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Research article

The effects of sports and gender on static and dynamic balance in children under 12 years old

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Abstract: The existing literature on balance in young children is mixed: while some studies report that girls sway less than boys up to the age of 10, others report no gender differences. Thus, this paper aims to investigate the effect of sport on postural control abilities and gender differences in a critical period of growth, namely children under twelve years of age. The sample consisted of 50 athletes, aged 11–12, from three different groups (gymnasts, handball players, and non-athletes). The participants were instructed to maintain an upright and quiet stance, as well as a static and/or dynamic balance, on a stabilometric platform with their eyes open. The center of pressure sway (COP) left/right and forward/backward sway displacements, velocity, and acceleration were measured in the frontal and sagittal planes. The results presented greater postural control in the athlete groups compared to the non-athletes. An expertise in gymnastics seemed to improve the postural performance compared to handball players and the sedentary groups. Gymnastics girls revealed better COP left/right sway displacements in static and dynamic balance than gymnastics, handball players, and non-athletes' boys, thus highlighting that gymnastics training promotes improvements in postural control of children under twelve. In conclusion, the main results revealed the importance of engaging in sports during childhood. Regular sport activities are crucial during this period to promote significant enhancements of neuromuscular control and balance, which are critical to maintain stability. Based on the results of the study, engaging in gymnastics is recommended to improve balance training, especially at a rich high-performance level in specific sports.

Keywords: dynamic balance; static balance; gymnasts; handball players

1. Introduction

Posture and movement are usually taken to be two different aspects of motor control [1]. Consequently, the coordination between posture and movement involves the dynamic control of the center of mass (COM) following in the base of support [2]. Balance, which involves the coordination of sensorimotor strategies to stabilize the body's center of pressure (COP) in the presence of both self-initiated and externally-initiated disturbances of stability [3], is categorized into two types: static and dynamic. When equilibrium is maintained for one stationary body position, it is called static balance, whereas dynamic balance refers to maintaining equilibrium during motion or re-establishing equilibrium through rapid and successively changing positions [4].

Biomechanically, postural control is achieved when the COM is maintained within the base of support and aligned with the COP. During bipedal standing, the COP represents the point of application of the vertical ground reaction forces exerted by the feet on a force plate [5]. Any external or internal perturbation that changes the projection of the COM to the limits of the base of support and the alignment between COM and COP may lead to postural challenge [6]. The COP analysis is most commonly used to assess postural sway [7]. Posturography, a sensitive and objective method that records COP sway over a predetermined period, is considered the gold standard for assessing postural balance [8].

The main sensory systems involved in postural control are proprioception, the vestibular system and vision, and their afferent pathways within the central nervous system (CNS) [9]. The neural process involved in stability organization and body orientation in space is necessary, practically for all dynamic motor actions [1]. Thus postural control is a complex motor skill derived from the interaction of multiple sensorimotor processes and combines the regulation of stability and orientation to the environment [3].

However, a stable standing position is fundamental for most other motor activities [7]. Thus, controlling one's vertical posture is indispensable for both ordinary life [10] and athletic activities [11]. Balance is a key component of motor skills, ranging from maintaining posture to executing complex sport skills [4]. Many years of training and participation in demanding competitions may significantly modify the redundancy of the postural control system and lead to the discipline-oriented optimal use of sensorimotor modalities responsible for body balance [12]. Moreover, practicing sports activities may facilitate the adaptation and mastery of postural strategies specific to the demands of each sport [13].

Considering, these valuable transformations in sports and the effect of postural stability at the levels of sports [14] and injuries [15], research has consistently investigated the critical importance of balance control in both sports performance and injury prevention. Several studies have demonstrated that adult athletes have greater postural skills than sedentary individuals [16–19], and athletes of individual sports disciplines have shown a superior postural stability [14,20−26]. These findings suggest that certain disciplines, alongside specific trainings, promote the development of new postural control skills [14,19,20]. However, most research has been conducted with experienced adult athletes, and relatively little is known about the intermediate phases of postural control development, particularly the rate at which stability improves in preadolescent athletes due to consecutive years of training [12]. Furthermore, Olivier Palluel and Nougier [27] affirmed that the age of seven is a critical period characterized by a change of postural strategy, which starts to look more and more similar to that adopted by the adults. In addition, Rogol Clark and Roemmich [28] and Dudziak Czubek Grabowski et al. [29] affirmed that children aged between 9 and 12 years were characterized by physiological changes, which may influence postural control. Additionally, there is evidence indicating a progressive decline in balance-system functioning during this transition period, which is a phenomenon that persists until approximately age 13 [30]. Moreover, different types of competitive sports exert different effects on the various subsystems of posture control [31]. Likewise, Thomis Claessens Lefevre et al. [32] suggested that the ages of 13 or 14 represent a critical period to increase sports performance, as only limited improvement occurs thereafter. Accordingly, Dallas Milosis Vogiatzi et al. [23] emphasized the importance of analyzing dynamic balance, which is not yet mature at this critical age, to make specific training programs and to enhance balance skills. Only a few studies examined the development of posture and stability control in children and adolescents, and they especially focused on pathologies, mostly without considering sports activities [11].

