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Evaluation of Voluntary Dynamic Balance through Standardized Squat-Lift Movements: A Comparison between Gymnasts and Athletes from Other Sports

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Abstract: In the quotidian, people perform voluntary whole-body movements requiring dynamic body balance. However, the literature is scarce of dynamic balance evaluations employing standardized voluntary movements. In this investigation, we aimed to analyze the sensitivity of balance evaluation between gymnasts and athletes from other sports in the performance of balance tasks. Participants were evaluated in upright quiet standing and the performance of cyclic dynamic tasks of hip flexion-extension and squat-lift movements. Movements were individually standardized in amplitude, while the rhythm was externally paced at the frequency of 0.5 Hz. Tasks were performed on a force plate, with dynamic balance measured through the center of pressure displacement. Results showed that in quiet standing and the dynamic hip flexion-extension task, no significant differences were found between the groups. Conversely, results for the squat-lift task revealed a better balance of the gymnasts over controls, as indicated by the reduced amplitude and velocity of the center of pressure displacement during the task execution. The superior balance performance of gymnasts in the squat-lift task was also observed when vision was suppressed. These findings suggest the employed squat-lift task protocol is a potentially sensitive procedure for the evaluation of voluntary dynamic balance.

Keywords: equilibrium; evaluation; young; center of pressure; protocol

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1. Introduction

Much of the current knowledge on balance control has been acquired through the assessment of quiet standing, characterized by keeping an upright motionless stance. On the other hand, our daily living activities are characterized by dynamic balance, with the maintenance of stance while performing voluntary movements with the trunk and limbs, like standing up from a chair or in manual reaching. Investigation of dynamic balance has recently attracted scientific interest ([1], for a review), with research aiming at developing reliable and valid evaluation protocols (cf. [2]). In functional or clinical assessment, Y-balance [3], star excursion [4], and timed up-and-go [5] tests have been employed as proxy measurements of dynamic balance. Performance on the Y-balance and star excursion tests is measured through the maximum distance one can move a single foot in different directions over the ground in unipedal stance. Beyond requiring dynamic balance, performance on these tests has been shown to be affected by joints' range of motion [6,7] and strength of hip extensor muscles [4]. The timed up-and-go test is evaluated through the completion time to stand up from a chair, walk 3 m straightforwardly, return to the chair, and sit down. Performance on this test is mainly affected by the legs' muscular power [8]. Thus, as these tests are affected by different confounding factors, the respective measurements based on range of motion or completion time could not be taken as faithful indexes of dynamic balance.

An alternative to achieve accurate and valid measurements of dynamic balance is employing biomechanical assessments of body stability when moving, as indexed by different variables related to the center of mass or the center of pressure displacement. The prevalent research strategy for a biomechanical analysis of dynamic balance has been assessing reactive responses to intrinsic or extrinsic perturbations to stance. Some variations of this experimental strategy include the following: (a) reacting to unexpected translations [9] or rotations [10] of the support base, (b) recovering balance after the release of a load attached to the trunk leading to fast body sway [11], balancing on (c) a continuously moving platform [12] or (d) on an unstable support board [13]. Whereas objective biomechanical measurements have provided valid and reliable assessments in these reactive balance tasks (cf. [9]), results are task-specific, with a lack of association with balance measurements either in quiet standing [9,14] or with voluntary movements [15]. In the study by Ringhof and Stein [15], in particular, gymnasts and swimmers were compared on three balance tasks, requiring balance recovery from self-perturbations induced by an unstable support base or by a mechanically provoked fast forward body sway, in addition to a voluntary task of one-leg landing after short horizontal jumping. Results showed that the expected higher balance performance of the gymnasts over swimmers was found only in the voluntary landing task, while in the reactive balance tasks, performance was found to be equivalent between the two groups. From these findings, it seems that task-specific measurements are required for an accurate evaluation of voluntary dynamic balance.

One of the experimental strategies employed to evaluate the effect of prior experience on balance control involves comparing athletes from different sports. These athletes are exposed to varying balance demands during their routine training sessions. A literature review has shown that athletes have greater balance stability than non-athletes and high-level athletes have better balance control than low-level athletes [16]. Gymnasts (gymnastics is a type of sport that involves physical exercises requiring balance, strength, flexibility, agility, coordination, artistry, and endurance. Gymnasts often perform controlled movements on special equipment, such as bars, beams, and mats) and, in particular, have been found to develop high balance skills compared with athletes from several other sports [17]. Further research has supported the notion that gymnasts have increased balance in comparison with individuals regularly exposed to less demanding balance tasks. For instance, Davlin [18] compared high-level gymnasts, soccer players, and swimmers, having non-athletes as controls, in a dynamic balance task of standing on a stabilometer. Results revealed that gymnasts had higher balance stability than all other groups. Gymnasts and experts in other sports were compared in balance tasks with different difficulty levels, ranging from full vision in a bipedal stance on a rigid surface to unipedal standing on a malleable surface with visual occlusion [19]. Results indicated that gymnasts had higher balance stability in the more challenging balance tasks represented by no vision and distorted somesthetic information from the feet soles due to the malleable surface. This result suggests that the increased balance proficiency of gymnasts can be detected in more challenging tasks, like those involving sensory manipulation. Vuillerme and Nougier [20] assessed attentional demands between expert gymnasts and expert performers in other non-gymnastic sports in the manual task of responding as quickly as possible to an unpredictable auditory stimulus. The manual task was performed while standing with different balance demands, including manipulation of area and malleability of the support base. Results revealed lower attentional demands in the gymnasts than in controls during the challenging unipedal stance. This finding can be interpreted as indicating increased gymnasts' automaticity in regulating the required anticipatory balance adjustments to prevent stance perturbations potentially induced by the voluntary movement (for further evidence of improved balance control in gymnasts, see [21–23]). From the reviewed results, one can assume that gymnasts represent an appropriate reference for testing probing tasks for the evaluation of voluntary dynamic balance.

A critical point for the appropriate evaluation of voluntary dynamic balance is setting test constraints to achieve similar movements across individuals during the evaluation. Movements performed with different amplitudes or rhythms can affect objective measurements of balance stability, imposing difficulties in the interpretation of balance control. A preliminary attempt to standardize voluntary movements for the evaluation of dynamic balance was made by Bueno et al. [24]. The task consisted of performing cyclic hip flexions and extensions, so that the hip was flexed at about 45 degrees at the extreme position, assuming then the upright posture at the end of the cycle. Movements were standardized in amplitude, while the rhythm of the repeated movements was paced through beeps emitted by a metronome at regular intervals. Another potential task for the evaluation of dynamic balance is the cyclic sit-to-stand task. Research has shown that the completion time to perform the functional five times sit-to-stand test [25] is importantly affected by dynamic balance [26–29]. From these findings, both cyclic hip flexion extension and sit-to-stand movements can be conceived to be potential candidates for a reliable assessment of voluntary dynamic balance. In the current investigation, we had as the primary aim to test the sensibility of tasks requiring cyclic hip flexion-extension and squat-lift (similar to sit-to-stand movements) for assessment of voluntary dynamic balance, comparing groups of gymnasts and non-gymnasts. The underlying rationale for this comparison is that if the tasks provide a sensitive and reliable evaluation of voluntary dynamic balance, the expected increased balance control of gymnasts should be reflected in objective measurements of body stability. As the secondary aim, we tested the extent to which visual occlusion affects voluntary dynamic balance.

2. Materials and Methods

2.1. Participants

Male athletes from gymnastics (n = 9) and from other sports (n = 10) participated in this study. The gymnasts were high-level athletes at the adult national level, with 3 of them making part of the national team. They trained in the sport for at least 5 consecutive years, with the most experienced athlete accumulating 20 years of training. At the time of testing, they were training with an average frequency of 6 times per week, completing 24–48 h of training per week across participants. The comparison group was composed of athletes from different sports, as follows: soccer (n = 3), rugby (n = 3), squash (n = 1), basketball (n = 2), and athletics (n = 1). Participants of this comparison group had a minimum of 5 years of practice in the trained sport, training with frequencies of 3–5 times per week. Table 1 shows participants' descriptive information separately for each group. In addition to expertise in the trained sport, the inclusion criteria were the absence of lower limb injuries at the time of testing; no participants were excluded. A post hoc estimation of the power of the sample size was made through G*Power (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany; http://www.gpower.hhu.de/, (accessed on 17 May 2024)) for repeated measures, within-between group by vision interaction, effect size = 0.25, α = 0.05. The result indicated a power of 0.70 for our sample size.

Table 1. Age, anthropometric data, and training times separately by group.

	Gymnasts	Other Athletes
Age (years)	20.44 (4.33)	22.7 (2.67)
Weight (Kg)	64.26 (7.41)	80.10 (12.38)
Height (cm)	167.67 (4.36)	178.80 (7.19)
Weekly training (h)	32.11 (5.27)	6.10 (5.57)
Weekly frequency (days)	6.00 (0)	4.20 (1.03)
Total practice time (years)	11.33 (7.82)	6.00 (2.02)

Means and standard deviations (in parenthesis).

2.2. Ethics

Participants provided written informed consent. The research procedures were approved by the local university ethics committee, following the principles outlined in the Declaration of Helsinki (approval code: CAAE: 85093718.2.0000.5391).

2.3. Tasks, Equipment and Procedures

Balance control was tested in bipedal support, barefoot, keeping the feet hip-width apart with the feet orientated forward in parallel on a force platform (Advanced Mechanical Technology, Inc., model OR6-6, Watertown, MA, USA). Tasks were performed barefoot over a force plate. The evaluation protocol consisted of three tasks, as presented in the following.

(a) Quiet standing. Maintenance of quiet standing, aiming to sustain the motionless upright posture for 30 s (cf. [30]).

(b) Cyclic hip flexion and extension. The initial position was an upright stance with the arms hanging relaxed beside the trunk. The task consisted of performing cyclic hip flexion and extension movements in coordination with shoulder extensions and flexions. In the flexion phase, the hip was flexed about 45 degrees (absolute vertical angle), leaning the trunk forward, while both shoulders were extended up to the arms reaching the horizontal orientation. In the hip extension phase, the reverse movements were performed, with hip extension and shoulder flexion, up to reaching an upright posture with the arms positioned beside the trunk. To favor the reproducibility of movement amplitude, a spatial marker was set individually in front of the participant, at the top of a tripod, at the appropriate height for reaching the specified hip flexion-extension range of motion (Figure 1A,B) (cf. [24]).

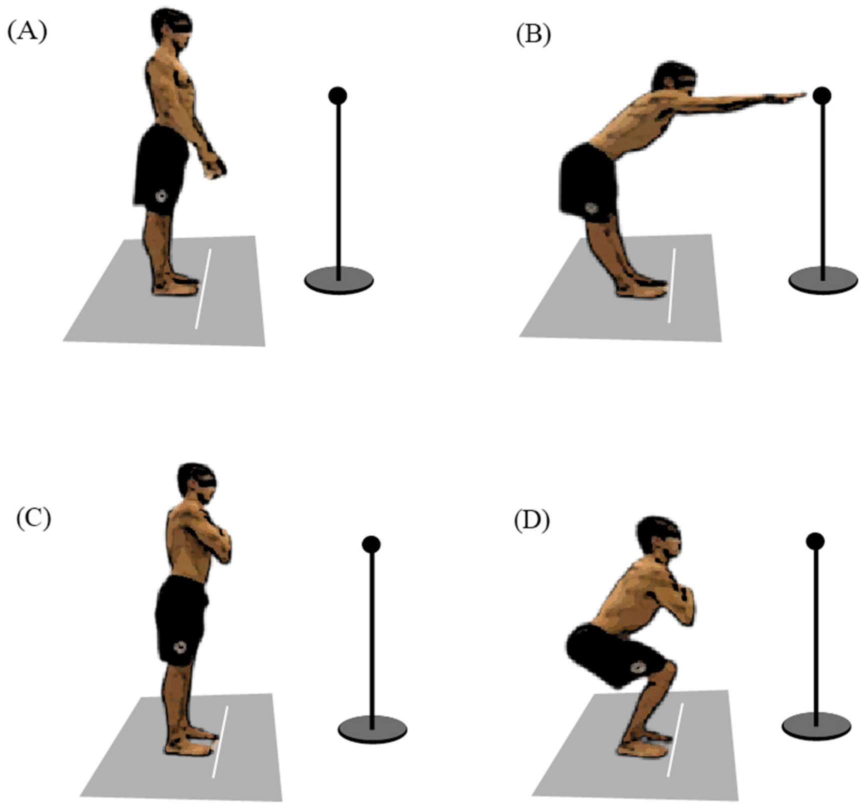

Figure 1. Representation of the postures at the onset and end of each movement phase, for the dynamic balance tasks of hip flexion-extension (**A**,**B**) and squat-lift (**C**,**D**). The top of the vertical shaft served as the spatial reference for standardizing movement amplitude.

(c) Cyclic squat-lift movements. This task emulated sit-to-stand movements employed in functional tests [26,28,31]. The initial position was an upright stance with the arms crossed over the chest. The range of motion was set at about 90° for knee and hip flexion-extension movements. In the squat phase, both the hip and knees were flexed simultaneously, while the trunk was bent forward. A spatial marker was used at the top of a tripod as a reference for the eye's height to finish the squat phase at the desired joint angles. In the lift phase, the reverse movements were performed up to reaching the upright posture. The arms were maintained crossed over the chest throughout a trial (Figure 1C,D).

Both the hip flexion-extension and squat-lift tasks were paced through an electronic metronome (BOSS brand, model DB-60), with trials lasting 20 s. Movement frequency was set at 0.5 Hz, aiming to achieve coincident timing of the end of each movement phase with the metronome beep.

The quiet standing and dynamic balance tasks were tested in the conditions of eyes open and eyes closed. