table 4.9. Handgrip of the dominant upper limb. Results for UNST, ST and CTRL group presented as mean ± standard deviation.

4.5.7 Timed up and go test

Table 4.10 reports the results for the Timed up and go test presented as mean and standard deviation. The two-way ANOVA did not show any statistically significant main effect of groups, training, or any interaction between them.

	Timed up and go (s)		
	T_0	T_1	T_2
CTRL	9.98 ± 1.78	9.93 ± 1.76	9.86 ± 1.86
ST	8.83 ± 1.00	8.88 ± 1.04	8.47 ± 0.81
UNST	9.19 ± 1.00	8.95 ± 1.00	8.64 ± 0.89

Table 4.10. Timed up and go results for UNST, ST and CTRL group presented as mean ± standard deviation.

4.5.8 10 meter-walking test

Table 4.11 reports the results for the 10 meter-walking test presented as mean and standard deviation. The two-way ANOVA did not show any statistically significant main effect of groups, training, or any interaction between them.

	10 meter-walking (s)		
	T_0	T_1	T_2
CTRL	7.46 ± 0.67	7.73 ± 0.82	7.85 ± 0.91
ST	7.15 ± 0.84	7.21 ± 0.61	7.09 ± 0.65
UNST	7.54 ± 0.48	7.32 ± 0.52	7.58 ± 0.77

Table 4.11. 10 meter-walking results for UNST, ST and CTRL group presented as mean ± standard deviation.

4.6 Discussion

The present 12-week longitudinal study aimed to evaluate the effectiveness of two training programs performed respectively, with and without unstable devices, on improving strength and balance in older adults over 65. The hypothesis was that training with unstable devices increased balance control, given the exercises performed in unstable conditions, while that training in stable conditions could show the greatest improvement in strength. Results showed significant improvements in maximal isometric strength in the ST group and significant changes in dynamic balance parameters in both groups. In detail, the lower-limb maximal isometric strength significantly improved only after 12 weeks of training in the ST group (+27%). However, the UNST group showed a non-significant improvement (+14%). These values align with the previously published results, which demonstrated the effect of training in increasing strength between 6% and 60% (Cadore et al., 2013). However, the studies considered in this meta-analysis (Cadore et al., 2013) were on highly deconditioned subjects with a very low starting level compared to the subjects of this work. Indeed, deconditioned or post-hospitalized older adults who participated in multicomponent training had greater functional gains with greater subsequent maintenance of these gains (Stevens-Lapsley et al., 2016). However, we intentionally investigated the effect of a multi-modal training protocol in healthy and physically active older adults giving an ecological impact to the results. Hence, the training protocols applied in this study are effective for a large population and are not limited to an institutionalized environment.

Moreover, the different training modalities can explain the difference between the two intervention groups. Precisely, the UNST group performed the strength exercises on UNST surfaces, and this did not allow using the same loads used by the ST group. Indeed, given the need for continuous adaptation to the unstable surface, exercising with unstable devices might cause a decrease in force expression (Behm et al., 2015). As per the balance parameters, there were no significant differences in the static tests. This can be due to the low selectivity of the test when administered to healthy populations (Petró et al., 2017). These results supported the theory that specific tasks are more selective than simple tasks in classifying subjects' balance performance (Asseman et al., 2008).

On the other hand, in the dynamic balance tests with the RAMP perturbation, there were improvements in the two groups in the Maximal Oscillations and the PPV. No statistically significant change was found in the First Peak parameter. The First Peak is the peak of the CoP displacement on the y-axis that occurs immediately after the perturbation point. This parameter is representative of the first reflex reaction of the postural control system. Therefore, the subject automatically responds actuating automatic strategies to move the CoP oppositely to the received perturbation. Even though the UNST group demonstrated a non-significant improvement in this parameter, we considered that the First Peak could not be sensitive to training being a reflex action. The Maximal Oscillations significantly decreased in the UNST group from T_0 to T_1 and from T_1 to T_2; the ST group had a significant improvement only from T_0 to T_1. Similarly, the PPV followed the trend found in the previous parameter. Spinal cord-mediated stretch reflexes are the first response to external perturbations. These reflexes have the shortest latencies (<70 ms), are independent of task demands, and produce stereotyped muscle contractions in response to external sensory stimuli. Conversely, voluntary responses have the most prolonged latencies (>150 ms), are independent of the task's parameters, and produce highly variable motor responses (Shemmell et al.; Ghez and Shinoda, 1978; Merriman et al., 2015). Since both the Maximal Oscillations and PPV detects postural responses with the longest latencies (>150 ms) we can speculate that voluntary control mechanisms occurred and were most sensitive to training. Thus, both training protocols improved the CoP-related parameters in dynamic balance control. Moreover, even not significantly, training with unstable devices seemed to improve dynamic balance in the medium-long term (from the sixth to the twelfth week). Indeed, compared to stable surfaces, unstable devices could better stimulate the proprioceptive system, one of the systems involved in balance control.

In the dynamic balance tests with Sine-Wave perturbation, the Area95 and the Unit Path showed significant improvements in both groups after training. However, only the Unit path parameter showed significantly better results from T_0 to T_2 for the CTRL group.

Since Area95 is considered an index of the overall postural performance (Asseman et al., 2004; Paillard and Noé, 2015), we can assume that both training protocol in improving the overall subjects' balance ability in responding to dynamic continuous stimuli. Conversely, the Unit Path reflects the efficiency of the postural control system characterizing the net neuromuscular activity necessary to maintain the balance (Paillard and Noé, 2006, 2015). Some authors (Prieto et al., 1996; Raymakers et al., 2005; Masani et al., 2014) also considered the most sensitive parameter to compare groups of individuals of different ages or with different neurological diseases. However, the theory of intending Area95 as the overall postural performance and the Unit Path as the efficiency of the postural control system should be applied with caution to dynamic tests since the first assumptions were made on static balance tests (Paillard and Noé, 2015).

Unlike the Area95 results, the Unit Path showed an improvement in balance efficiency also in the CTRL group that did not correspond to an improvement in the overall balance performance. Thus, considering the significant improvement of this parameter, we can speculate that a possible learning effect may have occurred, leading to better management of the dynamic balance task. However, this hypothesis needs further studies given the time elapsed between each balance test (i.e., six weeks) that did not imply a learning effect with certainty. Comparing the dynamic balance results with those in the literature is complex since previous studies that examined the effectiveness of training protocols on dynamic balance used mainly field tests to investigate balance ability. For instance, the analyzed studies in the scientific literature used field tests as the 8-foot-up-and-go test, timed-walking distance, Functional reach test, and 6-m backward walking (Rodriguez-Larrad et al., 2017; Cordes et al., 2019). Even though these tests showed good validity and reliability among older, frailer adults, a ceiling effect when applied in high-functioning older adults can be observed (Hayes and Johnson, 2003; Langley and Mackintosh, 2007; Pardasaney et al., 2012; Schoene et al., 2013; Fleig et al., 2016; Weber et al., 2018). Indeed, these tests resulted in undemanding for healthy people, failing to elicit postural stability deficiencies and discriminate the performance level (Ringhof and Stein, 2018).

This concept may also be applied to our results that, in any training, did not show an improvement in handgrip strength, static balance, and field test performance. Since older adults in this study were moderately physically active, we did not expect changes after a three-month training in walking velocity, handgrip strength, and static balance performance. Indeed, field tests (i.e., timed-up and go, 10-meter walking) and handgrip strength as an index of health-related physical fitness were not sensitive enough to detect improvements in high-functioning older adults, and their use should be appropriate with deconditioned subjects or in a clinical setting. Moreover, the non-improvement evidence in the static balance test is coherent with the proposed balance training, mostly performed dynamically or with the base of support restriction.

4.7 Conclusions

In conclusion, twelve weeks of training on stable surfaces significantly improved lower limb strength and dynamic balance parameters, even after the first six weeks. Training on unstable devices improved dynamic balance at 12 weeks without significantly improving strength. Therefore, the two workouts improved the analyzed variables in different time phases. In detail, the ST group showed improvements in strength and balance only in the first six weeks, with maintenance between the sixth and twelfth week. Conversely, the higher proprioceptive stimuli given by the unstable devices to the UNST group showed a tendency to improve dynamic balance from the sixth to the twelfth week without significant increases in strength in the same period. On this point, the ongoing increase in the sample size will confirm these hypothesis. Although the subjects were mainly physically active, and some performed one structured activity per week, the implemented training protocols allowed them to increase further their lower limb strength and balance ability. Finally, multimodal training should be used to improve balance and primary prevention of falls, especially among healthy older adults.

Our training protocol is not strictly comparable to training modality or fall education programs designed to promote fall prevention in the community-dwelling population or only those at high risk.

Chapter 5

Effectiveness and therapeutic compliance of digital therapy in shoulder rehabilitation: a randomized controlled trial

5.1 Introduction

The latest development of technologies and connectivity, together with ever-growing computing, networking, and sensing power is progressively changing people's habits (Do Nascimento et al., 2020). Nowadays, the employment of digital equipment and devices represents a focal core in most areas of society, including health and medical monitoring. Digital therapy with interactive games, virtual reality, websites, and robotics represents a new opportunity for multimodal treatments in many rehabilitation contexts (Wade et al., 2018). About that, the Nintendo Wii had been regularly used as a rehabilitation tool in 61% of Australian rehabilitation centers to treat people post-stroke (Taylor et al., 2011). Indeed, visual and sound feedbacks are essential to improve motor control in pathologies or injury treatment and prevention (Walker et al., 2000; Geiger et al., 2001). Low-cost devices such as the Kinect sensor or the Nintendo Wii Balance Board have been reported as playful and motivating tools in the rehabilitation of children with cerebral palsy (Decavele et al., 2020). In the pediatric field, De Kloet and colleagues reported that children with acquired brain injury had cognitive and motor benefits following a 12-week tailored rehabilitation program with the Nintendo Wii (De Kloet et al., 2012). The rationale behind the increased application of digital therapies is to improve patients' motivation influencing their affective response (Dennett and Taylor, 2015; Bethi et al., 2020). Additionally, since subjects can perceive therapeutic exercises as monotonous, an interactive approach has been demonstrated to improve the compliance of patients (Dennett and Taylor, 2015). Moreover, after completing the rehabilitation, virtual reality or gaming interventions showed improved treatment adherence, engagement (Lohse et al., 2013), and quality of life over conventional treatment of upper limb functions in patients with stroke (Kwon et al., 2012). However, many commercial video games are designed for leisure and are not oriented toward definite rehabilitation goals. Noteworthy, motivational factors related to engagement in rehabilitation though gaming systems are still limited (Subramanian et al., 2020). Although no specific recommendations exist on video games as a rehabilitation tool, several studies have shown promising results on specific parameters of upper limb function, gross motor function, and pain reduction (McNulty, 2012; Putrino et al., 2017; Domínguez-Téllez et al., 2020). In this context, the device PlayBall® (Playwork, Alon 10, Ness Ziona, Israel) is a novel digital therapy gaming system with possible motivational assets in physiotherapy. Specifically, PlayBall® is a smart exercise ball functioning as a performance-measuring tool and videogame controller that allows patients to complete rehabilitation games and receive real-time visual feedback. The interactive ball allows measuring both movement and pressure applied on it. Smart integrated sensors objectively measure and track the performance to monitor the patient's progress. Therefore, the objectives of this study were: (i) to evaluate whether the use of a novel digital therapy gaming system (PlayBall®) was therapeutically relevant during shoulder rehabilitation; (ii) to understand whether PlayBall® was effective in improving patients' engagement in comparison to a control non-gaming rehabilitation program.

5.2 Methods

5.2.1 Subjects

Subjects were recruited from a medical center (CEMES, Data Medica group, Synlab S.p.A., Padova, Italy). The following inclusion and exclusion criteria were considered for recruitment. Inclusion criteria: (i) presence of one of the following shoulder pathologies: impingement syndrome, capsulitis, tendon injuries, degenerative joint or tendon pathologies; (ii) pain between 2/10 and 8/10 on a visual analogue scale. Exclusion criteria: (i) post-surgical patients; (ii) inability to perform active exercises; (iii) peripheral neurological deficits; (iv) cervical-brachialgia; (v) algodystrophy. The choice of the sample size was based on an a priori power analysis (G*Power Version 3.1.9.4). Based on the MANOVA, we obtained a sample size of 22 subjects considering as input a large effect size ($f = 0.40$), $p = 0.05$, and Power (1-β error probability) = 0.7. Twenty-eight subjects were potentially screened, but six did not accept to participate to the study. Thus, twenty-two subjects (age = 61 ± 10.4 years; F = 16; M = 6) were finally enrolled.

5.2.2 Experimental design

The experimental protocol received approval by the Human Ethical Committee of the Department of Biomedical Sciences of the University of Padova (n° HEC-DSB/02-21; NCT 05230056) and adhered to the principles of the Declaration of Helsinki. All the subjects, informed about the methods of the study, gave their written informed consent, and were free to renounce the study at any stage. Specifically, they were informed that, before and after their shoulder rehabilitation protocols, they should have performed a strength and mobility assessment, and filled in some questionnaires. Subjects were randomly divided (https://www.graphpad.com/quickcalcs/randomize1/) by a researcher of the Department of Biomedical Sciences not involved in the study and unaware of the aims of the research. In detail, a group underwent a digital therapy with the Playball® device (PG; N=11; age: 59.9±10.2 yrs) and a group followed an equivalent but non-digital rehabilitation program (CTRL; N = 11; age: 62.0 ± 10.9 yrs). All participants, summarized in table 5.1, were blinded with respect to the differences between the two therapeutic protocols.

	Age (yrs)	Mass (kg)	Height (m)
Control Group (n=11)	62.0 ± 10.20	71.50 ± 12.90	166.90 ± 9.50
Playball Group (n=11)	59.91 ± 10.93	72.30 ± 15.90	163.60 ± 7.20

Table 5.1. Characteristics of the participants. Data are presented as mean ± standard deviation.

We outlined a randomized controlled trial in which both CTRL and PG underwent ten consecutive shoulder rehabilitation sessions (from Monday to Friday, excluding Saturday and Sunday). In particular, the daily rehabilitation session lasted 40 minutes. Within each session, the first 20 minutes, the subject was treated manually by the physiotherapist, while the last 20 minutes performed active exercises to improve shoulder strength and mobility. Physiotherapists performed an equal manual treatment for both CTRL and PG. Conversely, active exercises supervised by researchers had the same goals but differed in the exercising modality that was non-digital for CTRL and digital for PG. Before and immediately after the ten rehabilitation sessions, the subject participated in an evaluation session comprising functional and self-reported measures. The shoulder rehabilitation session of all the patients were administered in the same medical center (CEMES, Data Medica group, Synlab S.p.A., Padova, Italy).

5.3 Functional assessments

The shoulder mobility and strength assessments were carried out the day before (T_0) and the day after (T_1) the rehabilitation period by physiotherapists blind to the group allocation.

5.3.1 Mobility assessment

Shoulder mobility was measured with a wireless inertial sensor (Gyko, Microgate Italia - Bolzano, Italy) at a sampling frequency of 500 Hz. Following the manufacturer’s guidelines, the Gyko was applied to the injured arm with an elastic band at the distal level of the humerus, right above the elbow joint. The mobility assessment was performed for arm flexion, abduction, external rotation, and extension. Subjects performed all movements while seated with their backs on the wall, excluding the extension movement that was performed while standing. Subjects were instructed to perform all the movements at a self-selected speed and range of motion (ROM) with the indication not exceeding shoulder pain limits. Overall, three trials were performed, with a recovery of 30 seconds in between. Data were analyzed with the software GykoRePower (Gyko, Microgate Italia - Bolzano, Italy) to obtain the ROM (deg) and mean velocity (deg/s) of each movement.

5.3.2 Strength assessment

The Playball® was employed to measure the isometric maximal strength (F_{max}) of the injured shoulder. The device was positioned under the subject's hand and over a solid surface. From a seated position, the subject was asked to push down the Playball® as strongly as possible with the shoulder abducted to 70 deg and elbow extended. Three maximal voluntary contractions (MVC) lasting three seconds each, with a between-trial recovery of 30 seconds, were performed. During the MVC test, the subject had real-time visual feedback of the force he was expressing displayed on a tablet.

5.4 Questionnaires

A questionnaire package was used to assess three different dimensions: (a) the shoulder global health status; (b) the affective response; (c) the usability of the system. In all cases, the questionnaires were administered in a quiet room. The researcher made clear what each dimension of the questionnaire meant and clarified any queries. The subjects were not asked to give their names and were ensured that answers would remain anonymous. Questionnaires were administered in the same occasions the shoulder mobility and strength assessment occurred. A questionnaire for the usability of the system was administered only to PG. Moreover, during the mobility assessment, the level of pain corresponding to the execution of each movement was assessed with a visual analogue scale (VAS) (Hawker et al., 2011). The pain levels assessed after each movement (i.e., flexion, abduction, external rotation, and extension) with VASs were averaged in a single score as output (VAS-PAIN).

5.4.1 Shoulder global health status

The PENN Shoulder Score was employed to investigate the shoulder global health status. It consists of three sections that measure shoulder pain, satisfaction, and function. The pain section quantifies the pain of the shoulder at rest, during common and strenuous activities, for a maximum score of 30 points, indicating the absence of pain. The shoulder satisfaction corresponds to a single item for a maximum score of 10 points representing the highest degree of satisfaction. The functionality section consists of 20 items on a four-point Likert scale: 0 points (impossible to perform), 1 point (very difficult), 2 points (some difficult), and 3 points (no difficult). The subjects were asked to focus on the injured shoulder while performing daily living activities. The three-section best score is 100 points, indicating the absence of pain, high functionality, and good subject's satisfaction of the shoulder (Leggin et al., 2006).

5.4.2 Enjoyment

An adapted version of the Italian Physical Activity Enjoyment Scale (PACES) (Carraro et al., 2019) was used to assess pleasure during therapy. The PACES discriminates between pleasant and unpleasant experiences associated with physical activity. For this study, the PACES 12-item version (Carraro et al., 2014) was used adapting the stem in "When I perform the therapeutic exercises, I …", and participants rated their agreement with 6 positive (e.g., "*I enjoy*") and 6 negative (e.g., "*I feel bored*") items on five-point Likert scale (1 = "*totally disagree*" to 5 = "*completely agree*"). The total score ranged from 12 to 60 and Cronbach's α was 0.82 for T_0 and 0.92 for T_1.

5.4.3 Self-efficacy

Self-efficacy is defined as the perceived ability to plan and execute specific behaviors (Bandura et al., 1999); it is associated with the intention to perform the specific behavior. Self-efficacy in performing exercises during intervention was studied with a one-item scale (i.e., "How confident are you in your ability to perform the therapeutic exercises correctly?") ranging from 1 (*not confident at all*) to 7 (*absolutely confident*).

5.4.4 Attitude to train at home

Attitudes towards a behavior (i.e., a positive or negative predisposition towards a specific behavior) are crucial in the intention to perform that behavior (Ajzen, 1985). Specifically, attitudes towards exercise at home were estimated by the mean score of responses to the question "*Doing shoulder exercises one hour a day at home after the rehabilitation cycle is…*". Responses were rated on a 7-point Likert-type scale on six bipolar adjectives: bad/good, wrong/right, unpleasant/pleasant, useless/useful, difficult/easy, and boring/funny.

5.4.5 Intention to train at home

Intention can be defined as the will to perform a specific behavior and it is considered the most proximal antecedent to the behavior itself. Considering the theory of planned behavior (Ajzen, 1985), the intention to exercise at home was assessed using a two-item questionnaire (Ajzen, 2002). A seven-point scale ranging from 1 ("*totally disagree*"") to 7 ("*totally agree*") was used for each item. Answers were given to the following statements: (i) *"after the therapy period, I intend to perform shoulder exercises twenty minutes per three times a week at home"*; (ii) *"after the therapy period, I am* *determined to perform shoulder exercises twenty minutes per three times a week at home "*. The scores were averaged to compute a mean score.

5.4.6 Usability

The Italian version of the System Usability Scale (SUS), (Borsci et al., 2009) was employed to assess the Playball® system. The SUS is a ten-item questionnaire that operationally defines the subjective perception of interaction with a system (Brooke, 1996). Items from SUS considered the following sections: (i) subjects' ability to complete activities using the system and the quality of the output of activities performed (i.e., effectiveness); (ii) the level of resources consumed in carrying out the tasks (i.e., efficiency); (iii) the individual feelings and reactions of subjects using the system (i.e., satisfaction). Moreover, seven VASs (from 0 to 10) were employed to investigate the following dimensions: contact with the tool, controls, perception of security, general comfort, readability of the data, aesthetic pleasantness, and general pleasure; then generating a global averaged score named VAS-US measure.

5.5 Therapeutic protocol

The exercise intervention for both CTRL and PG consisted of a progressive strength and mobility rehabilitative program to be performed in the medical center with the supervision of the physiotherapists, not associated with either study condition.

5.5.1 Digital therapy

The digital therapy allowed the subject to complete the rehabilitation program while playing games and receiving real-time visual feedback. A single digital therapy session was organized in three different 4-minute bouts, including the "PlayMove" exercise and the "real-time force" exercise from seated and standing positions. The "PlayMove" exercise was performed on a 30-deg inclined surface (figure 5.1 A): the exercise started guiding the PlayBall® with the hand until session 3 and then with the elbow. After the fourth session, a contextual pressure to the circular motion of the cursor was added for two sessions at 2%, 5%, and 10% of the measured F_{max}, respectively. In the "Real-time force" exercise from the seated position (figure 5.1 B), the subject was required to perform subsequent isometric contractions on the Playball® with the elbow flexed at 90 deg. The tablet, positioned in front of the subject, allowed having real-time feedback on the force applied. Particularly, the patient was asked to push down and release the Playball® as follows: from session one, 3s contraction and 3s recovery; from session three, 4s contraction and 2s recovery; in session five, 5s contraction and 2s recovery. Patients performed 3 sets of 10 repetitions. "Real-time force" exercise was also performed from the standing position with the elbow extended. The Playball® was placed on a wedge and under the subject’s arm (figure 5.1 C). From sessions one to five, the repetitions were the same as for the seated position. From session six, a new strength exercise, the “Flying rocket”, substituted both the seated and standing “Real-time force” exercise. In this new exercise, the subject was required to guide a spaceship pushing down and releasing the Playball®, aiming to hit stars and avoid asteroids.

4.5.2 Control therapy

Subjects completed a rehabilitation program during the control therapy without any interactive processes or visual feedback. As per the digital therapy, the single session was organized in three different 4-minute bouts, including Perfetti’s circles and isometric contractions from seated and standing positions. In Perfetti’s circles (figure 5.1 D) the subject had to move a ball with the hand following specific circumferences drawn on a 30-deg inclined board. Specifically, the board had 20 concentric circles, tangents in one point, and an increasing radius. The exercise was performed clockwise and counterclockwise. The isometric contractions from seated (Figure 5.1 E) and standing (figure 5.1 F) positions were identical to those performed by the PG but with no visual feedback on the amount of force applied on the ball.

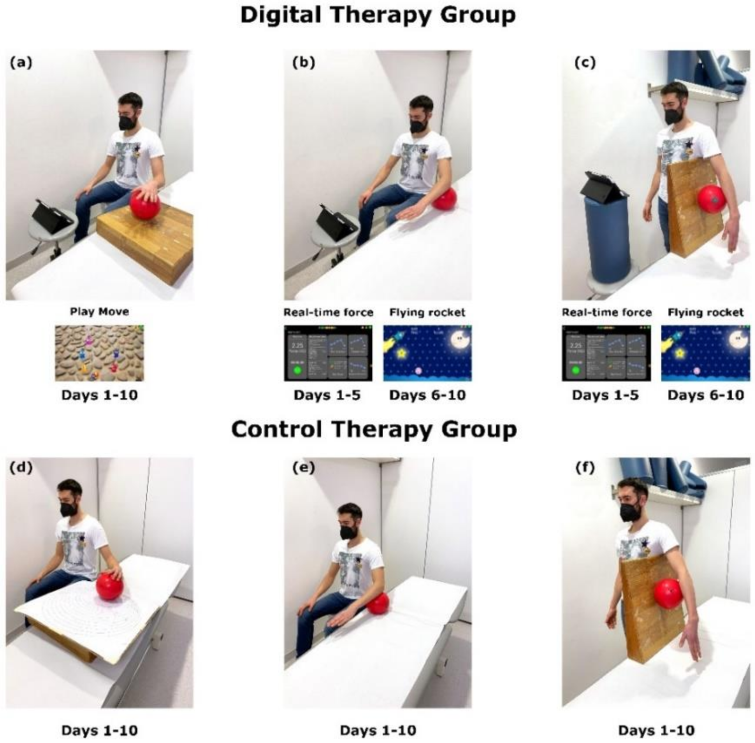


Figure 5.1. Graphical summary of the rehabilitation protocol. Digital therapy is represented in the upper panels together with the screenshots of the gaming interface: “PlayMove” exercise performed from the seated position on a 30-deg inclined surface (a); “Real-time force” and “Flying rocket” exercise from the seated (b) and standing (c) positions. Control therapy is represented in the lower panels: Perfetti’s circles exercise performed on a 30-deg inclined board (d); isometric contractions from the seated (e) and standing (f) positions.

