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Different Gymnastic Balls Affect Postural Balance Rather Than Core-Muscle Activation: A Preliminary Study

Alex Rizzato, Antonio Paoli and Giuseppe Marcolin *

Department of Biomedical Sciences, University of Padova, Via Marzolo 3, 35131 Padova, Italy; alex.rizzato@unipd.it (A.R.); antonio.paoli@unipd.it (A.P.)
* Correspondence: giuseppe.marcolin@unipd.it; Tel.: +39-049-8275869

Abstract: Background: 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. **Methods:** 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. **Results:** 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 ($p < 0.001$). **Conclusions:** 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.

Keywords: balance; unstable device; center of pressure; core stability

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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 the static and dynamic postural balance [1,2]. In the static condition, the balance performance is related to minimizing the body sway while assuming conventional body postures [3], with or without a reduced base of support [4]. Conversely, dynamic balance is defined as the subject's ability to react efficiently to the base of support displacements [3]. 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 [5]. 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 contexts [1]. Among these strategies, proprioceptive and functional training with the employment of unstable devices such as gymnastic balls is a widespread practice in professional [6], recreational [7], and rehabilitation [8,9] contexts. The rationale for this training modality is to increase the postural control systems' commitment and muscle activation to counterbalance the multidirectional perturbations caused by unstable devices. Methodologically, to assess the amount of destabilization during these kinds of exercises, the available scientific literature has identified two instruments: the force platform that quantifies the center of pressure (COP) displacements [10,11] and the surface electromyography to assess the core-muscle activation [12,13]. In more 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 [10]. Similarly, Dunn and colleagues documented significant improvements in seniors' COP-related parameter scores after running a Fitball exercise program [11]. Additionally, in a group of 23 older adults, Ogaya and colleagues found an improvement of COP-related parameters after attending a balance training program using wobble boards [14]. Unlike the COP-related parameters, core-muscle activation seems to show controversial responses to the destabilizing exercises. For instance, no effects on core-muscle activation were detected when performing upper-body strength exercises while sitting on a labile rather than stable surface [13]. In fact, Chulvi–Medrano and colleagues observed a higher paraspinal muscle activation when performing deadlifts with the feet on a stable surface with respect to the unstable counterpart [15]. Conversely, an increased activation of the rectus abdominis and external oblique muscles was observed during a prone bridge with the feet on a Swiss ball when compared to a stable surface [12]. These previous investigations focused on the destabilization produced by unstable devices when compared to stable conditions. Nevertheless, this approach does not 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. First, we aimed to investigate whether three gymnastic balls different in size and shape could affect the COP-related parameters of the same exercises. Second, we aimed to determine how specific muscles responsible for core stabilization responded to the destabilization produced by the gymnastic balls.

2. Materials and Methods

2.1. Subjects

Eleven healthy subjects volunteered for the study (all males; mean ± standard deviation (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 2020, but due to the COVID-19 emergency it was suspended from March to June 2020. Data collection ended in July 2020.

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 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 (Figure 1A). The third one had an ovoid shape with a diameter of 65 cm (Eggball, Figure 1A). All the gymnastic balls were inflated until they reached the circumference reported in the manufacturer's guidelines. The postural balance control was assessed through a computerized force platform (AMTI BP400600, Watertown, MA, USA), recording the CoP trajectory at a sampling frequency of 100 Hz (Figure 1B). The force platform had the following characteristics: average CoP accuracy typically less than 0.2 mm; crosstalk values typically ± 0.05% of the applied load; measurement accuracy typically ±0.1% of the applied load (minimum applied load of 22.6 kg). The CoP signal was analyzed with the software Balance Clinic 1.4.2. The core-muscle activation was recorded with a BTS FREEEMG (BTS Bioengineering, Milan, Italy). The device resolution was 16 bit, and the sampling frequency was set to

1 kHz. The analyzed muscles were the rectus abdominis (RA), the abdominal external oblique (EO), and erector spinae (ES) of both the right and left sides of each participant (Figure 1B). Ag/AgCl pre-gelled electrodes were applied with an interelectrode distance of 24 mm. The skin preparation, sensor location, and orientation on the muscle bellies followed previous studies [16,17]. 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 three experimental conditions are sketched in Figure 1C. Before recording the trials, all the subjects were familiarized with the tasks to perform on the gymnastic balls.

Figure 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 the subjects. From left to right: bipedal seated (BS), unipedal seated (US), and dynamic exercise (EX).

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 nondominant 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 while gripping two 1-kg kettlebells. The velocity of both leg extensions and arm lateral raises was standardized by setting a metronome at 50 beats per minute. The support surface on the force platform was enlarged by screwing a wooden board (length 1.50 m; width 0.80 m; depth 0.03 m) on it, allowing 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 to 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 s were performed with opened eyes.

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, the CoP parameters were averaged among the three trials. Regarding the core-muscle activation, 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 activation of each muscle was then computed, and finally, a global index of the level of core muscle activation was calculated by summing the means of the three muscles' EMG signals.