We build on the work of Ludwig Kelm Hammes et al. [11], who suggested that stability and postural control are fundamental motor skills that form the base of athletic activity. Additionally, we take taking the suggestion of Oliveira Silva Antunes et al. [33] into account, which highlights that regular sports activities improve postural balance in children aged 7 to 13. Opstoel Pion Elferink-Gemser et al. [34] expanded this insight and showed that children with a high training volume developed sport-specific characteristics. Similarly, Vuillerme Teasdale and Nougier [35] highlighted how different sports may induce distinct adaptations in postural control competence. Gender differences in balance control are also evident, as Dallas Mavidis Dallas et al. [26] found that women exhibited a superior postural balance compared to men. Collectively, these studies underscore the positive impact of training during the critical developmental periods on postural control [33,36], while acknowledging that gender differences in postural stability may vary with age [26,37].

This study investigates sport-specific differences in postural control (gymnastics vs. handball) in children under 12, with further analysis of gender-based variations in postural strategies. In this context, the current research's objective is to compare static and dynamic postural stability in young gymnasts and handball players with their inactive peers (i.e., video gamers). The following hypotheses were drawn:

(a) Athletes (i.e., gymnasts and handball players) would demonstrate a superior postural performance compared to non-athletes /video gamers;

(b) Gymnasts would exhibit better postural balance than handball players; and

(c) Women's artistic gymnasts would display enhanced postural stability.

2. Materials and methods

2.1. Participants

A minimum sample size of 50 participants agreed to participate in this study (i.e., across the three groups), which was determined through a priori statistical power analysis using the G*Power software (Version 3.1, University of Dusseldorf, Germany [38]). The power analysis (i.e., for ANOVA) was computed with an assumed power of 0.80 at an alpha level of 0.050 and a large effect size (d = 0.90 and critical F = 3.209) [39].

Table 1 summarizes the descriptive characteristics of the three groups (i.e., gymnasts, handball players, and video gamers).

Table 1. Participants characteristics.

Groups	Gender	n	APHV (years)	MO (years)	Age (years)	Height (m)	Body mass (kg)
Gymnasts	Boys	6	14.25 ± 1.31	−2.09 ± 1.02	12.15 ± 0.33	1.50 ± 0.09	36.67 ± 1.82
	Girls	6	11.98 ± 0.31	−0.001 ± 0.40	11.98 ± 0.33	1.52 ± 0.03	34.83 ± 1.17
Handball Players	Boys	9	12.27 ± 1.27	−0.36 ± 1.29	11.92 ± 0.27	1.66 ± 0.11	46.50 ± 9.92
	Girls	9	11.14 ± 0.25	0.84 ± 0.28	12.98 ± 0.22	1.66 ± 0.03	39.13 ± 1.81
Video Gamers	Boys	10	13.51 ± 0.97	−1.29 ± 1.04	12.22 ± 0.23	1.57 ± 0.09	38.2 ± 3.36
	Girls	10	11.74 ± 0.31	0.21 ± 0.42	11.95 ± 0.28	1.56 ± 0.04	37.30 ± 2.87

(APHV) Ages at peak height velocity; (MO) maturity offset.

For the athlete groups (i.e., artistic gymnasts and handball players), inclusion required competitive sports participation for at least five years. For the non-athlete group (i.e., video gamers), the participants had no history of competitive sports participation, engaged in physical activity only through school-based physical education, and reported weekly physical activity totalling ≤ 2 hours.

Participants were excluded if they had lower extremity injuries to the musculoskeletal system throughout the last six months before data collection [40], such as vestibular disorders (e.g., vertigo) and visual impairments.

2.1.1. Ethics approval of research

After being informed in advance of the procedures, methods, benefits, and possible risks of the study, each participant reviewed and signed a consent form to participate in the study. The experimental protocol was performed in accordance with the Declaration of Helsinki for human experimentation [41] and was approved by the Local Ethical Committee of the National Observatory of Sport (ONS/UR/18JS01-2024/3).

2.2. Experimental design and procedures

This study consisted of three random assessments (i.e., randomized, counterbalanced, and Latin Square [42]). Each assessment took place on a separate consecutive day. All assessments were carried out in the youth center at the same time of the day (i.e., between 09:00 AM and 12:00 PM). Each assessment included a static (i.e., standing position, Figure 1a) and/or dynamic balance (i.e., frontal balance, Figure 1b), and a sagittal balance (Figure 1c) using a single-plane balance board (SPBB, "i.e., Freeman tray"), which provided lateral and anteroposterior imbalances [43] on a stabilometric platform (Posture-Win©, Techno Concept®, Cereste, France, frequency 40 Hz, A/D conversion 12 [39].