5.6 Statistic al analysis

The mean value and the standard deviations were calculated for each variable. The D'Agostino-Pearson test was employed to check the data normality distribution. An unpaired sample T-test was used for baseline (T_0) comparisons between groups (CTRL vs. PG) on demographic data, functional variables, and shoulder global health status. Moreover, a paired-T-test was used to compare PRE (T_0) and POST (T_1) results of SUS and VAS-US in the PG. A multivariate analysis of variance (MANOVA) was used for comparing functional and affective variables between the two time points (T_0 vs. T_1) and the two groups (CTRL vs. PG). Finally, for both CTRL and PG, the Pearson correlation analysis was performed to investigate the relationship between affective variables considering the differences between T_0 and T_1. The significance level was set at $p < 0.05$. All analyses were performed using Statistical Package for Social Sciences (SPSS) version 27 (IBM, Armonk, New York, USA).

5.7 Results

All the subjects completed the study. Unpaired T-test for baseline comparisons (T_0) showed no statistically significant differences between CTRL and PG for demographic data, functional variables, and shoulder global health status (table 5.2).

	CTRL (T_0)	PG (T_0)	p value
Age (yrs)	62.00 ± 10.20	59.91 ± 10.93	ns
BMI (kg/m^2)	25.81 ± 4.24	26.39 ± 4.21	ns
F_{max} (kg)	15.16 ± 6.72	12.20 ± 5.94	ns
ROM (deg)	309.30 ± 62.66	286.38 ± 57.30	ns
VELOCITY (deg/s)	42.83 ± 26.44	39.05 ± 20.14	ns
VAS-PAIN	4.30 ± 2.52	4.04 ± 2.19	ns
PENN shoulder score	54.70 ± 14.55	54.30 ± 12.64	ns

Table 5.2. Baseline comparisons for all the variables. Data are expressed as mean ± standard deviation. ns: not statistically significant.

The MANOVA analysis revealed a significant main effect of time (T_0 vs. T_1) for F_{max} ($p < 0.05$), VAS-PAIN values ($p < 0.01$), and the PENN Shoulder Score ($p < 0.001$), (table 5.3). Conversely, no significant main effect of groups (CTRL vs. PG) was observed.

	CTRL		PG	
	PRE (T_0)	POST (T_1)	PRE (T_0)	POST (T_1)
F_{max} (kg)	15.16 ± 6.71	18.85 ± 9.16 *	12.20 ± 5.94	15.35 ± 10.67 *
ROM (deg)	309.30 ± 62.65	325.36 ± 70.20	286.38 ± 57.29	283.97 ± 60.47
VELOCITY (deg/s)	42.83 ± 26.44	47.48 ± 24.50	39.05 ± 20.14	40.69 ± 14.84
VAS-PAIN	4.30 ± 2.52	2.70 ± 2.02 **	3.17 ± 2.49	4.04 ± 2.19 **
PENN shoulder score	54.70 ± 14.55	67.29 ± 16.41 ***	54.30 ± 12.64	63.84 ± 13.96 ***

Table 5.3. Results of the MANOVA analysis for the functional variables (i.e., F_{max}, ROM, and Velocity), the VAS-PAIN, and the PENN Shoulder Score. Post-hoc comparisons show the significant main effect of time (T_0 vs. T_1) for both control (CTRL) and PlayBall (PG) group. Significantly different from PRE (T_0): * ($p < 0.05$); ** ($p < 0.01$); *** ($p < 0.001$).

Moreover, MANOVA analysis showed a significant main effect of time (T_0 vs. T_1) only for scores from self-efficacy ($p < 0.05$) and attitude to train at home ($p < 0.05$); post-hoc comparisons are presented in table 5.4. Again, no significant main effect of groups (CTRL vs. PG) was observed in any of the affective variables.

	CTRL		PG	
	PRE (T_0)	POST (T_1)	PRE (T_0)	POST (T_1)
PACES	53.90 ± 4.52	51.63 ± 10.97	50.18 ± 9.44	51.63 ± 8.41
Self-efficacy	5.36 ± 1.20	6.18 ± 0.87 *	5.0 0± 1.09	5.18 ± 1.07 *
Attitude to train at home	5.67 ± 1.59	6.29 ± 0.66 *	4.67 ± 1.24	5.48 ± 1.41 *
Intention to train at home	6.09 ± 1.62	5.90 ± 1.85	5.50 ± 1.56	6.18 ± 1.07

Table 5.4. Results of the MANOVA analysis for the affective variables. Post-hoc comparisons show the significant main effect of time (T_0 vs. T_1) for both control (CTRL) and PlayBall (PG) groups. Significantly different from PRE (T_0): * ($p < 0.05$).

Exclusively in the PG, paired T-test did not show any significant differences between PRE vs. POST comparisons considering the score from SUS (T_0: 67.72 ± 9.96; T_1: 74.54 ± 15.60) and the mean score from VAS-US (T_0: 7.78 ± 1.62; T_1: 7.97 ± 1.53).

Finally, the Pearson correlation analysis showed statistically significant correlations between the Δ scores ($T_1 - T_0$) of affective variables in the PG. Positive significant correlations were found between Δ scores from “PACES” and “Self-efficacy” ($r = 0.623$; $p = 0.041$) and between Δ scores from

"PACES" and "Intention to train at home" (r = 0.674; p = 0.023). In the CTRL, no significant correlations were found considering the Δ scores of affective variables.

5.8 Discussion

The present study aimed to determine the effectiveness of a digital therapy performed with the Playball® device during a shoulder rehabilitation protocol. Both the therapeutic and affective responses to the digital therapy were investigated and compared to a non-digital equivalent rehabilitation protocol. The main finding was that the rehabilitation program carried out with the Playball® was as effective as the equivalent non-digital therapy. Namely, both the proposed rehabilitation programs were effective for shoulder recovery, improving strength, reducing pain, and globally increasing the subjects' self-perceived satisfaction and functionality.

Our findings aligned with previous research (Sin and Lee, 2013; Rizzo et al., 2017; Santos et al., 2019) and revealed that digital therapy could be a viable therapeutic modality, also in shoulder rehabilitation. Briefly, Sin and colleagues studied the effect of a six-week digital intervention with Xbox Kinect in hemiplegic post-stroke patients showing an improved upper limb functionality in the intervention group (Sin and Lee, 2013). Santos and colleagues compared the effects of conventional and digital rehabilitation with Nintendo Wii on balance parameters, walking quality, functional mobility, and quality of life in patients with Parkinson's disease (Santos et al., 2019). Though on a different pathology, similarly to our study, the digital therapy was as successful as the traditional in improving the therapeutic outcomes after two months of rehabilitation (Santos et al., 2019). , Our results showed that the digital therapy effectively reduced pain throughout the range of motion and regained strength levels in short-term shoulder rehabilitation. Similarly, a pilot study on shoulder impingement showed that a Nintendo Wii-based protocol reduced pain and disability, improving quality of life and pain-free shoulder ROM in the sagittal and frontal planes (Rizzo et al., 2017).

Concerning the affective variables, the score from "Self-efficacy" and "Attitude to train at home" dimensions significantly improved following the shoulder rehabilitation, regardless of therapy. Therefore, the practice of therapeutic exercises themselves positively influenced the subjects' self-efficacy and their intention to practice at home. Thus, the longer the rehabilitation time, the more the subjects feel self-confident, and consequently, their will to exercise at home increases. It is well accepted that repeated practice, such as for an exercise training period, increases the subject's confidence and motor learning (Tsutsumi et al., 1997; Vealey and Chase, 2008; Dobkin, 2017). In our case, the therapeutic sessions allowed the subjects to become more familiar with the exercises over time, thus, improving the perception of their ability and performance. Self-efficacy, firstly stated by Bandura in the social cognitive theory (Bandura, 1986), is an important dimension in rehabilitation and physical activity, as it positively influences compliance to the exercise practice (Mcauley et al., 2011). In the field of rehabilitation, increment in self-efficacy in obese patients with knee osteoarthritis underlie higher functionality and lower pain (Mihalko et al., 2019). Another study by Baker and colleagues (Baker et al., 2001) demonstrated that a 4-month strength training significantly decreased pain and improved physical function in patients with knee osteoarthritis by 30% more than a control group. Interestingly, these clinical changes were accompanied by improvements in self-efficacy (Baker et al., 2001). Indeed, the contribution made by self-efficacy to physical function has to be considered in the management of subjects with joint pain or associated pathologies (Hermsen et al., 2016). Given the close relationship between self-efficacy, motivation, and the actuation of a behavior, we can speculate that the increased self-efficacy influenced the attitude to continue exercising even at home.

The usability of the Playball®, evaluated through the SUS, showed an increment score of almost 10% at the end of the rehabilitation program. Although this result was not statistically significant, it underlined that the employment of the Playball® became progressively easier and more familiar over time. In addition, the SUS mean score at the end of the rehabilitation program exceeded the cut-off value of 68 reported in the scientific literature to define "good" the usability of a device (Brooke, 2013). Thus, though the system's usability can be surely improved, no serious problems that limited its employment in the daily rehabilitation were registered. This scale has already proved to be a valid and reliable measure for assessing technological tools (Friesen, 2017). A study by Hägglund and colleagues recently employed the SUS to assess the Swedish patient accessible electronic health record (Hägglund and Scandurra, 2021). A point in favor of the device usability is the high sensitivity of the pressure sensor which allows the employment independently from the patients' level of strength. Moreover, the games are designed to be performed without requiring a minimum range of motion.

Given the importance of therapeutic effectiveness, the purpose of digital therapies is also to be more attractive and entertaining than conventional treatments, allowing patients to be less focused on their health status because of the enjoyment induced by the games. Indeed, two significant positive correlations were detected only in the PG. The Δ score from PACES significantly correlated with the Δ scores from the "self-efficacy" scale and the "intention to train at home" scale. Thus, the greater the enjoyment in rehabilitation with Playball®, the greater the self-efficacy and the stronger intention to continue exercising at home once the rehabilitation is ended. This result highlighted that the digital therapy with Playball® was positive and favored a greater patient engagement.

The present study has some potential limitations to acknowledge. First, though the short-term application of digital therapy could represent a novelty in this field, long-term compliance was not addressed in this study. Second, although researchers supervised the rehabilitation sessions, treatment-fidelity was not objectively measured. Third, a follow-up time-point after the end of the therapies should have been considered for assessing the retention of improvements. Moreover, results should be confirmed in a larger number of patients since the sample size of the present study was not fully representative of the whole population suffering from shoulder impairments.

5.9 Conclusions

Although digital therapy should not inevitably replace conventional methods, findings of the present study demonstrated that in shoulder rehabilitation, digital therapy with Playball® could be as effective as an equivalent non-digital therapy. Moreover, the device favored greater subject engagement, which could potentially lead to a greater predisposition to exercising individually at home. However, though the Playball® was globally evaluated as good in terms of usability, our results still encourage the improvement of the device usability.

Chapter 6

References

Adams, J. A. (1987). Historical review and appraisal of research on the learning, retention, and transfer of human motor skills. *Psychol. Bull.* 101, 41–74. doi:10.1037/0033-2909.101.1.41.

Agrawal, Y., Merfeld, D. M., Horak, F. B., Redfern, M. S., Manor, B., Westlake, K. P., et al. (2020). Aging, Vestibular Function, and Balance: Proceedings of a National Institute on Aging/National Institute on Deafness and Other Communication Disorders Workshop. *J. Gerontol. A. Biol. Sci. Med. Sci.* 75, 2471–2480. doi:10.1093/GERONA/GLAA097.

Ajzen, I. (1985). From Intentions to Actions: A Theory of Planned Behavior. *Action Control*, 11–39. doi:10.1007/978-3-642-69746-3_2.

Ajzen, I. (2002). Perceived Behavioral Control, Self-Efficacy, Locus of Control, and the Theory of Planned Behavior1. *J. Appl. Soc. Psychol.* 32, 665–683. doi:10.1111/J.1559-1816.2002.TB00236.X.

Ashmen, K. J., Buz Swanik, C., and Lephart, S. M. (1996). Strength and flexibility characteristics of athletes with chronic low-back pain. *J. Sport Rehabil.* 5, 275–286. doi:10.1123/jsr.5.4.275.

Asseman, F. B., Caron, O., and Crémieux, J. (2008). Are there specific conditions for which expertise in gymnastics could have an effect on postural control and performance? *Gait Posture* 27, 76–81. doi:10.1016/J.GAITPOST.2007.01.004.

Asseman, F., Caron, O., and Crémieux, J. (2004). Is there a transfer of postural ability from specific to unspecific postures in elite gymnasts? *Neurosci. Lett.* 358, 83–86. doi:10.1016/j.neulet.2003.12.102.

Axler, C. T., and McGill, S. M. (1997). Low back loads over a variety of abdominal exercises: searching for the safest abdominal challenge. *Med. Sci. Sports Exerc.* 29, 804–810. doi:10.1097/00005768-199706000-00011.

Baker, K. R., Nelson, M. E., Felson, D. T., Layne, J. E., Sarno, R., and Roubenoff, R. (2001). The efficacy of home based progressive strength training in older adults with knee osteoarthritis: a randomized controlled trial. *J. Rheumatol.* 28.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory.* , ed. Englewood Cliffs NJ: Prentice–Hall.

Bandura, A., Freeman, W. H., and Lightsey, R. (1999). Self-Efficacy: The Exercise of Control. *J. Cogn. Psychother.* 13, 158–166. doi:10.1891/0889-8391.13.2.158.

Bao, L., and Intille, S. S. (2004). "Activity Recognition from User-Annotated Acceleration Data," in (Springer, Berlin, Heidelberg), 1–17. doi:10.1007/978-3-540-24646-6_1.

Beers, E. A., Roemmich, J. N., Epstein, L. H., and Horvath, P. J. (2008). Increasing passive energy expenditure during clerical work. *Eur. J. Appl. Physiol.* 103, 353–360. doi:10.1007/s00421-008-0713-y.

Behm, D., and Colado, J. C. (2012a). The effectiveness of resistance training using unstable surfaces and devices for rehabilitation. *Int. J. Sports Phys. Ther.* 7, 226–41.

Behm, D., and Colado, J. C. (2012b). The effectiveness of resistance training using unstable surfaces and devices for rehabilitation. *Int. J. Sports Phys. Ther.* 7, 226–41. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22530196 [Accessed October 20, 2020].

Behm, D. G., Anderson, K., and Curnew, R. S. (2002). Muscle force and activation under stable and unstable conditions. *J. strength Cond. Res.* 16, 416–22.

Behm, D. G., Leonard, A. M., Young, W. B., Bonsey, W. A. C., and MacKinnon, S. N. (2005). Trunk Muscle Electromyographic Activity With Unstable and Unilateral Exercises. *J. Strength Cond. Res.* 19, 193. doi:10.1519/1533-4287(2005)19<193:TMEAWU>2.0.CO;2.

Behm, D. G., Muehlbauer, T., Kibele, • Armin, and Urs Granacher, • (2015). Effects of Strength Training Using Unstable Surfaces on Strength, Power and Balance Performance Across the Lifespan: A Systematic Review and Meta-analysis. *Sport. Med* 45, 1645–1669. doi:10.1007/s40279-015-0384-x.

Bethi, S. R., Rajkumar, A., Vulpi, F., Raghavan, P., and Kapila, V. (2020). Wearable Inertial Sensors for Exergames and Rehabilitation. *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS* 2020-July, 4579–4582. doi:10.1109/EMBC44109.2020.9175428.

Boccia, G., and Rainoldi, A. (2014). Innervation zones location and optimal electrodes position of obliquus internus and obliquus externus abdominis muscles. *J. Electromyogr. Kinesiol.* 24, 25–30. doi:10.1016/j.jelekin.2013.10.017.

Borghuis, J., Hof, A. L., and Lemmink, K. A. P. M. The Importance of Sensory-Motor Control in Providing Core Stability Implications for Measurement and Training.

Borsci, S., Federici, S., and Lauriola, M. (2009). On the dimensionality of the System Usability Scale: A test of alternative measurement models. *Cogn. Process.* 10, 193–197. doi:10.1007/S10339-009-0268-9/TABLES/3.

Bressel, E., Yonker, J. C., Kras, J., and Heath, E. M. (2007). Comparison of Static and Dynamic Balance in Female Collegiate Soccer , Basketb ... *J. Athl. Train.* 42, 42–46.

Brooke, J. (1996). "SUS: a 'quick and dirty' usability scale," in *Usability evaluation in industry*, eds. P. Jordan, B. Thomas, B. Weerdmeester, and I. McClelland (London: Taylor & Francis), 189–194.

Brooke, J. (2013). SUS: a retrospective Display design for fault diagnosis View project SUS: A Retrospective. 8, 29–40.

Brooke, J. D., Cheng, J., Collins, D. F., McIlroy, W. E., Misiaszek, J. E., and Staines, W. R. (1997). Sensori-sensory afferent conditioning with leg movement: Gain control in spinal reflex and ascending paths. *Prog. Neurobiol.* 51, 393–421. doi:10.1016/S0301-0082(96)00061-5.

Cadore, E. L., Rodríguez-Mañas, L., Sinclair, A., and Izquierdo, M. (2013). Effects of different exercise interventions on risk of falls, gait ability, and balance in physically frail older adults: a systematic review. *Rejuvenation Res.* 16, 105–114. doi:10.1089/REJ.2012.1397.

Calatayud, J., Borreani, S., Martin, J., Martin, F., Flandez, J., and Colado, J. C. (2015). Core muscle activity in a series of balance exercises with different stability conditions. *Gait Posture* 42, 186–192. doi:10.1016/j.gaitpost.2015.05.008.

Carraro, A., Elliot, C. A., and Gobbi, E. (2019). Perceived treadmill function is correlated with enjoyment of use in trained runners: A user-centred approach. *Appl. Ergon.* 74, 37–40. doi:10.1016/J.APERGO.2018.08.015.

Carraro, A., Gobbi, E., Ferri, I., Benvenuti, P., and Zanuso, S. (2014). Enjoyment perception during exercise with aerobic machines. *Percept. Mot. Skills* 119, 146–155. doi:10.2466/29.06.PMS.119C15Z3.

Carrière, B. (1999). The 'Swiss Ball'': An effective tool in physiotherapy for patients, families and physiotherapists.' *Physiotherapy* 85, 552–561. doi:10.1016/S0031-9406(05)61249-7.

Chulvi-Medrano, I., García-Massó, X., Colado, J. C., Pablos, C., de Moraes, J. A., and Fuster, M. A. (2010). Deadlift muscle force and activation under stable and unstable conditions. *J. strength Cond. Res.* 24, 2723–30. doi:10.1519/JSC.0b013e3181f0a8b9.

Cordes, T., Bischoff, L. L., Schoene, D., Schott, N., Voelcker-Rehage, C., Meixner, C., et al. (2019). A multicomponent exercise intervention to improve physical functioning, cognition and psychosocial well-being in elderly nursing home residents: A study protocol of a randomized controlled trial in the PROCARE (prevention and occupational health in long-term care) project. *BMC Geriatr.* 19, 1–11. doi:10.1186/S12877-019-1386-6/TABLES/2.

Cruz-Jentoft, A. J., and Sayer, A. A. (2019). Sarcopenia. *Lancet (London, England)* 393, 2636–2646. doi:10.1016/S0140-6736(19)31138-9.

De Kloet, A. J., Berger, M. A. M., Verhoeven, I. M. A. J., Van Stein Callenfels, K., and Vlieland, T. P. M. V. (2012). Gaming supports youth with acquired brain injury? A pilot study. *Brain*

Inj. 26, 1021–1029. doi:10.3109/02699052.2012.654592.

De Labra, C., Guimaraes-Pinheiro, C., Maseda, A., Lorenzo, T., and Millán-Calenti, J. C. (2015). Effects of physical exercise interventions in frail older adults: A systematic review of randomized controlled trials Physical functioning, physical health and activity. *BMC Geriatr.* 15. doi:10.1186/s12877-015-0155-4.

Decavele, S., Ortibus, E., Van Campenhout, A., Molenaers, G., Jansen, B., Omelina, L., et al. (2020). The Effect of a Rehabilitation Specific Gaming Software Platform to Achieve Individual Physiotherapy Goals in Children with Severe Spastic Cerebral Palsy: A Randomized Crossover Trial. *Games Health J.* 9, 376–385. doi:10.1089/G4H.2019.0097.

Dennett, A. M., and Taylor, N. F. (2015). Machines that go "ping" may improve balance but may not improve mobility or reduce risk of falls: a systematic review. *J. Rehabil. Med.* 47, 18–30. doi:10.2340/16501977-1899.

Do Nascimento, L. M. S., Bonfati, L. V., Freitas, M. L. B., Mendes Junior, J. J. A., Siqueira, H. V., and Stevan, S. L. (2020). Sensors and systems for physical rehabilitation and health monitoring—a review. *Sensors (Switzerland)* 20, 1–28. doi:10.3390/s20154063.

Dobkin, B. H. (2017). A Rehabilitation-Internet-of-Things in the Home to Augment Motor Skills and Exercise Training. *Neurorehabil. Neural Repair* 31, 217–227. doi:10.1177/1545968316680490.

Domínguez-Téllez, P., Moral-Muñoz, J. A., Salazar, A., Casado-Fernández, E., and Lucena-Antón, D. (2020). Game-Based Virtual Reality Interventions to Improve Upper Limb Motor Function and Quality of Life After Stroke: Systematic Review and Meta-analysis. *Games Health J.* 9, 1–10. doi:10.1089/G4H.2019.0043.

Dunn, B., Bocksnick, J., Hagen, B., Fu, Y., Li, X., Yuan, J., et al. (2008). Impact of Exercise on Seniors' Motor Control Response to External Dynamics. *Res. Sport. Med.* 16, 39–55. doi:10.1080/15438620701877024.

Era, P., Konttinen, N., Mehto, P., Saarela, P., and Lyytinen, H. (1996). Postural stability and skilled performance-a study On top-Level and naive rifle shooters. *J. Biomech.* 29, 301–306. doi:10.1016/0021-9290(95)00066-6.

Ermes, M., Parkka, J., Mantyjarvi, J., and Korhonen, I. (2008). Detection of Daily Activities and Sports With Wearable Sensors in Controlled and Uncontrolled Conditions. *IEEE Trans. Inf. Technol. Biomed.* 12, 20–26. doi:10.1109/TITB.2007.899496.

Fleig, L., McAllister, M. M., Chen, P., Iverson, J., Milne, K., McKay, H. A., et al. (2016). Health behaviour change theory meets falls prevention: Feasibility of a habit-based balance and strength exercise intervention for older adults. *Psychol. Sport Exerc.* 22, 114–122. doi:10.1016/J.PSYCHSPORT.2015.07.002.

Friesen, E. (2017). Measuring AT Usability with the Modified System Usability Scale (SUS). *Stud. Health Technol. Inform.* 242, 137–143.

Geiger, R. A., Allen, J. B., O'Keefe, J., and Hicks, R. R. (2001). Balance and mobility following stroke: effects of physical therapy interventions with and without biofeedback/forceplate training. *Phys. Ther.* 81, 995–1005.

Ghez, C., and Shinoda, Y. (1978). Spinal Mechanisms of the Functional Stretch Reflex. *Brain Res* 32, 55–68.

Gouttebarge, V., and Zuidema, V. (2018). Prevention of musculoskeletal injuries in recreational field hockey: the systematic development of an intervention and its feasibility. *BMJ Open Sport Exerc. Med.* 4, e000425. doi:10.1136/BMJSEM-2018-000425.

Gregory, D. E., Dunk, N. M., and Callaghan, J. P. (2006). Stability ball versus office chair: Comparison of muscle activation and lumbar spine posture during prolonged sitting. *Hum. Factors* 48, 142–153. doi:10.1518/001872006776412243.

Hägglund, M., and Scandurra, I. (2021). User Evaluation of the Swedish Patient Accessible Electronic Health Record: System Usability Scale. *JMIR Hum. factors* 8. doi:10.2196/24927.

Haller, J., Roberts, D., and Freedson, P. (2006). Increasing energy expenditure during sedentary activity. in *American College of Sports Medicine Annual Meeting*, S367.

Handoll, H. H., Rowe, B. H., Quinn, K. M., de Bie, R., and Handoll, H. (2001). “Interventions for preventing ankle ligament injuries,” in *Cochrane Database of Systematic Reviews*, ed. H. H. Handoll (Chichester, UK: John Wiley & Sons, Ltd), CD000018. doi:10.1002/14651858.CD000018.

Hawker, G. A., Mian, S., Kendzerska, T., and French, M. (2011). Measures of adult pain: Visual Analog Scale for Pain (VAS Pain), Numeric Rating Scale for Pain (NRS Pain), McGill Pain Questionnaire (MPQ), Short-Form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short Form-36 Bodily Pain Scale (SF. *Arthritis Care Res. (Hoboken).* 63 Suppl 1. doi:10.1002/ACR.20543.

Hayes, K. W., and Johnson, M. E. (2003). Measures of adult general performance tests: The Berg Balance Scale, Dynamic Gait Index (DGI), Gait Velocity, Physical Performance Test (PPT), Timed Chair Stand Test, Timed Up and Go, and Tinetti Performance-Oriented Mobility Assessment (POMA). *Arthritis Care Res. (Hoboken).* 49, S28–S42. doi:10.1002/ART.11411.

Henry, M., and Baudry, S. (2019). Age-related changes in leg proprioception: Implications for postural control. *J. Neurophysiol.* 122, 525–538. doi:10.1152/JN.00067.2019/ASSET/IMAGES/LARGE/Z9K0071951360003.JPEG.

Hermsen, L. A. H., Van Der Wouden, J. C., Leone, S. S., Smalbrugge, M., Van Der Horst, H. E., and Dekker, J. (2016). The longitudinal association of cognitive appraisals and coping strategies with physical functioning in older adults with joint pain and comorbidity: a cohort study. *BMC Geriatr.* 16. doi:10.1186/S12877-016-0204-7.

Hildenbrand, K., and Noble, L. (2004). Abdominal Muscle Activity while Performing Trunk-Flexion Exercises Using the Ab Roller, ABslide, FitBall, and Conventionally Performed Trunk Curls. *J. Athl. Train.* 39, 37–43. Available at: www.journalofathletictraining.org [Accessed January 25, 2021].

Hill, J. O., Wyatt, H. R., and Peters, J. C. (2012). Energy balance and obesity. *Circulation* 126, 126–132. doi:10.1161/CIRCULATIONAHA.111.087213.

Hrysomallis, C. (2007). Relationship between balance ability, training and sports injury risk. *Sport. Med.* 37, 547–556. doi:10.2165/00007256-200737060-00007.

Imai, A., Kaneoka, K., Okubo, Y., Shiina, I., Tatsumura, M., Izumi, S., et al. (2010). Trunk muscle activity during lumbar stabilization exercises on both a stable and unstable surface. *J. Orthop. Sports Phys. Ther.* 40, 369–375. doi:10.2519/jospt.2010.3211.

Kapteyn, T. S., Bles, W., Njiokiktjien, C. J., Kodde, L., Massen, C. H., and Mol, J. M. (1983). Standardization in platform stabilometry being a part of posturography. *Agressol. Rev. Int. physio-biologie Pharmacol. Appl. aux Eff. l’agression* 24, 321–6. doi:10.1007/s10874-011-9211-4.

Kavcic, N., Grenier, S., and McGill, S. M. (2004). Determining the stabilizing role of individual torso muscles during rehabilitation exercises. *Spine (Phila. Pa. 1976).* 29, 1254–1265. doi:10.1097/00007632-200406010-00016.

Khaiyat, O. A., and Norris, J. (2018). Electromyographic activity of selected trunk, core, and thigh muscles in commonly used exercises for ACL rehabilitation. *J. Phys. Ther. Sci.* 30, 642–648. doi:10.1589/JPTS.30.642.

Kidgell, D. J., Horvath, D. M., Jackson, B. M., and Seymour, P. J. (2007). Effect of six weeks of dura disc and mini-trampoline balance training on postural sway in athletes with functional ankle instability. *J. Strength Cond. Res.* 21, 466–469. doi:10.1519/R-18945.1.

Kingma, I., and van Dieën, J. H. (2009). Static and dynamic postural loadings during computer work in females: Sitting on an office chair versus sitting on an exercise ball. *Appl. Ergon.* 40, 199–205. doi:10.1016/j.apergo.2008.04.004.

Kwon, J. S., Park, M. J., Yoon, I. J., and Park, S. H. (2012). Effects of virtual reality on upper extremity function and activities of daily living performance in acute stroke: a double-blind randomized clinical trial. *NeuroRehabilitation* 31, 379–385. doi:10.3233/NRE-2012-00807.

Lajoie, Y., Teasdale, N., Bard, C., and Fleury, M. (1993). Attentional demands for static and dynamic equilibrium. *Exp. Brain Res.* 97, 139–144. doi:10.1007/BF00228824.

Langley, F., and Mackintosh, S. (2007). Functional Balance Assessment of Older Community Dwelling Adults: A Systematic Review of the Literature. *Internet J. Allied Heal. Sci. Pract.* 5, 13. doi:10.46743/1540-580X/2007.1174.

Lee, J. H., Ooi, Y., and Nakamura, K. (1995). Measurement of muscle strength of the trunk and the lower extremities in subjects with history of low back pain. *Spine (Phila. Pa. 1976).* 20, 1994–1996. doi:10.1097/00007632-199509150-00006.

Leggin, B. G., Michener, L. A., Shaffer, M. A., Brenneman, S. K., Iannotti, J. P., and Williams, G. R. (2006). The Penn shoulder score: reliability and validity. *J. Orthop. Sports Phys. Ther.* 36, 138–151. doi:10.2519/JOSPT.2006.36.3.138.

Lehman, G. J., Gordon, T., Langley, J., Pemrose, P., and Tregaskis, S. (2005a). Replacing a Swiss ball for an exercise bench causes variable changes in trunk muscle activity during upper limb strength exercises. *Dyn. Med.* 4, 6. doi:10.1186/1476-5918-4-6.

Lehman, G. J., Hoda, W., and Oliver, S. (2005b). Trunk muscle activity during bridging exercises on and off a Swiss ball. *Chiropr. Osteopat.* 13, 14. doi:10.1186/1746-1340-13-14.

Lehman, G. J., MacMillan, B., MacIntyre, I., Chivers, M., and Fluter, M. (2006). Shoulder muscle EMG activity during push up variations on and off a Swiss ball. *Dyn. Med.* 5, 7. doi:10.1186/1476-5918-5-7.

Lohse, K., Shirzad, N., Verster, A., Hodges, N., and Van Der Loos, H. F. M. (2013). Video games and rehabilitation: using design principles to enhance engagement in physical therapy. *J. Neurol. Phys. Ther.* 37, 166–175. doi:10.1097/NPT.0000000000000017.

Lowe, B. D., Swanson, N. G., Hudock, S. D., and Lotz, W. G. (2015). Unstable sitting in the workplace-Are there physical activity benefits? *Am. J. Heal. Promot.* 29, 207–209. doi:10.4278/ajhp.140331-CIT-127.

Macpherson, J. M., and Horak, F. B. (2013). “Posture,” in *Principles of neural science*, eds. J. H. E. R. Kandel, T. M. Schwartz, S. A. Jessell, and A. J. Siegelbaum (New York: McGraw-Hill.), 935–959.

Marcolin, G., Rizzato, A., Zuanon, J., Bosco, G., and Paoli, A. (2019). Expertise level influences postural balance control in young gymnasts. *J. Sports Med. Phys. Fitness* 59. doi:10.23736/S0022-4707.18.08014-3.

Marques, J., Botelho, S., Pereira, L. C., Lanza, A. H., Amorim, C. F., Palma, P., et al. (2013a). Pelvic floor muscle training program increases muscular contractility during first pregnancy and postpartum: electromyographic study. *Neurourol. Urodyn.* 32, 998–1003. doi:10.1002/nau.22346.

Marques, J., Botelho, S., Pereira, L. C., Lanza, A. H., Amorim, C. F., Palma, P., et al. (2013b). Pelvic floor muscle training program increases muscular contractility during first pregnancy and postpartum: Electromyographic study. *Neurourol. Urodyn.* 32, 998–1003. doi:10.1002/nau.22346.

Marshall, P. W., and Murphy, B. A. (2005). Core stability exercises on and off a Swiss ball. *Arch. Phys. Med. Rehabil.* 86, 242–9. doi:10.1016/j.apmr.2004.05.004.

Masani, K., Vette, A. H., Abe, M. O., and Nakazawa, K. (2014). Center of pressure velocity reflects body acceleration rather than body velocity during quiet standing. *Gait Posture* 39, 946–952. doi:10.1016/j.gaitpost.2013.12.008.

Mcauley, E., Szabo, A., Gothe, N., and Olson, E. A. (2011). Self-efficacy: Implications for Physical Activity, Function, and Functional Limitations in Older Adults. *Am. J. Lifestyle Med.* 5, 361–369. doi:10.1177/1559827610392704.

McGill, S. M., Kavcic, N. S., and Harvey, E. (2006). Sitting on a chair or an exercise ball: various perspectives to guide decision making. *Clin. Biomech. (Bristol, Avon)* 21, 353–360. doi:10.1016/J.CLINBIOMECH.2005.11.006.

McNulty, P. A. (2012). Games for Rehabilitation: Wii-based Movement Therapy Improves

Poststroke Movement Ability. *Games Health J.* 1, 384–387. doi:10.1089/G4H.2012.0055.

Merriman, N. A., Whyatt, C., Setti, A., Craig, C., and Newell, F. N. (2015). Successful balance training is associated with improved multisensory function in fall-prone older adults. *Comput. Human Behav.* 45, 192–203. doi:10.1016/j.chb.2014.12.017.

Mihalko, S. L., Cox, P., Beavers, D. P., Miller, G. D., Nicklas, B. J., Lyles, M., et al. (2019). Effect of intensive diet and exercise on self-efficacy in overweight and obese adults with knee osteoarthritis: The IDEA randomized clinical trial. *Transl. Behav. Med.* 9, 227–235. doi:10.1093/TBM/IBY037.

Morasso, P., Cherif, A., and Zenzeriid, J. (2019). Quiet standing: The Single Inverted Pendulum model is not so bad after all. doi:10.1371/journal.pone.0213870.

Nardone, A., Godi, M., Artuso, A., and Schieppati, M. (2010). Balance rehabilitation by moving platform and exercises in patients with neuropathy or vestibular deficit. *Arch. Phys. Med. Rehabil.* 91, 1869–1877. doi:10.1016/j.apmr.2010.09.011.

Neumayr, G., Hoertnagl, H., Pfister, R., Koller, A., Eibl, C., and Raas, E. (2003). Physical and physiological factors associated with success in professional alpine skiing. *Int. J. Sports Med.* 24, 571–575. doi:10.1055/S-2003-43270.

Ng, J. K. F., Kippers, V., and Richardson, C. A. (1998). Muscle fibre orientation of abdominal muscles and suggested surface EMG electrode positions. *Electromyogr. Clin. Neurophysiol.* 38, 51–58.

Noé, F., and Paillard, T. (2005). Is postural control affected by expertise in alpine skiing? *Br. J. Sports Med.* 39, 835–837. doi:10.1136/BJSM.2005.018127.

O’Sullivan, P. B., Grahamslaw, K. M., Kendell, M., Lapenskie, S. C., Möller, N. E., and Richards, K. V. (2002). The effect of different standing and sitting postures on trunk muscle activity in a pain-free population. *Spine (Phila. Pa. 1976).* 27, 1238–1244. doi:10.1097/00007632-200206010-00019.

Ogaya, S., Ikezoe, T., Soda, N., and Ichihashi, N. (2011). Effects of Balance Training Using Wobble Boards in the Elderly. *J. Strength Cond. Res.* 25, 2616–2622. doi:10.1519/JSC.0b013e31820019cf.

Paillard, T. (2017). Plasticity of the postural function to sport and/or motor experience. *Neurosci. Biobehav. Rev.* 72, 129–152. doi:10.1016/j.neubiorev.2016.11.015.

Paillard, T. (2019). Relationship between sport expertise and postural skills. *Front. Psychol.* 10. doi:10.3389/fpsyg.2019.01428.

Paillard, T., Costes-Salon, C., Lafont, C., and Dupui, P. (2002). Are there differences in postural regulation according to the level of competition in judoists? *Br. J. Sports Med.* 36, 304–305. doi:10.1136/BJSM.36.4.304.

Paillard, T., and Noé, F. (2006). Effect of expertise and visual contribution on postural control in soccer. in *Scandinavian Journal of Medicine and Science in Sports* (Scand J Med Sci Sports), 345–348. doi:10.1111/j.1600-0838.2005.00502.x.

Paillard, T., and Noé, F. (2015). Techniques and Methods for Testing the Postural Function in Healthy and Pathological Subjects. *Biomed Res. Int.* 2015. doi:10.1155/2015/891390.