2.4. Statistical Analysis

The collected data passed the D'Agostino–Pearson test for a 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) was investigated by performing a two-way ANOVA for repeated measures for both the CoP and EMG variables. When the F-value showed main effects or interactions, a Bonferroni post-hoc analysis was carried out for pair-wise comparisons. Moreover, a one-way ANOVA for repeated measures was performed to investigate the effect of the three different gymnastic balls on the CoP and EMG variables in the EX condition. Data were processed with the software packages JASP for Windows (Version 0.11.1, Amsterdam, The Netherlands) and presented as the mean ± standard deviation (SD). The significant level for differences was set to $p < 0.05$.

3. Results

3.1. CoP-Related Parameters

Figure 2A,B shows 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.

The 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. The 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 ($p < 0.001$; $\eta_p{}^2 = 0.494$) and Unit Path ($p < 0.001$; $\eta_p{}^2 = 0.516$) in the EX condition. The post-hoc analysis showed a statistically significant difference ($p < 0.001$) between Gym53 and Gym65 for the Area95. Moreover, significantly higher values for the Unit Path were detected in the Gym65 condition with respect to Eggball ($p < 0.01$) and Gym53 ($p < 0.01$).

Table 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 the mean ± standard deviation. # significantly different from Gym65 ($p < 0.001$); $ significantly different from Gym65 ($p < 0.01$); § significantly different from Gym65 ($p < 0.01$).

	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

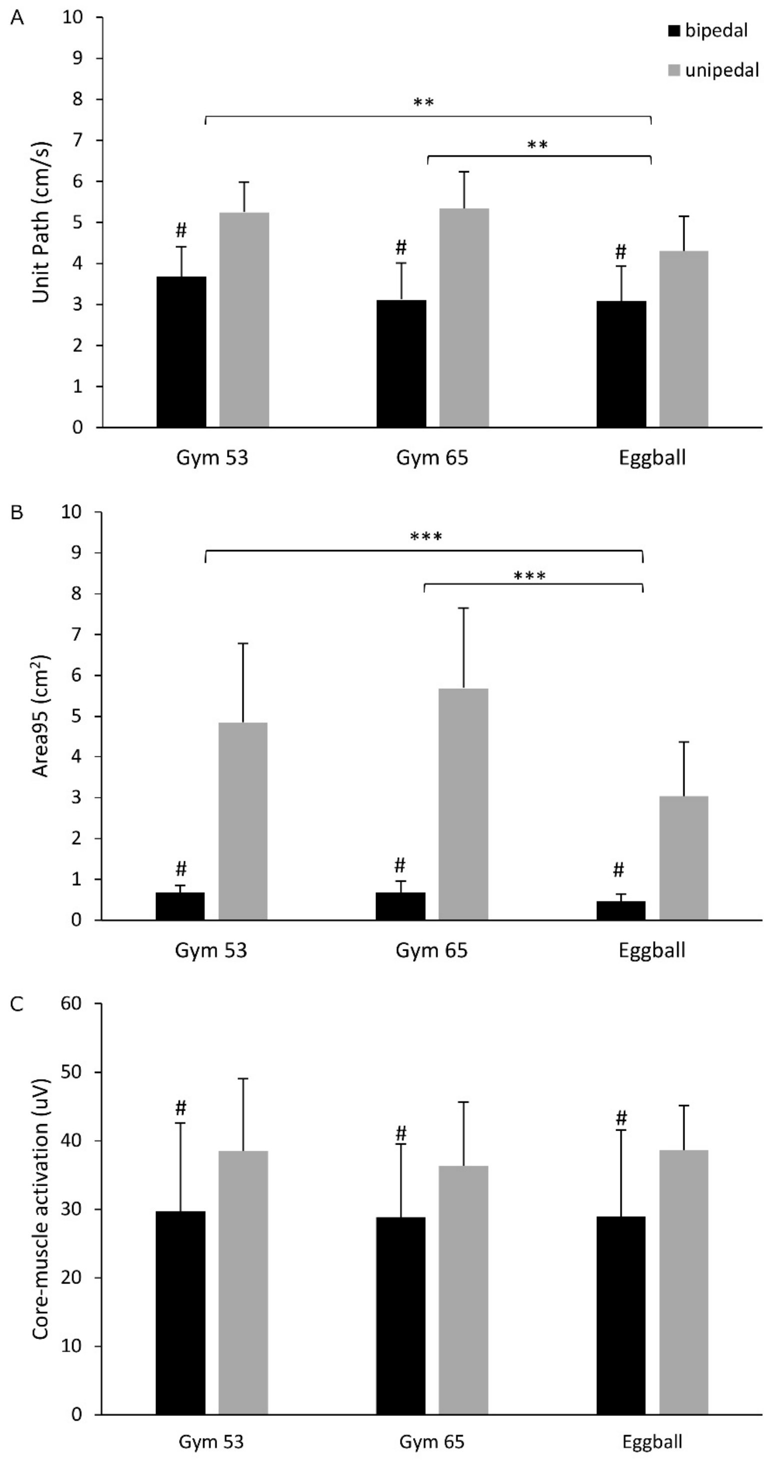

Figure 2. Two-way ANOVA results comparing the different gymnastic balls under the BS and US posture. Data are presented as the mean ± standard deviation. (**A**) Unit Path results; ** significantly different from Eggball ($p < 0.01$), # significantly different from US posture ($p < 0.001$). (**B**) Area95 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 ($p < 0.01$).