The postural performance was evaluated through a series of balance tests, which are mentioned as follows:

(a) Bipedal sways in the standing position (ST): The subject stood in the upright position on the Posture-Win stabilometric platform for two minutes in a static standing balance (Figure 1a);

(b) Bipedal sways in a frontal balance (FB): The subject stood upright on the Posture-Win stabilometric platform with a SPBB placed on it for two minutes in a dynamic frontal balance (Figure 1b); and
(c) Bipedal sways in a sagittal balance (SB): The subject stood upright on the Posture-Win stabilometric platform with a SPBB placed on it for two minutes in a dynamic sagittal balance (Figure 1c).

To quantify postural sway, the participants' COP trajectories were analyzed over time using a Posture-Win stabilometric platform, which provides precise data on the COP movement patterns during static and dynamic balance tasks.

In a controlled stance position, the palms face the body without making contact, while the feet are positioned narrowly on either side of a three-centimeter-wide tape separated by an angle of 30°, and their heels are placed 5 cm apart. The participants were asked to keep their regard horizontal on a visual target positioned 2 m away [44]. This setup ensures that the heels remain aligned with another tape to maintain standardized foot placements. Such methodologies are essential in research and clinical assessments to ensure consistency in body positioning, which can significantly impact the balance and coordination measurements [45].

Finally, left/right sway displacements ($d_{L/R}$) and forward/backward sway displacements ($d_{F/B}$), alongside the resultant velocity (vt) and acceleration (at) of the COP, were measured. The x-axis is the horizontal trace of the latero-lateral plane aimed towards the right side of the participant (left/right sway displacements); alternatively, the y-axis is the horizontal trace of the antero-posterior plane aimed in front of the participant (forward/backward sway displacements) [46].

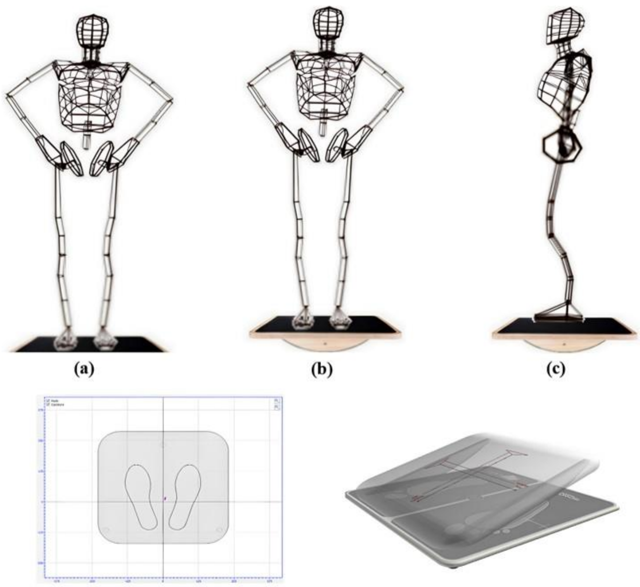

Figure 1. Posture-Win© stabilometric force platform experimental protocol: (a) Bipedal sway, static balance; (b) Bipedal sway, dynamic frontal balance with a single plane balance board; (c) Bipedal sway, dynamic sagittal balance with a single plane balance board [39].

2.3. Statistical analysis

As part of the statistical analysis, the SPSS 27 package (SPSS. Chicago. IL. USA) and JAPS

0.19.3.0 (JAPS Team, Department of Psychological Methods University of Amsterdam) [47] programs were used. Descriptive statistics (i.e., means ± SD) were applied for all variables. The effect size was conducted using the G*Power software (Version 3.1. University of Dusseldorf. Germany). The following scale was used for the interpretation of *d*: < 0.2, trivial; 0.2–0.59, small; 0.6–1.19, moderate; 1.2–2.0, large; and > 2.0, very large [48,49]. The normality of distribution estimated by the Kolmogorov-Smirnov test was acceptable for all variables ($p > 0.05$). Consequently, a two-way analysis of variance (ANOVA) (i.e., groups and gender) was used to benchmark the different conditions. The Tukey test was applied in a post-hoc analysis for pairwise comparisons. Additionally, the effect sizes (*d*) were determined from the ANOVA output by converting the partial eta-squared to the Cohen's *d*. A priori level less than or equal to 0.5% ($p \leq 0.05$) was used as a criterion for significance.

3. Results

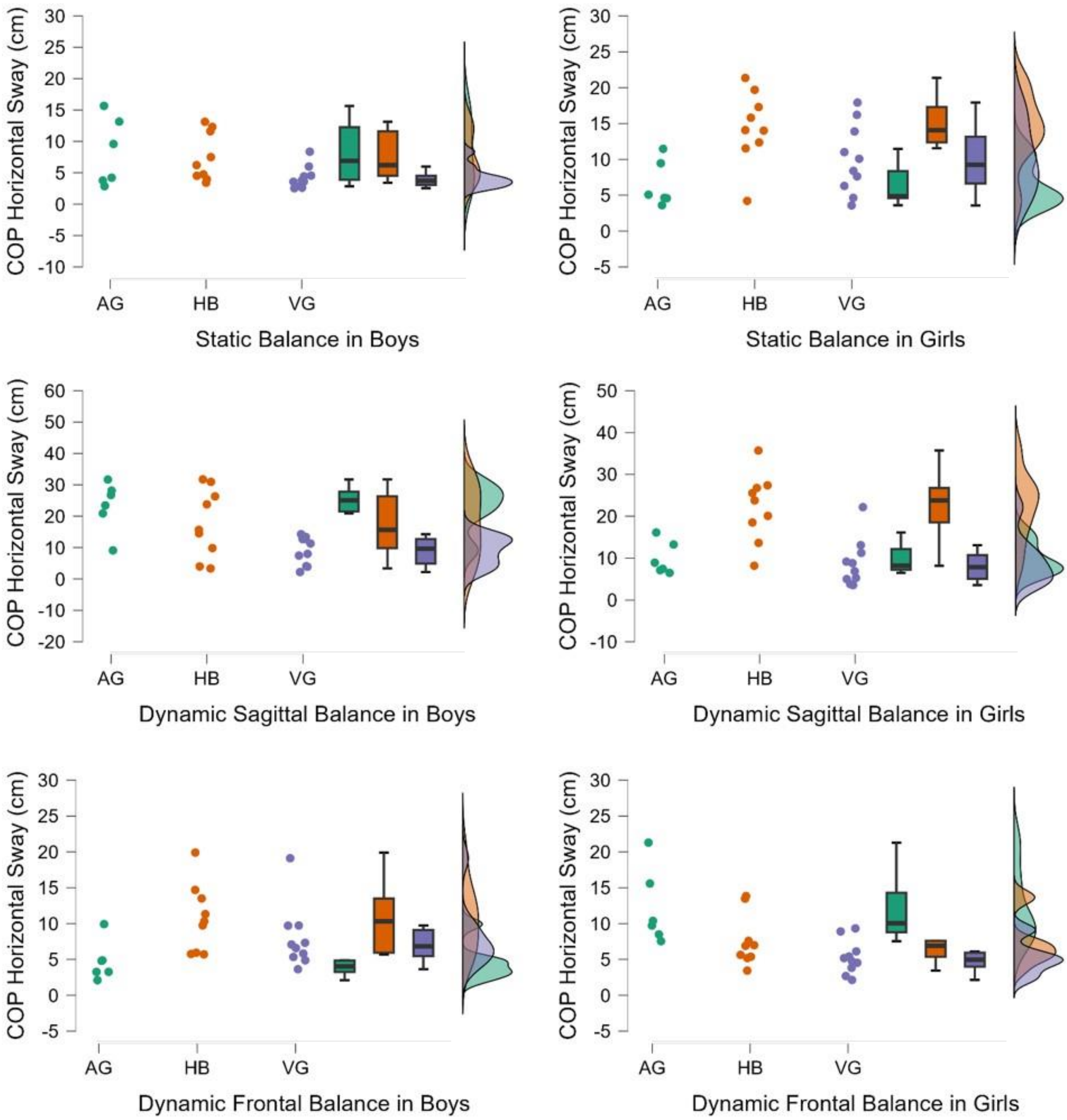

Figure 2. COP left/right sway displacements by condition, groups, and gender.

Table 2. Two ways ANOVA between groups and gender.

	Variables	Sum of Squares	df	Mean Square	F	P value	ES
Groups	COP $d_{L/R}$ ST	166.016	2	83.008	4.833	0.013*	0.937
	COP $d_{L/R}$ SB	1206.882	2	603.441	11.360	0.001**	1.438
	COP $d_{L/R}$ FB	66.370	2	33.185	2.125	0.132	0.621
	COP $d_{F/B}$ ST	365.415	2	182.707	1.134	0.331	0.454
	COP $d_{F/B}$ SB	2219.951	2	1109.976	8.825	0.001	1.210
	COP $d_{F/B}$ FB	2597.356	2	1298.678	7.206	0.002	1.145
	COP vt ST	1.957	2	0.979	0.082	0.922	0.126
	COP vt SB	7.080	2	3.540	0.054	0.947	0.089
	COP vt FB	1239.616	2	619.808	7.034	0.002**	1.130
	COP at ST	1601.239	2	800.619	0.150	0.861	0.167
	COP at SB	89769.180	2	44884.590	0.578	0.565	0.326
	COP at FB	464872.479	2	232436.240	5.338	0.008**	0.984
Gender	COP $d_{L/R}$ ST	159.013	1	159.013	9.258	0.004**	0.987
	COP $d_{L/R}$ SB	112.643	1	112.643	2.120	0.152	0.439
	COP $d_{L/R}$ FB	3.688	1	3.688	0.236	0.629	0.141
	COP $d_{F/B}$ ST	578.972	1	578.972	3.594	0.065	0.573
	COP $d_{F/B}$ SB	700.016	1	700.016	5.566	0.023*	0.905
	COP $d_{F/B}$ FB	824.908	1	824.908	4.577	0.038*	0.901
	COP vt ST	22.958	1	22.958	1.921	0.173	0.418
	COP vt SB	127.990	1	127.990	1.955	0.169	0.423
	COP vt FB	102.688	1	102.688	1.165	0.286	0.326
	COP at ST	7643.372	1	7643.372	1.430	0.238	0.357
	COP at SB	7942.688	1	7942.688	0.102	0.751	0.089
	COP at FB	11934.822	1	11934.822	0.274	0.603	0.155
Groups*Gender	COP $d_{L/R}$ ST	151.654	2	75.827	4.415	0.018*	0.902
	COP $d_{L/R}$ SB	592.639	2	296.319	5.578	0.007**	1.006
	COP $d_{L/R}$ FB	244.112	2	122.056	7.816	0.001**	1.191
	COP $d_{F/B}$ ST	324.729	2	162.364	1.008	0.373	0.429
	COP $d_{F/B}$ SB	554.309	2	277.154	2.204	0.122	0.632
	COP $d_{F/B}$ FB	472.797	2	236.398	1.312	0.280	0.487
	COP vt ST	13.015	2	6.508	0.545	0.584	0.313
	COP vt SB	45.572	2	22.786	0.348	0.708	0.255
	COP vt FB	211.414	2	105.707	1.200	0.311	0.468
	COP at ST	611.597	2	305.799	0.057	0.944	0.109
	COP at SB	86815.233	2	43407.616	0.559	0.576	0.320
	COP at FB	160210.866	2	80105.433	1.840	0.171	0.577

(COP) Centre of pressure; (ST) Static balance; (SB) Sagittal balance; (FB) Frontal Balance; ($d_{L/R}$) Left/right sway displacements; ($d_{F/B}$) Forward/backward sway displacements; (vt) Velocity; (at) Acceleration; (*) Significant at $p < 0.05$; (**) Significant at $p < 0.01$.

The results showed a significant interaction effect ($p = 0.018$ to 0.001) between groups * gender for the COP static left/right sway displacements and a significant interaction effect for the COP dynamic left/right sway displacements (i.e., frontal and sagittal plane) (Table 2; Figure 2). In addition, the results showed a significant difference ($p = 0.013$) between groups in COP static left/right sway displacements and a significant interaction in the COP dynamic left/right sway displacements ($p = 0.001$) in the sagittal plane (Figure 3). Additionally, the COP dynamic sway velocity and acceleration in the frontal plane showed a significant difference between the groups (Figure 4). Moreover, the findings demonstrate a significant difference ($p = 0.038$) between gender in the COP static left/right sway displacements (Figure 5) and the COP dynamic (i.e., fontal and sagittal) forward/backward sway displacements ($p = 0.004$) (Figure 5).

Between the groups effect, the Tukey post hoc analysis showed a significant difference ($p < 0.05$; $d = 0.936$) between the handball players (HB) and the video gamers (VG) in the static balance COP left/right sway displacements. Likewise, there was a significant difference between the artistic gymnasts (AG) and the VG groups ($p < 0.05$; $d = 1.051$), and between the HB and the VG groups ($p < 0.001$; $d = 1.514$) in dynamic sagittal balance COP left/right sway displacements. A similar significant difference was detected between the AG and the HB groups ($p < 0.01$; $d = 1.315$), and between the HB and the VG groups ($p < 0.05$; $d = 0.928$) in the dynamic frontal balance COP velocity. Similarly, there is a significant variation between the AG and the HB groups ($p < 0.01$; $d = 1.191$) in the dynamic frontal balance COP acceleration.

Likewise, between the genders effect, the Tukey post hoc analysis revealed a significant difference for the static balance COP left/right sway displacements ($p < 0.01$; $d = 0.978$) and the dynamic balance (i.e., frontal and sagittal) COP forward/backward sway displacements ($p < 0.05$; $d = 0.920$ and $p < 0.05$; $d = 0.914$ in the frontal and sagittal planes, respectively).

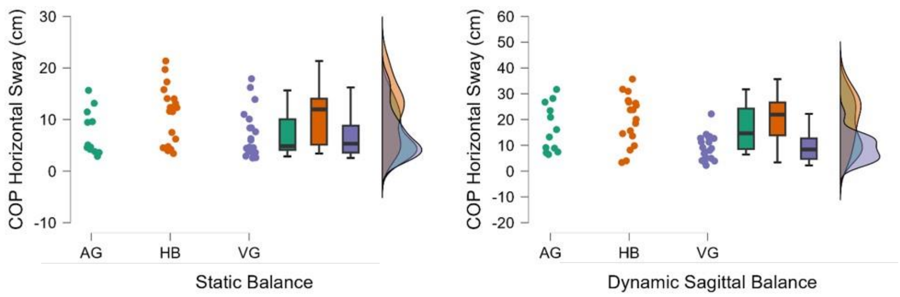

Figure 3. COP left/right sway displacements in the static and dynamic balances between groups.

