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Effect of cognitive tasks on balance abilities in U-12 gymnasts, handball players and video gamers

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Abstract

Purpose: This study aims to investigate the immediate effects of cognitive tasks on static and dynamic balance in gymnasts, handball players, and video gamers under the age of 12 years, using dual-task paradigm. *Methods:* A sample of 50 children under the age of 12 years was divided into three groups (i.e., gymnasts, handball players, and video gamers). They participated in a dual-task experiment involving mental rotation tasks with static and dynamic balance assessments. Participants performed mental rotation tasks (i.e., object-based 3D cube and human body conditions) while simultaneously maintaining static and/or dynamic balance on a stabilometric platform. Center of pressure sway, acceleration, and displacement were measured. Performance in both cognitive and balance tasks was recorded and analyzed. *Results:* The results revealed significant immediate beneficial effects of cognitive tasks on dynamic balance. Specifically, dual tasks led to improved performance in mental rotation tasks and enhanced postural control, as evidenced by a reduced center of pressure sway ($p < 0.01$). Athletes demonstrated greater improvements than non-athletes, highlighting the effectiveness of cognitive engagement in improving postural control. *Conclusion:* These results suggest that participation in sports during childhood can significantly enhance neuromuscular control and balance, which are critical for maintaining stability. The findings highlight the importance of integrating cognitive challenges into physical training. This approach enhances both cognitive and motor performance in young athletes.

Keywords: dynamic balance; static balance; mental rotation; gymnasts; handball players; video gamers.

Introduction

Physical activity is one of the most important factors that enhance the mental rotation (MR) performance [36]. MR task, as a cognitive task, was first introduced by Shepard and Metzler [44] to assess the ability to mentally manipulate two- or three-dimensional objects. This task involves visualizing and mentally rotating objects in any direction or translating them in space, thereby providing a measure of spatial reasoning and cognitive processing capabilities. Moreover, a study by Jansen and Pietsch [24] showed that participants engaged in physical activity improved their MR performance more than the control group. In addition, much research including studies by Schmidt et al. [43], Jansen and Lehmann [22], and Jansen et al. [23] has demonstrated that athletes outperformed non-athletes in MR tasks. Furthermore, this advantage is often attributed to the extensive training athletes undergo in sports that demand spatial awareness and body control [48]. Relative to sport also, Chen et al. [12] found that athletes exhibit a higher postural stability when performing dual tasks compared to non-athletes. Also, Amara et al. [2] demonstrated that female volleyball and badminton players showed a reduced center of mass (COM) sway velocity and displacement when engaging in MR tasks. Athletes often outperform non-athletes in these tasks due to their extensive training in sports that require spatial awareness and body control [48]. Kenville et al. [27] affirmed that athletes generally exhibit better balance abilities compared to non-athletes. However, based on the reviewed literature, differences exist in these abilities among athletes from different disciplines. So, building on these findings, including the work of Jansen and Lehmann [22], who demonstrated that gymnasts exhibit superior MR performance compared to non-athletes, and Ozel et al. [35], who similarly found that gymnasts outperformed non-athletes in MR tasks, this study aims to further investigate the relationship between cognitive tasks and postural stability in athletes. Additionally, considering the growing popularity of handball, as highlighted by Picot et al. [38], and the findings of Karcher and Buchheit [25], which suggest that handball requires high-intensity skills such as intermittent sprinting, jumping, landing, and rapid directional changes-activities that may significantly influence cognitive functions the current study seeks to explore the effects of cognitive tasks on postural stability among athletes from different sports backgrounds. Specifically, comparing gymnasts and handball players to better understand how sport-specific demands may shape cognitive and postural control abilities. In this context, stability must be taken into consideration. Historically, postural control was considered an automatic process that required minimal attentional resource [51]. However, recent studies involving both adults and children demonstrated that maintaining or restoring stability demands actually necessitates significant attentional resources [5], [9], [21], [37]. In studies investigating the relationship between attention and postural control in adults, researchers usually have employed dual-task paradigms. Van Impe et al. [47] affirm that dual-task paradigms are commonly used to study interactions between cognitive and postural control. These paradigms require participants to perform a postural control task and a cognitive task simultaneously. The extent to which performance declines in one or both tasks serves as an indicator of the degree to which attentional resources are shared between the tasks [41].

Additionally, Broglio et al. [8] indicated that using a dual-task paradigm in which participants maintained balance while simultaneously performing cognitive tasks was the most effective method for assessing the influence~~s~~ of cognitive load on postural stability. Similarly, Huxhold et al. [21] confirmed that when maintaining balance in an upright stance while engaging in a cognitive task simultaneously, requires attention to be divided between sensorimotor and cognitive tasks. Furthermore, Maylor et al. [33] found that in both young and older adults, sway velocity and variability decreased significantly (i.e., balance improved) during the encoding phase of the Brooks' spatial memory task. Regarding the dual task paradigm, Pellecchia [37] who explored the relationship between body sway and attentional focus during cognitive and physical tasks, suggested that increased body sway may result from the difficulty of performing concurrent cognitive tasks.

In contrast, little attention has been given to adolescent participants in assessments of MR ability and postural control in dual task paradigm [15]. Similarly, a meta-analysis conducted by Voyer and Jansen [48] found that participants of all available studies were older than 17 years of age. It is still unclear whether motor-cognitive process in children and adults are similar. Taken together, the suggestions of Hofmann and Jansen [18] and Budde and Weigelt [10], who noted a lack of research examining the interplay between balance and MR tasks, particularly within sports science students. This gap presents an opportunity to investigate the effects of cognitive tasks on postural stability among athletes from different sports.

To provide new insights, this study aims to determine the extent to which postural control (i.e., static and/or dynamic balance) is influenced by additional cognitive tasks, specifically MR, in children U-12 years old.

Considering that motor activity plays a significant role in improving MR task performance [36], and to address gaps in research that has primarily investigated the effects of sports on MR in participants older than 17 years [15], this study will examine the impact of MR task in two different sports (i.e., gymnastics and handball) and gaming activities on balance in children U-12 years old.

This research employs a dual-task paradigm to explore the influence of MR tasks involving both cube and human body stimuli under different upright conditions (i.e., with and without dynamic balance) and to examine the immediate effects of MR tasks on balance performance (i.e., static and dynamic balance in the frontal and/or sagittal planes) in gymnasts, handball players, and video gamers U-12 years old.

Additionally, this study will investigate whether specific sports and/or gaming activities during childhood can enhance postural control.

Methods

Participants

A minimum sample size of 50 participants (i.e., across three groups) was determined through an a priori statistical power analysis using G*Power software (Version 3.1, University of Dusseldorf, Germany [14]). The power analysis (i.e., for repeated measure ANOVA between and within groups analysis) was computed with an assumed power at 0.90 at an alpha level of 0.050 and a small effect size (*d* = 0.40 and critical F = 1.871) [1], [2].

Therefore, fifty volunteer male and female U-12 participants comprising by 12 artistic gymnasts (i.e., 6 males: age of pack high velocity (APHV) 14.25 ± 1.31 years; maturity offset (MO) = -2.09 ± 1.02 years; age 12.15 ± 0.33 years; height 1.50 ± 0.09 m; body mass 36.67 ± 10.82 kg, and 6 females: APHV 11.98 ± 0.31 years; MO = 0.001 ± 0.40 years; age 11.98 ± 0.33 years; height 1.52 ± 0.03 m; body mass 34.83 ± 1.17 kg), 18 handball players (i.e., 9 males: APHV 12.27 ±1.27 years; (MO) = -0.36 ± 1.29 years; age 11.92 ± 0.27 years; height 1.66 ± 0.11 m; body mass 46.50 ± 9.92 kg, and 9 females: APHV 11.14 ± 0.25 years; MO = 0.84 ± 0.28 years; age 12.98 ± 0.22 years; height 1.66 ± 0.03 m; body mass 39.13 ± 1.81 kg), and 20 video gamers (i.e., 10 males: APHV 13.51 ± 0.97 years; (MO) = -1.29 ± 1.04 years; Age 12.22 ± 0.23 years; height 1.57 ± 0.09 m; Body mass 38.2 ± 3.36 kg. 10 females: APHV 11.74 ± 0.31 years; (MO) = 0.21 ± 0.42 years; age 11.95 ± 0.28 years; Height 1.56 ± 0.04 m; Body mass 37.30 ± 2.87 kg) agreed to participate in this study.

None of the participants had any disease or injury affecting balance. 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 [11] and was approved by the Local Ethical Committee of the National Observatory of Sport (ONS/UR/18JS01-2024/3).

Experimental design and procedures

This study consisted of six random assessments (i.e., randomized, counterbalanced, Latin Square) [53]. 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 sagittal balance, figure 1c, using a single-plane balance board "i.e., Freeman tray") on a stabilometric platform (Posture-Win©, Techno Concept®, Cereste, France, frequency 40 Hz, A/D conversion 12 [31]), with and without a 3D human and/or cube MR task.

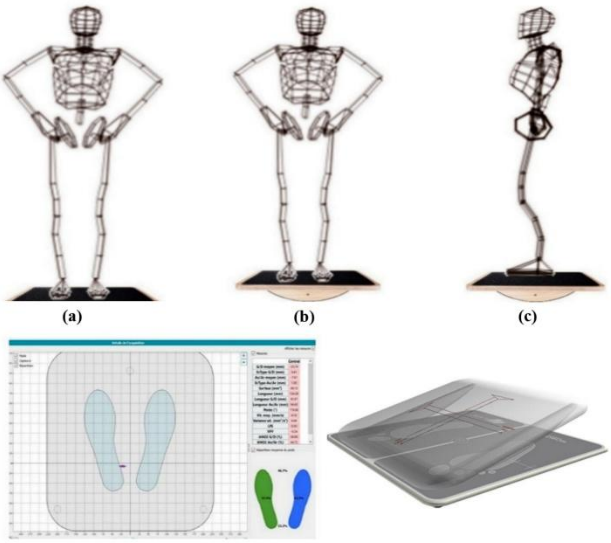

Figure 1. Posture-Win© stabilometric force platform experimental protocol: (a) Bipedal sway, standing balance; (b) Bipedal sway, frontal balance with single plane balance board; (c) Bipedal sway, sagittal balance with single plane balance board.

Seven stimuli (i.e., 45°,90°, 135°, 180°, 225°, 270° and 315°) were used in the MR task. The object-based 3D cube (OC) condition and object-based human body (OB) condition included pairs of standard and comparison images (Figure 2). The standard image was displayed on the left side of the monitor screen, while the comparison image, rotated to one of seven orientations (i.e., 45°.90°. 135°. 180°. 225°.270° and 315°) was shown on the right side of the screen [1], [2], [17], [28], [29].

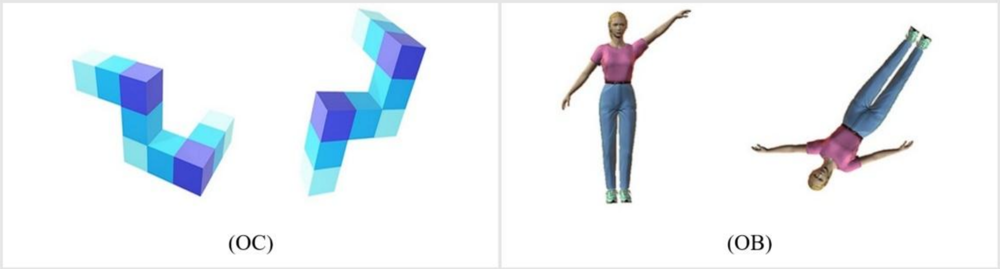

Figure 2. Examples of two stimuli conditions: (OC – object-based cube. OB – object-based human body) [1], [2].

Postural performance was evaluated through a series of balance tests with and/or without MR task (i.e., 3D cubes and human) mentioned as follows:

The balance abilities will be studied in nine conditions:

- Bipedal sways in standing position: The subject stood upright position on the Posture-Win stabilometric platform for two minutes in static standing balance (ST) without mental rotation (WMR).
- Bipedal sways in standing position with human MR task (HMR): The subject stood upright on the Posture-Win stabilometric platform facing a PC while holding a wireless joystick and completed a HMR task for two minutes in ST.
- Bipedal sways in standing position with cube MR task (CMR): The subject stood upright on the Posture-Win stabilometric platform facing a PC while holding a wireless joystick and completed a CMR task for two minutes in ST.
- Bipedal sways in frontal balance: The subject stood upright on the Posture-Win stabilometric platform with a single-plane balance board (SPBB) placed on it for two minutes in dynamic frontal balance (FB).
- Bipedal sways in frontal balance with HMR task: The subject stood upright on the Posture-Win stabilometric platform with a SPBB placed on it, facing a PC while holding a wireless joystick and completed a HMR task for two minutes in FB.
- Bipedal sways in frontal balance with CMR task: The subject stood upright on the Posture-Win stabilometric platform with a SPBB placed on it, facing a PC while holding a wireless joystick and completed a CMR task for two minutes in FB.

- Bipedal sways in sagittal balance: The subject stood upright on the Posture-Win stabilometric platform with a SPBB placed on it for two minutes in dynamic sagittal balance (SB).
- Bipedal sways in sagittal balance with HMR task: The subject stood upright on the Posture-Win stabilometric platform with a SPBB placed on it, facing a PC while holding a wireless joystick and completed a HMR task for two minutes in SB.
- Bipedal sways in sagittal balance with CMR task: The subject stood upright on the Posture-Win stabilometric platform with a SPBB placed on it, facing a PC while holding a wireless joystick and completed a CMR task for two minutes in SB.

In the balance with MR conditions (i.e., CMR and HMR), the participant stands on the SPBB placed on the Posture-Win stabilometric platform facing a PC while holding a wireless joystick, they were asked to respond to the stimuli (i.e., cube and/or human) as quickly as possible. Each trial begins with a blank screen for 1000 ms followed by a black fixation cross displayed at the center for 500 ms. After fixation, the test image is presented for a maximum of 5000 ms and remains on the screen until a response is given. Stimuli are displayed and response times are recorded via the free software OpenSesame [32]. The MR task lasts approximately 2 minutes. In all trials, subjects were instructed to keep their body straight and their arms relaxed at their sides [49]. A MR test (i.e., CMR and HMR) was performed under normal conditions (i.e., without balance conditions) before the experiment. These results serve as a baseline value (BV) for comparison.