Pardasaney, P. K., Latham, N. K., Jette, A. M., Wagenaar, R. C., Ni, P., Slavin, M. D., et al. (2012). Sensitivity to Change and Responsiveness of Four Balance Measures for Community-Dwelling Older Adults. *Phys. Ther.* 92, 388–397. doi:10.2522/PTJ.20100398.

Peel, N. M. (2011). Epidemiology of Falls in Older Age. *Can. J. Aging / La Rev. Can. du Vieil.* 30, 7–19. doi:10.1017/S071498081000070X.

Perry, J., and Burnfield, J. (1992). *Gait Analysis: Normal And Pathological.*

Petró, B., Papachatzopoulou, A., and Kiss, R. M. (2017). Devices and tasks involved in the objective assessment of standing dynamic balancing - A systematic literature review. *PLoS One* 12. doi:10.1371/JOURNAL.PONE.0185188.

Powell, D. W., and Williams, D. S. B. (2015). Athletes trained using stable compared to unstable surfaces exhibit distinct postural control profiles when assessed by traditional and nonlinear measures. *Hum. Mov. Sci.* 44, 73–80. doi:10.1016/j.humov.2015.08.013.

Prieto, T. E., Myklebust, J. B., Hoffmann, R. G., Lovett, E. G., and Myklebust, B. M. (1996). Measures of postural steadiness: Differences between healthy young and elderly adults. *IEEE Trans. Biomed. Eng.* 43, 956–966. doi:10.1109/10.532130.

Putrino, D., Zanders, H., Hamilton, T., Rykman, A., Lee, P., and Edwards, D. J. (2017). Patient Engagement Is Related to Impairment Reduction During Digital Game-Based Therapy in Stroke. *Games Health J.* 6, 295–302. doi:10.1089/G4H.2016.0108.

Quant, S., Maki, B. E., Verrier, M. C., and McIlroy, W. E. (2001). Passive and active lower-limb movements delay upper-limb balance reactions. *Neuroreport* 12, 2821–2825. doi:10.1097/00001756-200109170-00014.

Raymakers, J. A., Samson, M. M., and Verhaar, H. J. J. (2005). The assessment of body sway and the choice of the stability parameter(s). *Gait Posture* 21, 48–58. doi:10.1016/j.gaitpost.2003.11.006.

Reed, C. A., Ford, K. R., Myer, G. D., and Hewett, T. E. (2012). The Effects of Isolated and Integrated 'Core Stability' Training on Athletic Performance Measures. *Sport. Med.* 42, 697–706. doi:10.2165/11633450-000000000-00000.

Riach, C., and Starkes, J. (1993). Stability limits of quiet standing postural control in children and adults. *Gait Posture* 1, 105–111. doi:10.1016/0966-6362(93)90021-R.

Ringhof, S., and Stein, T. (2018). Biomechanical assessment of dynamic balance: Specificity of different balance tests. *Hum. Mov. Sci.* 58, 140–147. doi:10.1016/j.humov.2018.02.004.

Rizzato, A., Paoli, A., and Marcolin, G. (2021). Different gymnastic balls affect postural balance rather than core-muscle activation: A preliminary study. *Appl. Sci.* 11. doi:10.3390/app11031337.

Rizzo, J. R., Thai, P., Li, E. J., Tung, T., Hudson, T. E., Herrera, J., et al. (2017). Structured Wii protocol for rehabilitation of shoulder impingement syndrome: A pilot study. *Ann. Phys. Rehabil. Med.* 60, 363–370. doi:10.1016/J.REHAB.2016.10.004.

Rodriguez-Larrad, A., Arrieta, H., Rezola, C., Kortajarena, M., Yanguas, J. J., Iturburu, M., et al. (2017). Effectiveness of a multicomponent exercise program in the attenuation of frailty in long-term nursing home residents: Study protocol for a randomized clinical controlled trial. *BMC Geriatr.* 17, 1–10. doi:10.1186/S12877-017-0453-0/TABLES/5.

Rubenstein, L. Z. (2006). Falls in older people: epidemiology, risk factors and strategies for prevention. *Age Ageing* 35, ii37–ii41. doi:10.1093/AGEING/AFL084.

Saeterbakken, A. H., and Fimland, M. S. (2012). Muscle activity of the core during bilateral, unilateral, seated and standing resistance exercise. *Eur. J. Appl. Physiol.* 112, 1671–1678. doi:10.1007/s00421-011-2141-7.

Saftari, L. N., and Kwon, O. S. (2018). Ageing vision and falls: a review. *J. Physiol. Anthropol.* 37. doi:10.1186/S40101-018-0170-1.

Santos, P., Machado, T., Santos, L., Ribeiro, N., and Melo, A. (2019). Efficacy of the Nintendo Wii combination with Conventional Exercises in the rehabilitation of individuals with Parkinson's disease: A randomized clinical trial. *NeuroRehabilitation* 45, 255–263. doi:10.3233/NRE-192771.

Schaff, P., and Hauser, W. (1989). [Skin boot versus knee joint--a sports medicine, orthopedic and biomechanical problem]. *Sportverletz. Sportschaden* 3, 149–161. doi:10.1055/S-2007-993653.

Schoene, D., Wu, S. M.-S., Mikolaizak, A. S., Menant, J. C., Smith, S. T., Delbaere, K., et al. (2013). Discriminative Ability and Predictive Validity of the Timed Up and Go Test in Identifying Older People Who Fall: Systematic Review and Meta-Analysis. *J. Am. Geriatr. Soc.* 61, 202–208. doi:10.1111/JGS.12106.

Schult, T. M., Awosika, E. R., Schmunk, S. K., Hodgson, M. J., Heymach, B. L., and Parker, C. D. (2013). Sitting on stability balls: Biomechanics evaluation in a workplace setting. *J. Occup. Environ. Hyg.* 10, 55–63. doi:10.1080/15459624.2012.748324.

Scoppa, F., Capra, R., Gallamini, M., and Shiffer, R. (2013). Clinical stabilometry standardization.

Basic definitions - Acquisition interval - Sampling frequency. *Gait Posture* 37, 290–292. doi:10.1016/j.gaitpost.2012.07.009.

Shemmell, J., Krutky, M. A., and Perreault, E. J. Stretch sensitive reflexes as an adaptive mechanism for maintaining limb stability. doi:10.1016/j.clinph.2010.02.166.

Sherrington, C., Michaleff, Z. A., Fairhall, N., Paul, S. S., Tiedemann, A., Whitney, J., et al. (2017). Exercise to prevent falls in older adults: an updated systematic review and meta-analysis. *Br. J. Sports Med.* 51, 1750–1758. doi:10.1136/BJSPORTS-2016-096547.

Siirtola, P., and Röning, J. (2012). *International journal of interactive multimedia and artificial intelligence.* ImaI-Software.

Sin, H., and Lee, G. (2013). Additional virtual reality training using Xbox kinect in stroke survivors with hemiplegia. *Am. J. Phys. Med. Rehabil.* 92, 871–880. doi:10.1097/PHM.0B013E3182A38E40.

Słomka, K. J., Pawłowski, M., Michalska, J., Kamieniarz, A., Brachman, A., and Juras, G. (2018). Effects of 8-Week Complex Balance Training in Young Alpine Skiers: A Pilot Study. *Biomed Res. Int.* 2018. doi:10.1155/2018/6804534.

Steinberg, N., Adams, R., Tirosh, O., Karin, J., and Waddington, G. (2019). Effects of Textured Balance Board Training in Adolescent Ballet Dancers With Ankle Pathology. *J. Sport Rehabil.*, 1–9. doi:10.1123/jsr.2018-0052.

Stevens-Lapsley, J. E., Loyd, B. J., Falvey, J. R., Figiel, G. J., Kittelson, A. J., Cumbler, E. U., et al. (2016). Progressive multi-component home-based physical therapy for deconditioned older adults following acute hospitalization: A pilot randomized controlled trial. *Clin. Rehabil.* 30, 776–785. doi:10.1177/0269215515603219/ASSET/IMAGES/LARGE/10.1177_0269215515603219-FIG1.JPEG.

Subramanian, S., Dahl, Y., Skjæret Maroni, N., Vereijken, B., and Svanæs, D. (2020). Assessing Motivational Differences Between Young and Older Adults When Playing an Exergame. *Games Health J.* 9, 24–30. doi:10.1089/G4H.2019.0082.

Takakusaki, K., Takahashi, M., Obara, K., and Chiba, R. (2017). Neural substrates involved in the control of posture. *Adv. Robot.* 31, 2–23. doi:10.1080/01691864.2016.1252690.

Taylor, M. J. D., McCormick, D., Shawis, T., Impson, R., and Griffin, M. (2011). Activity-promoting gaming systems in exercise and rehabilitation. *J. Rehabil. Res. Dev.* 48, 1171–1186. doi:10.1682/JRRD.2010.09.0171.

Tsaklis, P., Malliaropoulos, N., Mendiguchia, J., Korakakis, V., Tsapralis, K., Pyne, D., et al. (2015). Muscle and intensity based hamstring exercise classification in elite female track and field athletes: implications for exercise selection during rehabilitation. *Open access J. Sport. Med.* 6, 209–17. doi:10.2147/OAJSM.S79189.

Tsutsumi, T., Don, B. M., Zaichkowsky, L. D., and Delizonna, L. L. (1997). Physical fitness and psychological benefits of strength training in community dwelling older adults. *Appl. Human Sci.* 16, 257–266. doi:10.2114/JPA.16.257.

Tudor-Locke, C., Schuna, J. M., Frensham, L. J., and Proenca, M. (2014). Changing the way we work: elevating energy expenditure with workstation alternatives. *Int. J. Obes. (Lond).* 38, 755–765. doi:10.1038/IJO.2013.223.

Uchida, M. C., Nishida, M. M., Sampaio, R. A. C., Moritani, T., and Arai, H. (2016). Thera-band(®) elastic band tension: reference values for physical activity. *J. Phys. Ther. Sci.* 28, 1266–71. doi:10.1589/jpts.28.1266.

Van Criekinge, T., Saeys, W., Vereeck, L., De Hertogh, W., and Truijen, S. (2017). Are unstable support surfaces superior to stable support surfaces during trunk rehabilitation after stroke? A systematic review. *https://doi.org/10.1080/09638288.2017.1323030* 40, 1981–1988. doi:10.1080/09638288.2017.1323030.

Vealey, R. ., and Chase, M. (2008). "Self-confidence in sport," in *Advances in sport psychology*, ed. T. Horn (Human Kinetics), 68–97.

Vera-Garcia, E., Mayoral-Cleries, F., Vancampfort, D., Stubbs, B., and Cuesta-Vargas, A. I. (2015). A systematic review of the benefits of physical therapy within a multidisciplinary care approach for people with schizophrenia: An update. *Psychiatry Res.* 229, 828–839. doi:10.1016/J.PSYCHRES.2015.07.083.

Vera-Garcia, F. J., Grenier, S. G., and McGill, S. M. (2000). Abdominal muscle response during curl-ups on both stable and labile surfaces. *Phys. Ther.* 80, 564–9.

Vera-Garcia, F. J., Irles-Vidal, B., Prat-Luri, A., García-Vaquero, M. P., Barbado, D., and Juan-Recio, C. (2020). Progressions of core stabilization exercises based on postural control challenge assessment. *Eur. J. Appl. Physiol.* doi:10.1007/s00421-020-04313-9.

Verhagen, E., Van Der Beek, A., Twisk, J., Bouter, L., Bahr, R., and Van Mechelen, W. (2004). The effect of a proprioceptive balance board training program for the prevention of ankle sprains: A prospective controlled trial. *Am. J. Sports Med.* 32, 1385–1393. doi:10.1177/0363546503262177/ASSET/IMAGES/10.1177_0363546503262177-IMG1.PNG.

Vuillerme, N., Danion, F., Marin, L., Boyadjian, A., Prieur, J. M., Weise, I., et al. (2001). The effect of expertise in gymnastics on postural control. *Neurosci. Lett.* 303, 83–86. doi:10.1016/S0304-3940(01)01722-0.

Wade, S. L., Narad, M. E., Shultz, E. L., Kurowski, B. G., Miley, A. E., Aguilar, J. M., et al. (2018). Technology-assisted rehabilitation interventions following pediatric brain injury. *J. Neurosurg. Sci.* 62, 187–202. doi:10.23736/S0390-5616.17.04277-1.

Walker, C., Brouwer, B. J., and Culham, E. G. (2000). Use of Visual Feedback in Retraining Balance Following Acute Stroke. *Phys. Ther.* 80, 886–895. doi:10.1093/PTJ/80.9.886.