3.2. EMG Core-Muscle Activation

Figure 2C shows the results of the core-muscle activation. 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 when comparing the different gymnastic balls. In the EX condition, no statistically significant differences were detected for the core-muscle activation ($p > 0.05$).

4. Discussion

With the current interest in core stability and postural balance, a broad range of unstable devices and exercises are emerging in the field of functional training [18,19]. However, the destabilizing effect produced by different unstable devices on the same exercise lacks 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 activation under the same postural condition or exercise. Indeed, understanding the effects of different unstable devices allows one to better modulate training progression over time, sensitizing trainers and therapists on the choice of the proper destabilizing device.

CoP-related parameters resulted in being more sensitive than core-muscle activation in assessing 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. Based on the assumption that the higher the CoP mean velocity, the more destabilizing the exercise [10], the development of training protocols of increasing difficulty has to focus not only on the type of exercise but also on the device to be employed. In our case, the Eggball should be suggested for employment in the early stages of rehabilitation or training, rather than the Gym53 or the Gym65.

Furthermore, the postural balance control showed greater CoP displacements and a greater velocity under the US with respect to the BS posture. A widely accepted assumption is that, biomechanically speaking, 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 [20]. In our case, the feet on the ground and the ball on which the subject was seated established the base of support. During the US posture, the nondominant lower limb was raised, leading to the base of support's restriction. Thus, the Unit Path and Area95 results confirmed the abovementioned assumption when unstable devices contributed to determining the base of support.

Our results showed nonsignificant differences between the three gymnastic balls (i.e., Gym53, Gym65, and Eggball) on the core-muscle activation for the same body posture (i.e., BS and US). Thus, core-muscle activation was independent of the shape and size of the gymnastic ball that was used. The easy postural task that was proposed with a foothold always on the stable ground could have accounted for the unchanged core-muscle activation. Otherwise, we can speculate that core muscles equally contributed to the trunk stabilization while concurrent muscle coactivations could have occurred in order to face the different perturbations induced by the gymnastic 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 the activation of core muscles during tasks performed on unstable surfaces [21] or in a seated position (in addition to a standing one) [22] are needed. As far as we are concerned, our study is the first to investigate muscle activation while performing the same exercise with different gymnastic balls. Indeed, previous studies focused on the effect of core-muscle activation in different exercises or when comparing labile versus stable surfaces [15,21]. The significantly different activation of core muscles between the BS and US conditions that we found was in line with previous findings [23]. Even though the muscles that were 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 activation in the single-leg stance vs. the two-leg stance while subjects were sitting on an exercise ball [23]. This suggested that progressive postural control disruption might involve an incremental amount of core muscle activation 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. Though the core-muscle activation 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 to Gym53 and Gym65. An explanation of these differences could be that the balance response was more influenced by the subjects' active movements in the EX condition 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 [24]. Similarly, the sensory discharge from lower-limb activity could attenuate sensory stimuli (visual, somatosensory, or vestibular inputs) that convey sensations of whole-body instability [25]. A further explanation could be the higher competition of cognitive processes due to continuous changes in the surrounding environments, acting forces, and sensory inputs [26]. In the EX condition, subjects had to simultaneously perform voluntary movements maintaining their balance on the gymnastic balls. Indeed, these two actions competed for the same control mechanisms [26]. These abovementioned theories could explain the different behaviors 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 limitations that should be acknowledged. Certainly, a larger and more heterogeneous sample size is needed to test the inferences of our findings for a vaster population. However, a post-hoc power (1-β err prob) analysis with the G*Power software showed values higher than 0.95 for all the COP-related variables in our sample. Then, we only considered core-muscle activation. The inclusion of thigh and shank muscles could have contributed to understanding the whole-body mechanisms adopted to counteract the destabilizations caused by the three gymnastic balls.

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 left the core-muscle activation unaltered. Our findings corroborate the view that besides exercise prescriptions, trainers and therapists should objectively focus on the most suitable device for increasing the difficulty of the postural exercises. Conversely, the employment of unstable devices in the dynamic exercise has not proven to be the main determinant in producing destabilizing effects. Although further investigations are needed, the shapes and sizes of gymnastic balls are more important in generating different destabilizing stimuli when assuming static postures than dynamic exercises do.

Author Contributions: G.M., A.R. and A.P. conceived and designed the experiments; A.R. and G.M. performed the experiments; G.M. and A.R. analyzed the data; A.P. contributed materials; G.M., A.R. and A.P. wrote the paper. All authors approved the final version of the manuscript.

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Conflicts of Interest: The company Ledragomma Srl provided the three gymnastic balls employed in this research, but it had no role in the design, conducting, and data analysis of the study. There is no other competing interest to declare.

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