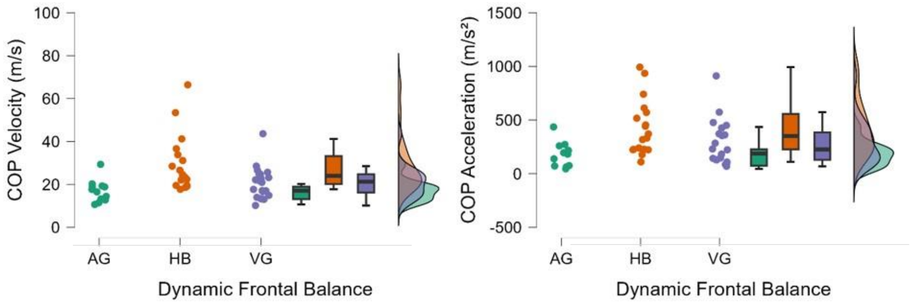

Figure 4. COP velocity and acceleration in the dynamic frontal balances between groups.

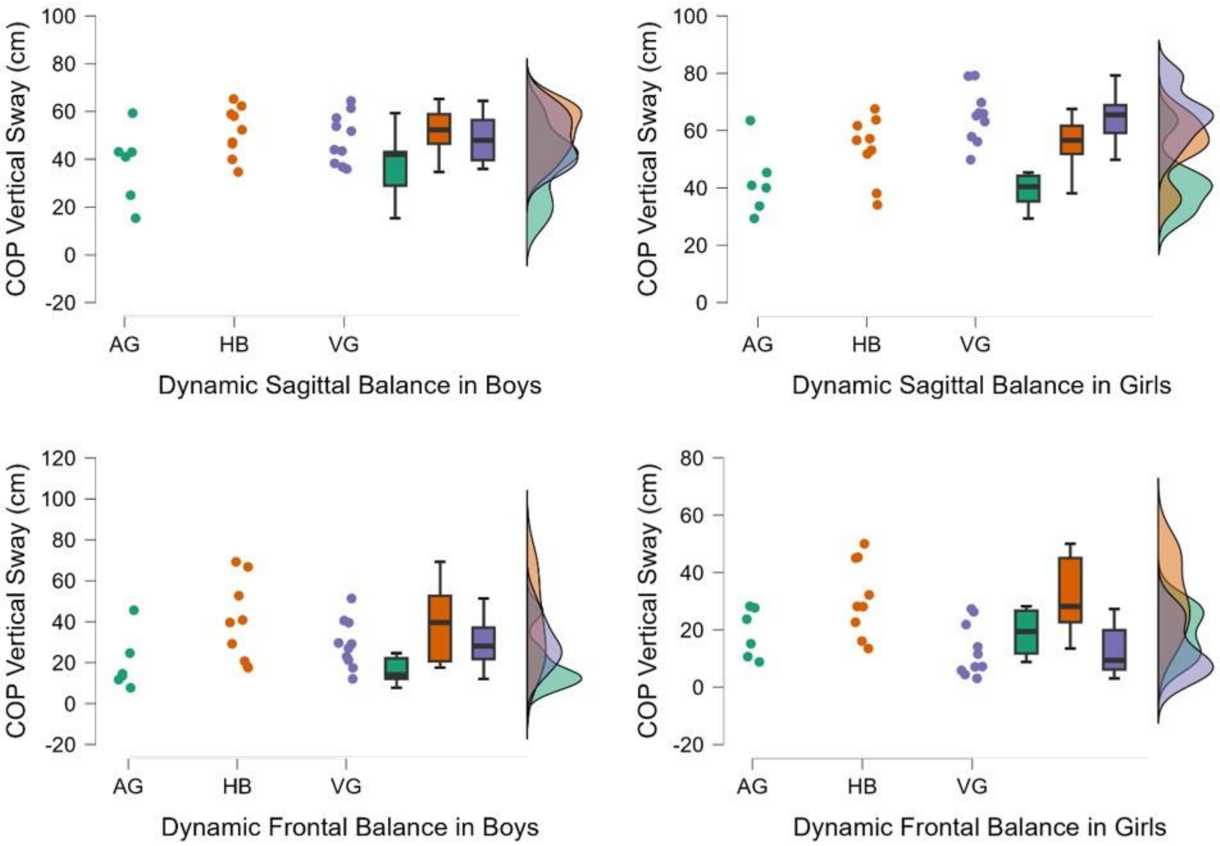

Figure 5. COP forward/backward sway displacements in the dynamic frontal balances between genders.

Finally, between the groups and genders effect, the Tukey post hoc analysis demonstrated a significant difference for the static balance COP left/right sway displacements between the AG girls and the VG boys ($p < 0.001$; $d = 2.468$), and between the AG girls and the HB boys and girls ($p < 0.05$; $d = 1.685$ and $p < 0.01$; $d = 1.931$, respectively). Additionally, in the dynamic balance conditions (i.e., frontal and sagittal), the AG girls showed better COP left/right sway displacements than the AG boys ($p < 0.05$; $d = 1.886$ and $p < 0.05$; $d = 1.847$, respectively), the HB boys ($p < 0.05$; $d = 1.384$ and $p < 0.05$; $d = 1.686$, respectively), and the VG boys ($p < 0.05$; $d = 1.740$ and $p < 0.01$; $d = 1.822$, respectively).