Weber, M., Van Ancum, J., Bergquist, R., Taraldsen, K., Gordt, K., Mikolaizak, A. S., et al. (2018). Concurrent validity and reliability of the Community Balance and Mobility scale in young-older adults. *BMC Geriatr.* 18. doi:10.1186/s12877-018-0845-9.

White, A. T., and Johnson, S. C. (1993). Physiological aspects and injury in elite Alpine skiers. *Sports Med.* 15, 170–178. doi:10.2165/00007256-199315030-00003.

Willardson, J. M. (2007). Core stability training: Applications to sports conditioning programs. *J. Strength Cond. Res.* 21, 979–985. doi:10.1519/R-20255.1.

Xing Su, Hanghang Tong, and Ping Ji (2014). Activity recognition with smartphone sensors. *Tsinghua Sci. Technol.* 19, 235–249. doi:10.1109/TST.2014.6838194.

Zazulak, B., Cholewicki, J., and Reeves, N. P. (2008). Neuromuscular control of trunk stability: clinical implications for sports injury prevention. *J. Am. Acad. Orthop. Surg.* 16, 497–505. doi:10.5435/00124635-200809000-00002.

Zemková, E. (2014). Sport-specific balance. *Sport. Med.* 44, 579–590. doi:10.1007/s40279-013-0130-1.

Appendix A

International visiting research project

Balance control assessment in young alpine skiers with different levels of expertise

This project was carried out during the three-month international visit at prof. Supej's Laboratory - Faculty of Sport, University of Ljubljana. The well-recognized expertise in sports biomechanics of this research group highly enriched my experience in monitoring and studying the relationship between balance control strategies and sports performance, which is one of the core research areas of my Ph.D. project.

Introduction

Postural balance control is specific for sports, such as skiing, where complex motor skills are performed. Few studies analyzed subjects' balance performance to discriminate the expertise level (Marcolin et al., 2019) among highly skilled athletes of a specific discipline (Paillard and Noé, 2015). However, its specificity remains a widely debated theme in literature. Indeed, Era et al. (Era et al., 1996) showed that international rifle shooters stabilized their posture better than national-level shooters, whereas Paillard et al. revealed that postural performance was similar for judoists at different levels of competition (Paillard et al., 2002). On this topic, several studies investigated if gymnasts have better postural balance control with respect to non-sport people or athletes in simple tasks. Vuillerme et al. compared gymnasts to non-gymnasts and found that both groups showed a comparable balance performance when visual cues were available (Vuillerme et al., 2001). Thus, their results do not support the theory of the transfer of motor skills (Adams, 1987; Vuillerme et al., 2001). Bressel and colleagues investigated static and dynamic balance among collegiate athletes competing or training in soccer, basketball, and gymnastics (Bressel et al., 2007). They concluded that the differences between gymnasts and soccer players were non-existent. Therefore, the concept of a gymnast having superior balance in everyday tasks compared to a non-gymnast is still debated.

Alpine skiing is a sport that requires fine postural control to maintain balance in challenging conditions (Schaff and Hauser, 1989). Past studies on performance factors in alpine skiing mainly focused in particular on physiology, that is, on investigating muscular strength and aerobic and anaerobic power (White and Johnson, 1993; Neumayr et al., 2003). Conversely, only a few studies were carried out to evaluate postural control in alpine skiers. For instance, Paillard and colleagues showed that national-level skiers did not present better postural performance than regional-level skiers (Noé and Paillard, 2005). Moreover, national-level skiers displayed postural performance inferior to the regional-level skiers in simple balance tasks (i.e., quiet standing).

This study examined the balance performance of two groups of young elite skiers ranked at different levels: high-ranked (i.e., ranked < 50 chart position) and low-ranked (i.e., ranked > 50 chart position). The aim was to evaluate static and dynamic balance control to understand whether performance in simple and sport-oriented balance tasks could depend on the skiers' expertise.

Material and methods

The 25 recruited skiers (table 1) were divided into two groups considering the International Ski Federation ranking: high-ranked (i.e., ranked <50; n=13) and low-ranked (i.e., ranked >50; n=12).

	Subjects	Age (yrs)	Mass (kg)	Height (m)	Practice (yrs)
High-level	13 (F=5)	15.46 ± 1.45	66.39 ± 7.12	1.72 ± 0.55	7.86 ± 1.81
Low-level	12 (F=5)	14.41 ± 1.67	53.04 ± 6.44	1.65 ± 0.68	7.58 ± 2.77

Table 1. Characteristics of the subjects. Data are presented as mean ± standard deviation.

Each group underwent three experimental balance conditions: static, dynamic unspecific (US), and dynamic sport-specific (SS) sketched in figure 1. During US task, the subjects stood on an unstable board positioned over a force platform (AMTI, USA). During the SS task, subjects wore their own racing ski boots, grasped ski poles, and stood on two unstable boards, positioned over two force plates (Kistler, Germany). Unstable boards allowed only anterior-posterior oscillations. In both dynamic conditions, the unstable boards' angular displacement was recorded synchronously to the CoP trajectory by a 12-camera optoelectronic system (Qualisys, Sweden). For this purpose, four reflective markers were placed at the vertices of the unstable board, and their three-dimensional trajectories were recorded.

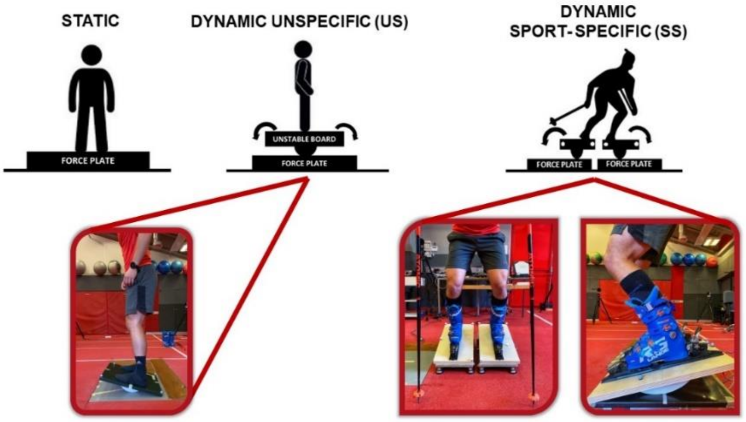


Figure 1. Experimental design.

Data analysis

The CoP-related parameters were calculated in both static and dynamic conditions. In detail, the Area95 (the area of the 95th percentile ellipse measured in cm2) and Unit Path (the path length per unit time, i.e., the average CoP velocity measured in cm/s) were considered as outcomes. In the SS condition, starting from the single-foot CoP trajectories (i.e., right and left foot), the whole-body CoP-related parameters were also calculated (DewesoftX software), taking into account the distance between the two force plates (i.e., 5 cm). The kinematic data were recorded at 150 Hz for consistency with the kinetic data for US and SS conditions. The four reflective markers on the edge of the unstable board allowed calculating the rotation angle of the square board: when the markers were parallel to the floor, the angle was 0 deg. Positive and negative angle values were measured when the unstable board rotated clockwise or counterclockwise. Three parameters (figure 2) were calculated to assess the dynamic balance performance: the integral of the curve considered an index of the overall postural performance (Full Balance, FB); the time spent between +5 deg and -5 deg considered an index of fine-tuning balance adjustments (Fine Balance, FiB); the time spent between +10 deg and -10 deg considered an index of gross-tuning balance adjustments (Gross Balance, GB).

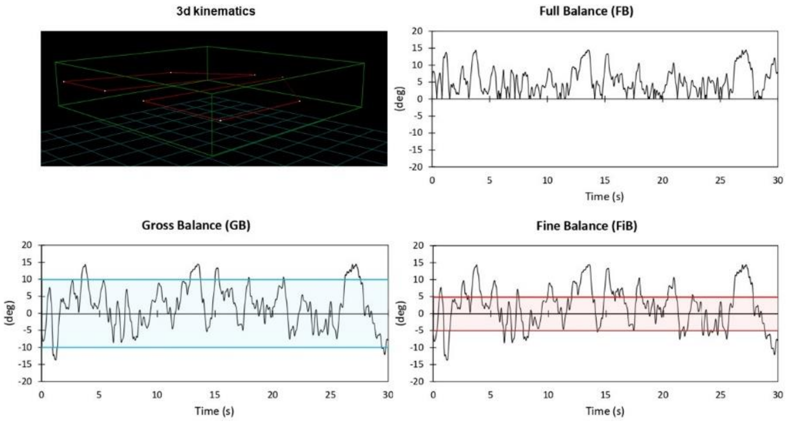


Figure 2. Graphical representation of the kinematic parameters used as outputs.

Statistical analysis

The mean value and the standard deviations were calculated for each variable. The D'Agostino-Pearson test was used to check the data normality distribution. A two-way ANOVA test for repeated measures was used to investigate any significant main effect of the balance condition (i.e., ST, US, and SS) vs. the group (i.e., High-level vs. Low-level skiers) in the mean differences for all variables. The significance level was set at $p < 0.05$. In case of any statistically significant main effect or interaction, the Holm post-hoc test was performed. JASP Software, version 0.16.3.0 was used for statistical analysis.

Results

Figure 3 reports the results for the Area95 parameter in the static and dynamic balance test both in the US and SS conditions. The two-way ANOVA showed a statistically significant main effect of the balance condition ($p < 0.001$) and an interaction balance vs. group ($p < 0.05$): High-level skiers (ST: 1.27 ± 0.82, US: 17.71 ± 7.63, SS: 26.04 ± 21.12); Low-level skiers (ST: 1.44 ± 0.66, US: 19.34 ± 6.45, SS: 39.83 ± 16.29). In detail, the Holm post-hoc comparisons showed significantly higher values in the US ($p < 0.01$) and SS ($p < 0.001$) conditions compared to ST condition for both high-level and low-level skiers. Moreover, only in the low-level skiers, significantly higher values in SS than US condition were observed ($p < 0.001$). Finally, comparing the balance performance in the SS condition, the high-level skiers showed a significantly better performance than the low-level skiers ($p < 0.01$).

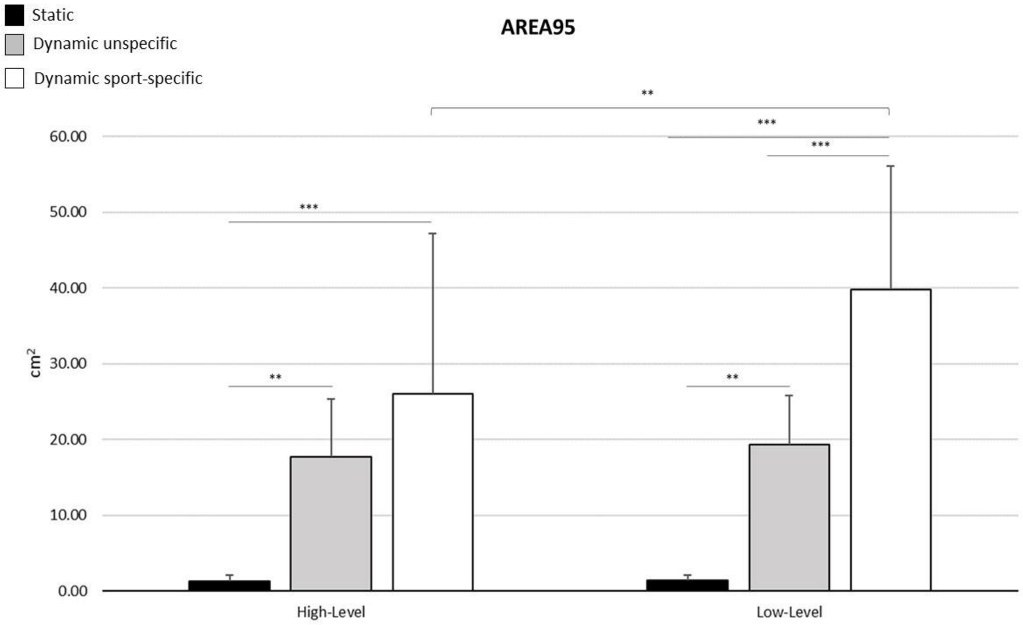


Figure 3. Area95 results in the ST, SS, and US conditions for high-level and low-level skiers; data are presented as mean ± standard deviation. Significantly different ** ($p < 0.01$); *** ($p < 0.001$).

Figure 4 reports the results for the Unit Path parameter in the static and dynamic balance test both in the US and SS conditions. The two-way ANOVA showed a statistically significant main effect of group ($p < 0.01$) and the balance condition ($p < 0.001$): High-level skiers (ST: 7.10 ± 0.49, US: 10.66 ± 2.25, SS: 11.21 ± 3.57); Low-level skiers (ST: 8.52 ± 1.27, US: 12.63 ± 2.74, SS: 13.66 ± 2.48). In detail, the Holm post-hoc comparisons showed significantly higher values in US ($p < 0.001$) and SS ($p < 0.001$) conditions compared to ST condition for both high-level and low-level skiers.

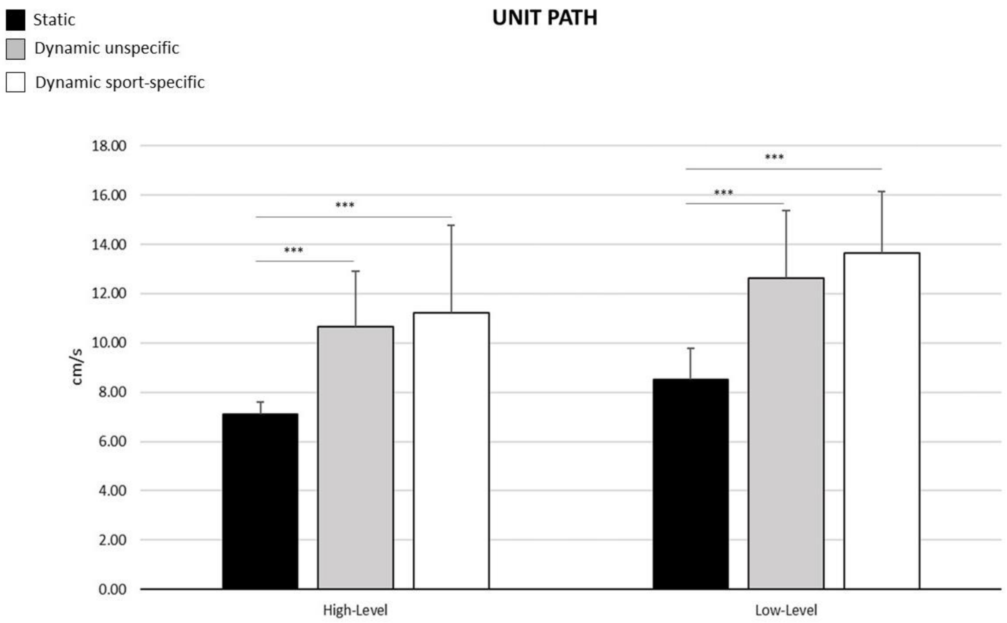


Figure 4. Unit Path results in the ST, SS, and US conditions for high-level and low-level skiers; data are presented as mean ± standard deviation. Significantly different *** ($p < 0.001$).

Table 2 reports the results for the FB, FiB, and GB parameters in the dynamic balance test both in the US and SS conditions. The two-way ANOVA showed a statistically significant main effect of balance condition ($p < 0.001$) and group ($p = 0.05$).

	Full Balance (deg./s)	
	High-level	Low-level #
Dynamic unspecific (US)	154.48 ± 26.80	168.31 ± 29.40
Dynamic sport-specific (SS)	114.72 ± 37.02***	137.02 ± 27.24***
	Fine Balance (s)	
	High-level	Low-level
Dynamic unspecific (US)	17.59 ± 2.40	16.04 ± 2.57
Dynamic sport-specific (SS)	21.13 ± 4.57***	19.86 ± 3.83***
	Gross Balance (s)	
	High-level	Low-level #
Dynamic unspecific (US)	26.46 ± 1.97	25.08 ± 2.13
Dynamic sport-specific (SS)	28.23 ± 1.68***	26.77 ± 1.93***

Table 2. Full Balance (FB), Gross Balance (GB), and Fine Balance (FiB) results in the ST, SS, and US conditions for high-level and low-level skiers. Data are presented as mean ± standard deviation. ***significantly different from US condition ($p < 0.001$); # significantly different from high-level ($p < 0.05$)

Discussion

This study aimed to evaluate skiers' static and dynamic balance control to examine whether their ability to perform simple and sport-oriented balance tasks reflects their expertise level. Indeed, besides the relationship between balance ability and sports injury risk has been established in many cases (Hrysomallis, 2007), the relationship between balance ability and athletic performance is less clear and still poorly debated.

Results from CoP-related parameters (i.e., Area95 and Unit Path) highlighted a considerable difference between the static and the dynamic conditions both in high-level and low-level skiers. Thus, being the Area95 an index of the overall postural control and the Unit Path of the efficiency of the postural control system (Noé and Paillard, 2005), subjects obtained the best control and the highest efficiency in the static task. These results were not surprising. Indeed, since dynamic tasks were more challenging, they usually induced higher body adjustments reflected in greater CoP oscillations to counteract external destabilizations imposed by the unstable board, both with and without ski boots.

Our results do not support the transfer of motor skills according to previous literature (Vuillerme et al., 2001; Asseman et al., 2004; Bressel et al., 2007). Indeed, as reported in figure 1, the main effect of the group (i.e., high-level vs. low-level) showed significant differences only when the condition was sport-specific. Thus, we support the theory that a sport-specific task better represents the athletes' level of expertise. These results do not agree with those reported by Paillard and colleagues, who found similar balance performances between regional-level and national-level skiers in static and dynamic balance tests. Moreover, other studies already investigated the skiers in simple and sport-specific tasks (Noé and Paillard, 2005) and with and without ski boots (Noé and Paillard, 2005; Zemková, 2014), subjects could not manage balance with their feet independently due to the seesaw device used for generating dynamic instability. Thus, the dynamic task proposed was not as specific as the competition and training conditions.

The kinematic parameters (i.e., FB, FiB, and GB) assessing the skiers' dynamic balance performance in US and SS showed a better balance when the task was sport-specific, independently from the level. Indeed, our results showed that when skiers were nearer to the sport-specific condition, namely wearing ski boots and holding ski poles, they could elicit a better balance performance. Moreover, two out of three kinematic parameters (i.e., FB and GB) showed that the high-level skiers had a better balance performance in both US and SS conditions. Again, the balance performance obtained in the dynamic tests represents the skiers' level considering the International Ski Federation ranking.

Conclusion

The periodic assessment of balance in young athletes can be an important instrument to correctly define and change training programs, taking into account the sport practiced. Balance performance (i.e., Full Balance, Fine Balance, and Gross Balance) was better in the SS task, independently from the skiers' level. Our results showed that when skiers were near race conditions, namely wearing ski boots and holding ski poles, they could elicit a better balance performance. As reported in the results, the main effect of the group (i.e., high-level vs. low-level) showed statistically significant differences only when the dynamic balance condition was sport-specific (i.e., SST). This demonstrated that the higher the specificity of the dynamic balance task, the more it represents the athletes' level of expertise. Hence, in young elite skiers, dynamic balance tests are more selective when the task is sport-specific than simple balance tasks. Indeed, the balance performance in the static test did not reflect the performance obtained in the more challenging dynamic balance test. Thus, attempting to infer dynamic balance ability based on static balance should also be avoided in young elite skiers.

Appendix B

Scopus indexed publications within the three-year PhD program

1. **Rizzato, A.,** Marcolin, G., & Paoli, A. (2022). Non-exercise activity thermogenesis in the workplace: The office is on fire. Frontiers in Public Health, 10.
   IF: 6.461; Q1

   Abstract

   From the second half of the previous century, there has been a shift toward occupations largely composed of desk-based behaviors. This, inevitably, has led to a workload reduction and a consequent lower energy expenditure. On this point, small increments of the non-exercise activity thermogenesis (NEAT) could be the rationale to reach health benefits over a prolonged period. Different published researches suggest solutions to reverse sitting time and new alternative workstations have been thought to increase total physical activity. Therefore, the purpose of this narrative review is to summarize the current state of the research regarding the "NEAT approach" to weight-gain prevention in work environments. This review analyzes the main evidence regarding new alternative workstations such as standing, walking workstations, seated pedal, and gymnastic balls to replace a standard office chair.

2. Passavanti, G., Paoli, A., **Rizzato, A.,** Ceccarelli, I., Fiorenzani, P., Casini, I., & Aloisi, A. M. (2022). Age and training intensity differently affect male runners' endocrine and sexual parameters. Chinese Journal of Physiology, 65(1), 37.
   IF: 1.568; Q4

   Abstract

   Physical activity is widely recognized to improve health and its inclusion in daily life at all ages is highly recommended. Gonadal hormones are known to be affected by physical activity. The exercise-induced effects on male runners of different ages were investigated by dividing 31 runners by age (Young, Y, 30–55 years; Old, O, 56–70 years) and amount of training (Light, L, <50 km/week; Heavy, H, 50 or more km/week). To test the somatic, sexual, and psychological health aspects, the Aging Male's Symptoms Scale (AMS) and

the International Index of Erectile Function-6 (IIEF-6) questionnaires were administered and blood samples were drawn for adrenocorticotropic hormone, testosterone (Total-TT), free testosterone (Free-T), cortisol (C), dihydrotestosterone (DHT), estradiol, and sex hormone-binding globulin determinations. Clinical evaluations and questionnaire results showed the presence in all groups of some subclinical symptoms and “Light” dysfunctions. TT in the old-heavy (OH) group was significantly lower than in the OL group (2.38 ± 0.18 ng/mL vs. 3.36 ± 0.44 ng/ml, $P = 0.05$). The TT/DHT ratio was significantly higher in YH than in OH (3.64 ± 0.16 vs. 2.92 ± 0.23, $P < 0.05$). TT was positively correlated with AMS sexual subscale and negatively correlated with IIEF-6. Physical activity can significantly affect andrological health and testosterone levels in runners at all ages. Thus, due to the important testosterone-mediated vital functions in men, the evaluation of these parameters would be indicated in old as well as in young subjects.

3. **Rizzato, A.,** Paoli, A., Andretta, M., Vidorin, F., & Marcolin, G. (2021). Are static and dynamic postural balance assessments two sides of the same coin? A cross-sectional study in the older adults. Frontiers in Physiology, 12, 939.
   IF: 4.755; Q1

Abstract

The aim of this study was to investigate if the combination of static and dynamic postural balance assessments gives more accurate indications on balance performance among healthy older adults. We also aimed at studying the effect of a dual-task condition on static and dynamic postural balance control. Fifty-seven healthy older adults (age = 73.2 ± 5.0 year, height = 1.66 ± 0.08 m, and body mass = 72.8 ± 13.8 kg) completed the study. Static and dynamic balance were assessed both in single-task and dual-task conditions through a force plate and an oscillating platform. The dominant handgrip strength was also measured with a dynamometer. Pearson’s correlation revealed non-statistically significant correlations between static and dynamic balance performance. The dual-task worsened the balance performance more in the dynamic (+147.8%) than in the static (+25.10%, +43.45%, and +72.93% for ellipse area, sway path, and AP oscillations, respectively) condition ($p < 0.001$). A weak correlation was found between dynamic balance performance and handgrip strength both in the single ($p < 0.05$; $r = -0.264$) and dual ($p < 0.05$; $r = -0.302$) task condition. The absence of correlations between static and

dynamic balance performance suggests including both static and dynamic balance tests in the assessment of postural balance alterations among older adults. Since cognitive-interference tasks exacerbated the degradation of the postural control performance, dual-task condition should also be considered in the postural balance assessment.

4. **Rizzato, A.,** Paoli, A., & Marcolin, G. (2021). Different Gymnastic Balls Affect Postural Balance Rather Than Core-Muscle Activation: A Preliminary Study. Applied Sciences, 11(3), 1337.
   IF: 2.838; Q3

Abstract

In proprioceptive training, unstable devices produce multidirectional perturbations that must be counterbalanced by the postural control systems and core-muscle activation. We investigated whether different sizes and shapes of three gymnastic balls could affect core-muscle activation and postural balance when performing the same exercise. Eleven young healthy subjects were assessed on the balls, assuming two body postures (bipedal seated and unipedal seated) and performing a dynamic exercise. Two balls were spherical with different diameters, and one was ovoid. Postural balance and muscle activation were assessed through center of pressure (CoP)-related parameters and surface electromyography. Statistical analysis showed a significant effect of the gymnastic balls ($p < 0.001$) and the body postures ($p < 0.001$) for the CoP-related parameters, with the ovoid shape and the bipedal sitting representing the easiest conditions. Core-muscle activation was affected only by body postures, with a higher activation in the unipedal sitting ($p < 0.01$). In the dynamic exercise, significant differences were only detected for the CoP-related parameters ($p < 0.001$). The shapes and sizes of the gymnastic balls produced different degrees of destabilization under the same body posture but left the core-muscle activation unaltered. In the dynamic exercise, the conformation of the balls did not represent the main determinant in producing destabilizing effects.