This results in a total of 252 trials: 3 (balance conditions: standing, frontal and sagittal) × 3 (groups: gymnasts, handball players and video gamers) × 2 (mental rotation tasks: cubes and human) × 7 (angle display: 45°, 90°, 135°, 180°, 225°, 270°, and 315°) × 2 (response types: same or different). The order of stimulus presentation was counterbalanced, ensuring that no rotation angle appeared twice in succession.

To quantify the postural sway of participants we analyzed the center of pressure (COP) trajectory over time. This measurement was obtained using a Posture-Win stabilometric platform, which provides precise data on the COP's movement patterns during static and dynamic balance tasks. During bipedal standing, the COP represents the point of application of vertical ground reaction forces exerted by the feet on a force plate [50]. 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. This setup ensures that the heels remain aligned with another tape to maintain standardized foot placement. Such methodologies are essential in research and clinical assessments to ensure consistency in body positioning which can significantly impact balance and coordination measurements [42]. Finally, we measured the horizontal (dx) and vertical (dy) displacement, as well as the resultant velocity (vt) and acceleration (at) of the COP.

Statistical analysis

As part of statistical analysis, the SPSS 25 package (SPSS. Chicago. IL. USA) program was used for the data analysis. Descriptive statistics (i.e., means ± SD) were performed for all variables. The effect size was conducted using 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 [19]. The normality of distribution estimated by the Kolmogorov-Smirnov test was acceptable for all variables ($p>0.05$). Consequently, ANOVA with repeated measures with three factors (i.e., balance, mental rotation and sports) was used to benchmark different conditions. Bonferroni test was applied in post-hoc analysis for pairwise comparisons. Additionally, effect sizes (d) were determined from ANOVA output by converting partial eta-squared to Cohen's d. A priori level less than or equal to 0.5% ($p \leq 0.05$) was used as a criterion for significance.

Results

The repeated measures ANOVA with three factors (i.e., balance, MR, and groups) revealed a significant interaction between balance and MR in all variables studied, between balance and groups in horizontal displacement, velocity and acceleration, between MR and groups for velocity, and finally between balance, MR and groups in horizontal displacement and velocity (Table 1, Figures 3 and 4).

Table 1. Repeated measures ANOVA

		df	Mean^2	F	Sig.	Effect Size	Power
Balance	dx	2	4499.657	19.219	0.000**	1.278	1.000
	dy	2	7223.289	19.776	0.000**	1.296	1.000
	vt	2	3691.174	77.844	0.000**	2.576	1.000
	at	2	2171664.844	59.580	0.000**	2.251	1.000
MR	dx	2	1689.878	8.001	0.001**	0.823	0.951
	dy	2	2702.557	9.243	0.000**	0.885	0.974
	vt	2	538.472	20.618	0.000**	1.324	1.000
	at	2	332953.230	11.802	0.000**	1.003	0.993
Groups	dx	2	3027.280	6.832	0.002**	1.077	0.904
	dy	2	510.383	0.851	0.433	0.380	0.187
	vt	2	383.815	2.117	0.132	0.601	0.413
	at	2	176287.198	2.839	0.069	0.695	0.531
Balance * MR	dx	4	580.700	3.490	0.009**	0.544	0.856
	dy	4	677.449	2.481	0.045*	0.458	0.700
	vt	4	105.223	7.029	0.000**	0.773	0.994
	at	4	91793.130	4.221	0.003**	0.597	0.920
Balance * Groups	dx	4	643.388	2.748	0.033*	0.685	0.738
	dy	4	206.474	0.565	0.688	0.306	0.182
	vt	4	150.747	3.179	0.017*	0.735	0.806
	at	4	94483.144	2.592	0.041*	0.666	0.709
MR * Groups	dx	4	141.810	0.671	0.613	0.339	0.211
	dy	4	388.709	1.329	0.265	0;477	0.401
	vt	4	73.619	2.819	0.029*	0.692	0.750
	at	4	47737.235	1.692	0.158	0.536	0.501
Balance * MR * Groups	dx	8	338.939	2.037	0.044*	0.590	0.819
	dy	8	70.264	0.257	0.978	0.210	0.130
	vt	8	53.067	3.545	0.001**	0.776	0.980
	at	8	37456.570	1.722	0.096	0.540	0.736

(dx) horizontal displacement; (dy) vertical displacement; (vt) sway velocity; (at) sway acceleration; (MR) mental rotation; (*) significant at p<0.05; (**) significant at p<0.01.

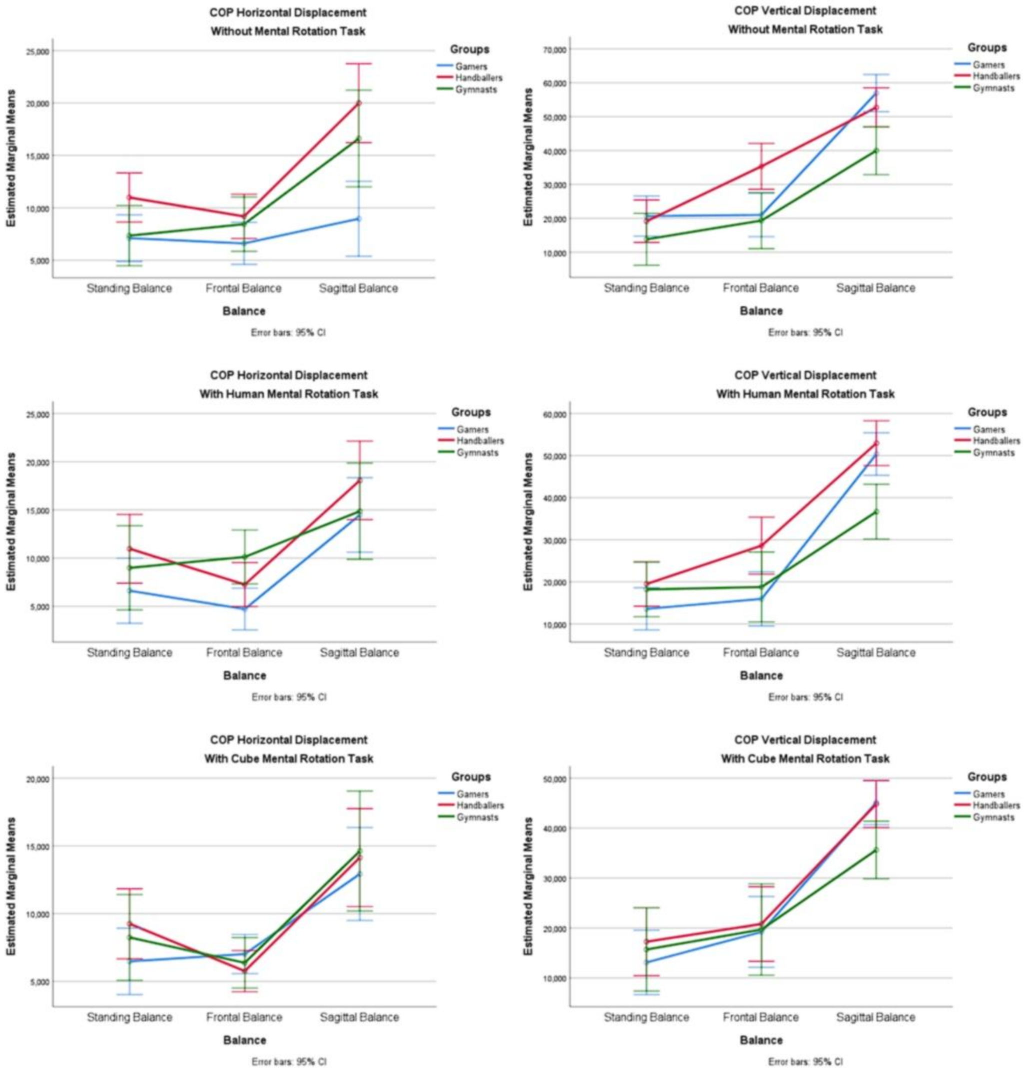

Figure 3. COP displacement in different balance conditions for the three groups.

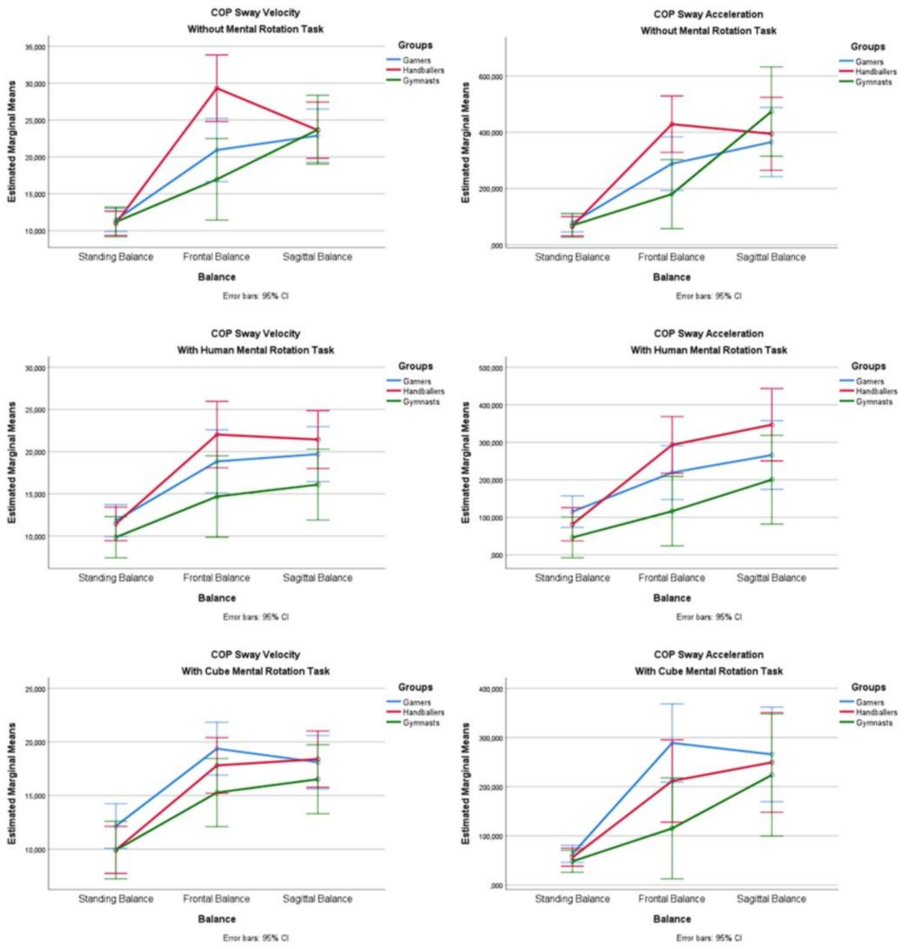

Figure 4. COP velocity and acceleration in different balance conditions for the three groups.

In addition, a significant difference was observed between balance conditions (i.e., ST, FB, and SB) for all studied variables at $p < 0.001$ (Table 1). Displacement (i.e., *dx* and *dy*), velocity (*vt*) and acceleration (*at*) increased significantly from static to dynamic balance (Figures 3 and 4). However, a significant decrease was noted when cognitive tasks were introduced in dynamic balance conditions (i.e., FB and SB). The pairwise comparisons are presented in Table 2.

Table 2. Pairwise comparison between balance conditions.

		Mean Diff.	SE Diff.	Sig.	Effect Size
dx	ST vs. FB	-10.963	1.838	0.000**	1.491
	ST vs. SB	-3.408	1.873	0.226	0.468
	FB vs. SB	7.555	1.715	0.000**	1.101
dy	ST vs. FB	-1.506	1.931	1.000	0.195
	ST vs. SB	-12.996	2.765	0.000**	1.175
	FB vs. SB	-11.49	1.990	0.000**	1.443
vt	ST vs. FB	-8.497	0.863	0.000**	2.461
	ST vs. SB	-9.078	0.837	0.000**	2.711

	FB vs. SB	-0.581	0.739	1.000**	0.192
at	ST vs. FB	-168.574	17.135	0.000**	2.459
	ST vs. SB	-240.06	22.495	0.000**	2.668
	FB vs. SB	-71.486	27.025	0.033*	0.661

(dx) horizontal displacement; (dy) vertical displacement; (vt) sway velocity; (at) sway acceleration; (ST) standing balance; (FB) frontal balance; (SB) sagittal balance; (*) significant at p<0.05; (**) significant at p<0.01.

Additionally, a significant difference was observed between MR tasks (i.e., WMR, HMR, and CMR) for all studied variables at $p < 0.001$ (Table 1). A difference was also noted between static and dynamic balance in relation to MR task. In the static condition displacement, velocity and acceleration increased when the MR task was introduced. However, in dynamic balance, all values decreased compared to WMR (Figures 3 and 4). The pairwise comparisons are presented in Table 3.

Table 3. Pairwise comparison between mental rotation tasks.

		Mean Diff.	SE Diff.	Sig.	Effect Size
dx	WMR vs. HMR	5.221	1.845	0.021*	0.707
	WMR vs. CMR	6.486	1.753	0.002**	0.925
	HMR vs. CMR	1.265	1.545	1.000	0.203
dy	WMR vs. HMR	7.696	1.443	0.000**	1.333
	WMR vs. CMR	7.355	2.296	0.007**	0.812
	HMR vs. CMR	-0.341	2.218	1.000	0.038
vt	WMR vs. HMR	2.794	0.673	0.000**	1.038
	WMR vs. CMR	3.731	0.631	0.000**	1.478
	HMR vs. CMR	0.937	0.496	0.196	0.472
at	WMR vs. HMR	73.069	21.394	0.004**	0.854
	WMR vs. CMR	91.157	21.362	0.000**	1.067
	HMR vs. CMR	18.088	16.437	0.830	0.275

(dx) horizontal displacement; (dy) vertical displacement; (vt) sway velocity; (at) sway acceleration; (WMR) without mental rotation; (HMR) human mental rotation; (CMR) cube mental rotation; (*) significant at p<0.05; (**) significant at p<0.01.

Moreover, no significant difference was observed between groups (i.e., video gamers, handball players and gymnasts) except for the COP horizontal displacement at $p < 0.05$ (Table 1). The pairwise comparisons are presented in Table 4.

Table 4. Pairwise comparison between groups.

		Mean Diff.	SE Diff.	Sig.	Effect Size
dx	Gamers vs. Handballers	1.578	2.280	1.000	0.245
	Gamers vs. Gymnasts	9.184	2.562	0.002**	1.267
	Handballers vs. Gymnasts	7.606*	2.615	0.017*	1.028
dy	Gamers vs. Handballers	2.106	2.652	1.000	0.283

	Gamers vs. Gymnasts	3.796	2.981	0.627	0.453
	Handballers vs. Gymnasts	1.690	3.042	1.000	0.197
vt	Gamers vs. Handballers	-1.076	1.458	1.000	0.195
	Gamers vs. Gymnasts	2.345	1.639	0.477	0.565
	Handballers vs. Gymnasts	3.421	1.673	0.139	0.723
at	Gamers vs. Handballers	-19.714	26.988	1.000	0.262
	Gamers vs. Gymnasts	53.046	30.332	0.261	0.618
	Handballers vs. Gymnasts	72.760	30.958	0.069	0.831

(dx) horizontal displacement; (dy) vertical displacement; (vt) sway velocity; (at) sway acceleration; (*) significant at $p<0.05$*; (**) significant at* $p<0.01$.

In the same way, response time (RT) showed a significant difference between conditions (i.e., ST, FB and SB) in both MR tasks (i.e., CMR and HMR) when compared to the WMR condition. RT decreased significantly with the introduction of dynamic balance (i.e., ST $\Delta = 55.89\%$ and $51.97\ \%$ with $p < 0.001$ and $d = 2.392$. FB $\Delta = 50.37\ \%$ and $42.02\ \%$ with $p < 0.001$ and $d = 2.005$, and SB $\Delta = 46.85\ \%$ and $40.81\ \%$ with $p < 0.001$ and $d = 2.645$, respectively, in CMR and HMR conditions).

Discussion

The aim of this study was to investigate the effect of MR tasks (i.e., CMR and HMR) on static (i.e., ST) and dynamic (i.e., FB and SB) balance abilities in video gamers, gymnasts and handball players using a Posture-Win stabilometric platform [31], with single-plane balance board (i.e., Freeman tray) in a bipedal stance. Fifty participants, evenly split between males and females, divided into three groups (i.e., 12 gymnasts, 18 handball players and 20 video gamers) participated in this study. The main findings of this study indicate that COP sway velocity and horizontal displacement varied significantly when interacting between Balance, MR and Groups both in 3D CMR and HMR conditions.

The main results revealed a significant interaction between balance and MR in all variables studied, between balance and groups in horizontal displacement, velocity and acceleration. Between MR and groups in the velocity, and finally between balance and MR and groups in horizontal displacement and velocity. In addition, there is a significant difference between balance conditions (i.e., ST, FB and SB) in all studied variables at $p<0.001$. The displacement (i.e., dx and dy), velocity and acceleration increase significantly from static to dynamic balance. However, a notable decrease in sway velocity and sway acceleration was observed when cognitive tasks were introduced in dynamic balance conditions (i.e., FB and SB).

Less body sway during performance of MR tasks indicates a more stable position as noted by Dault et al. [13] who found that an egocentric MR task leads to postural stabilization compared to viewing at a fixation cross on the screen. Similarly, our findings align with Hofmann and Jansen [18], who demonstrated that MR tasks can lead to improve postural stability compared to neutral conditions. Also, Andersson et al. [3] suggest that the ability to mentally imagine body movements (i.e., HMR) may be related to postural stability during challenging postural tasks. For instance, egocentric mental rotation tasks, where participants visualize movements of their own body parts (i.e., HMR), often resulting in reduced body sway and a more stable center of pressure during balance tasks [2], [20]. Furthermore, our finding as noted by Pellecchia [37], Swan et al. [45], Swan et al. [46] indicate that performing additional cognitive tasks during balance assessments can reduce medio-lateral COP motion, suggesting that cognitive load affects balance performance.

Moreover, Kawasaki et al. [26] demonstrated that MR interventions can provide immediate improvements in dynamic balance. Additionally, previous studies by Dault, Geurts, Mulder and Duysens [13] and Broglio et al. [8] have shown simultaneously engaging in both balance and cognitive tasks can enhance postural control, highlighting a beneficial interaction between these domains. More specifically, the significant interaction between MR, balance and groups highlighted the link between motor skills and MR abilities, which are defined by Blake and Shiffrar [7] that motor expertise plays a decisive role in the perception of human movement. These findings are also in agreement with research conducted by Geisen et al. [16], Lehmann et al. [30], and Jansen and Lehmann [22], who indicate that athletes trained in specific sports can better manage cognitive loads, leading to enhanced stability and performance during complex tasks. In particular, it is noteworthy that there was no significant difference between the groups (i.e., video gamers, handball players, and gymnasts) except in the COP horizontal displacement when MR were introduced at $p < 0.05$ (Table 1). This could be explained by the influence of cognitive abilities and the relationship between motor expertise. Additionally, when cognitive tasks were introduced, gymnasts showed a significant decrease in COP sway during the SB condition, while handball players exhibited a significant decrease in COP sway during the FB condition.

The significant difference between video gamers and athletes' children in the COP horizontal displacement was also demonstrated by Reeschke et al. [40] who indicated that young athletes exhibited better postural control compared to their non-athlete peers and found that athletes under-11 who engaged in sports such us soccer and basketball showed superior postural stability compared to non-athletes of the same age group by measuring the sway velocity and COP metrics. So, participation in sports activities helps develop postural control and balance enabling athletes to maintain stability and athletes often engage to improve their proprioceptive abilities, which allows them to better manage their body position during dynamic movements. This is particularly relevant as children are still developing these skills during early childhood [4].

Furthermore, there is a significant difference between MR tasks (i.e., WMR, HMR, and CMR) in all studied variables at $p < 0.001$. Likewise, there is a difference between static and dynamic balance in relation to MR tasks. In the static condition, we observed an increase in displacement, velocity and acceleration when the MR tasks were introduced. However, in dynamic balance, all values decreased compared to WMR. This could be explained by the difficulty of the dynamic test which demands more automatic control. In this regard, Wulf et al. [52], showed that an external focus enhances performance by promoting more automatic control processes in the brain. They reported that directing attention externally during tasks requiring balance can improve postural stability. This suggests that when individuals are engaged in a concurrent cognitive task allowing their postural control to operate automatically (i.e., by focusing externally) may enhance their ability to maintain balance.

Therefore, in comparing RT of video gamers with athletes we did not find a significant difference. This could be attributed to the effect of gaming. In this line, a previous meta-analysis by Bediou et al. [6] demonstrated enhancements in several cognitive skills and spatial cognition when comparing individuals who rarely play video games with those trained on action video games. In contrast, we found a significant difference when incorporating balance. Thus, we can indicate the effect of sport as noted by Powers et al. [39] who found that training with a first-person shooter video game improved perceptual processing and spatial imagery but not motor skills or executive functions.

Similarly, the RT showed a significant difference between conditions (i.e., ST, FB and SB) in both MR tasks (i.e., CMR and HMR) when compared to WMR condition. RT decreased significantly when introducing dynamic balance (i.e., ST $\Delta = 55.89$ % and 51.97 % with $p < 0.001$ and $d = 2.392$, FB $\Delta = 50.37$ % and 42.02 % with $p < 0.001$ and $d = 2.005$ and SB $\Delta = 46.85$ % and 40.81 % with $p < 0.001$ and $d = 2.645$, respectively in CMR and HMR conditions). Therefore, participants subjected to unstable balance conditions (i.e., SB and FB), demonstrated a notable improvement in the execution speed of MR tasks. This enhancement can be attributed to the increased cognitive stimulation that arises from the challenges posed by maintaining balance in unstable conditions. Our finding aligns with Kawasaki et al. [26] who showed that participants who engaged in dynamic postural tasks exhibited faster MR task completion times compared to those in static positions, reinforcing the idea that cognitive and physical domains are interlinked. Additionally, Amara et al. [2] demonstrated that dynamic balance has a positive effect on cognitive abilities, allowing participants to complete the mental rotation task more quickly, which ensuring that both cognitive and motor functions operate harmoniously.

Finally, our results seem to endorse several studies [2], [18], [34] that indicate that the dual task (i.e., MR and balance) develops cognitive abilities and postural control (i.e., RT and COP sway) in FB and SB conditions.

Conclusion

In conclusion, our study found significant and immediate beneficial effects of cognitive tasks, specifically CMR and HMR, on dynamic balance in gymnasts and handball players under the age U-12. Our results indicate that both groups of athletes benefited from reduced COM sway velocity and displacement, particularly when performing cognitive tasks. Gymnasts demonstrated a significant decrease in SB, while handball players showed a significant decrease in FB conditions in COP sway.

Additionally, we confirmed that dual-task activities (e.g., MR combined with dynamic balance tasks) improve performance in MR tasks and enhance postural control and COP sway, especially in athletes. Furthermore, the findings suggest that engaging in MR tasks alongside dynamic balance exercises improves response times and postural control, highlighting the interconnectedness of cognitive and motor processes. These insights emphasize the potential benefits of incorporating cognitive training, particularly aimed at improving MR abilities, to enhance athletic performance in dynamic balance contexts.

Moreover, we observed that video gaming positively impacts mental rotation abilities but does not significantly improve motor skills or executive functions in children under the age of 12. More specifically, these findings suggest that engaging in sports during childhood can enhance MR abilities and improve neuromuscular control and balance, which are critical for maintaining stability.

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