4. Discussion

The purpose of this study was to compare postural stability in young gymnasts and handball players with their inactive peers (i.e., video gamers) assessed via a COP analysis. Since sports activities can contribute to improving postural control [50], this study compares static and dynamic balance between two different disciplines, individual and team sports, and also examines the effects of gender on static and dynamic balance in children under twelve years of age.

Our results showed a significant interaction ($p = 0.018$ to 0.001) between the groups and gender in the COP static and dynamic (i.e., frontal and sagittal) left/right sway displacements. More specifically, a significant difference between the groups in the COP static and dynamic left/right sway displacements in the sagittal plane and in the COP dynamic sway velocity and acceleration in the frontal plane was observed.

Furthermore, the Tukey post-hoc analysis showed a significant difference ($p < 0.05$; $d = 0.936$) between the HB and the VG groups in the static balance COP left/right sway displacements. An additional difference was clear in the dynamic sagittal balance COP left/right sway displacements between the AG and the VG groups ($p < 0.05$; $d = 1.051$), and between the HB and the VG groups ($p < 0.001$; $d = 1.514$). These results align with Noé and Paillard [14], who affirmed that athletes systematically demonstrate better postural performances than sedentary subjects because physical training enhances their ability to use proprioceptive and somesthesic information.

Our results obtained for the dynamic frontal balance demonstrated a reduced COP sway and velocity for the AG compared to the VG and HB groups. Moreover, there was a significant difference between the AG and the HB groups ($p < 0.01$; $d = 1.315$) and between the HB and the VG groups ($p < 0.05$; $d = 0.928$) in the dynamic frontal balance COP velocity. Similarly, there was a significant variation between the AG and the HB groups ($p < 0.01$; $d = 1.191$) in the dynamic frontal balance COP acceleration. This could be considered as the best postural performance of the AG group in the frontal positions. However, this performance was not observed for the dynamic sagittal balance.

The latter finding is supported by Vuillerme Danion Marin et al. [21], who compared skilled athletes in other sports and showed that gymnasts displayed better postural control. They reported that gymnasts recovered from disturbed proprioception earlier than the other athletes. Our results were also confirmed by Sloanhoffer Harrison and McCrory [51], who find out that gymnasts demonstrated less total sway than the control group and less sway velocity than the non-gymnast athletes in response to dynamic perturbations. In static testing, gymnasts display better medio-lateral stability than non-athletes.

In agreement with our results, research by Opala-Berdzik Głowacka and Juras [52] indicated that gymnasts who practiced from an early age had an enhanced development of postural control. Moreover, Hrysomallis [16] suggested that gymnasts developed superior balance compared to athletes in other sports and non-athletes by practicing stationary balance in challenging postures and dynamic landings from acrobatic skills, which enhanced their sensory and musculoskeletal systems. Likewise, Busquets Aranda-Garcia Ferrer-Uris et al. [53] reported that gymnastics training might accelerate the development of proprioceptive dominance during visual perturbations around the age of 10 years.

Moreover, Davlin [4] compared the dynamic balance performances of elite gymnasts, non-gymnast athletes, and control groups, and found that gymnasts had better values than athletes in other branches, while soccer players and swimmers had better balance values than the control group. Similar to our results, Kyselovičová Zemková Péliová et al. [54] demonstrated that training in various gymnastic disciplines affects the development of balance positively and allows an almost perfect stability, even in difficult conditions.

In our study, no significant difference between the AG and the HB groups in all COP static balance parameters was found, which align with Erkmen Suveren Göktepe et al. [55]. In their study, which was conducted in all balance performances, the static balance of the gymnasts and soccer players was similar to each other, and the dynamic balance performance was in favor of the gymnasts.

Hence, the inferior postural performance observed with the VG group may be illustrated by the long term effect of repetitive and specific trainings of athletic groups based on the suggestion of Perrin Deviterne Hugel et al. [20], who affirmed that learning a sport and practicing it over a long period of time appeared to improve the efficiency of both static and dynamic postural control.

Another major finding of our study is that a significant gender difference was observed in the COP static left/right sway displacements and the COP dynamic (i.e., fontal and sagittal) forward/backward sway displacements. Likewise, between the genders effect, the Tukey post hoc analysis revealed a significant difference in the static balance COP left/right sway displacements ($p < 0.01$; $d = 0.978$) and the dynamic balance (i.e., frontal and sagittal) COP forward/backward sway displacements ($p < 0.05$; $d = 0.920$ and $p < 0.05$; $d = 0.914$ in the frontal and sagittal planes, respectively).

In this context, Petran Potop Mihai et al. [56] asserted that when it comes to differences between male and female gymnasts in the bipedal standing position, girls showed a better performance compared to boys. Similarly, Rusek Adamczyk Baran et al. [57] affirmed that girls had a better balance than their peers in all analyzed parameters. Additionally, Azevedo Ribeiro and Machado [58] found out that girls showed a higher stability than boys, which was supported by lower values of the stabilometric variables for stable static balance tasks.

Therefore, several studies have reported that postural stability varies with age and gender [11,26,37,59,60], and, consistent with our results, have also found that girls exhibit less postural sway than boys of similar ages [61−65], because the sway parameters are developed earlier in girls [37]. More specifically, Shams Vameghi Shamsipour Dehkordi et al. [66] affirmed that girls exhibited superior balance posture compared to boys across all ages, from two to eighteen years. Moreover, Steindl Kunz Schrott-Fischer et al. [60] affirmed that females showed a greater rate of improvement in stability until the range of 11–12 years, and younger males under the age of 10 years seemed to be less attentive and agitated.

Finally, between the groups and genders effect, the Tukey post hoc analysis demonstrated a significant difference for the static balance COP left/right sway displacements between the AG girls and the VG boys ($p < 0.001$; $d = 2.468$), and between the AG girls and the HB boys and girls ($p < 0.05$; $d = 1.685$ and $p < 0.01$; $d = 1.931$, respectively). Moreover, for the dynamic balance conditions (i.e., frontal and sagittal), the AG girls showed better COP left/right sway displacements than the AG boys ($p < 0.05$; $d = 1.886$ and $p < 0.05$; $d = 1.847$, respectively), the HB boys ($p < 0.05$; $d = 1.384$ and $p < 0.05$; $d = 1.686$, respectively), and the VG boys ($p < 0.05$; $d = 1.740$ and $p < 0.01$; $d = 1.822$, respectively).

This finding was not surprising because gymnastic training positively affects the development of balance and allows for an almost perfect stability, even in difficult conditions [26,67]. Additionally, given that the standard dimensions for the balance beam is 10 cm wide, female gymnasts who have trained for many hours on the balance beam display significantly less medio-lateral COP movements during static balance. When it comes to the dynamic perturbation testing, gymnasts displayed less total sway than the controls and less sway velocity than the other non-gymnast athletes [51]. Similarly, Dallas Mavidis Dallas et al. [26] demonstrated that practicing gymnastics at an early age enables women utilize their automated motor system more effectively, recover faster from unexpected disruptions, and demonstrated greater stability compared to men.

The results of this study suggest that athlete groups have the best postural control abilities than their sedentary peers VG under twelve years of age. Nevertheless, the present study supports the idea that practicing sports, specifically individual sports such as gymnastics, potentially leads to greater postural stability and more pronounced changes in balance control abilities. This aligns with Balter Stokroos Akkermans et al. [68], who suggested that the superior balance control of gymnasts might be more likely to arise from the specific training that they received. These results suggest that gymnastics training has a positive effect on postural control and supports the inclusion of balance training in many sports to further improve stability. Specifically, Dallas Mavidis Dallas et al. [26] advised coaches to incorporate balance training into their programs to enhance stability in male athletes and achieve a higher overall performance.

Moreover, practicing gymnastics in this critical developmental stage could provide children with improved postural control, as supported by Schedler Graf and Muehlbauer [69], who indicated that balance training is effective to improve the balance performance in healthy children under twelve years of age. Additionally, our findings showed that girls appear to be more capable of maintaining postural control, particularly female gymnasts, which is consistent with other research showing that girls have better-developed vestibular functions at this age [61].

5. Conclusions

In this study, we aimed to compare static and dynamic postural stability among young gymnasts, handball players, and their inactive peers (i.e., video gamers), as well as to examine gender differences in stability skills. The results showed that the AG group exhibited a reduced COP sway and velocity compared to the VG and HB groups during dynamic balance tasks on the SPBB, particularly in the frontal plane. This suggests that gymnasts recover from disturbed proprioception more rapidly than the other athletes. Additionally, significant gender differences were observed in the static COP left/right sway displacements and the dynamic COP forward/backward sway displacements in both the frontal and sagittal planes. Notably, the AG girls demonstrated better COP left/right sway control compared to boys.

In the sports disciplines, there is a constant demand for progressively higher performance levels. Therefore, balance training at an appropriate age can enhance the athletes' ability to integrate information from predictive and vestibular systems during stability control. Indeed, practicing individual sports, especially gymnastics, may lead to greater postural stability and more pronounced improvements in their balance control abilities. Furthermore, early engagement in gymnastics enables women to utilize their automated motor systems more effectively, recover more quickly from unexpected disruptions, and demonstrate greater stability compared to men.

In conclusion, gymnastics training has a positive impact on postural control and supports the inclusion of balance training across various sports to further enhance stability and overall performance.

Use of AI tools declaration

The writers of this article affirm that they did not create it using artificial intelligence (AI) methods.

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Conflict of interest

No conflicts of interest are disclosed by the authors.

Author contributions

Conceptualization, B.B. and B.M.; methodology, B.B. and B.M.; software, B.M.; validation, S.A. and B.M.; formal analysis, B.M.; investigation, B.B.; resources, B.B. and B.M.; data curation, B.M.; writing original draft preparation, B.B.; writing-review and editing, B.M. and S.A.; visualization, B.B., and S.A.; supervision, B.M. and S.A.; project administration, B.M. All authors have read and agreed with the published version of the manuscript.

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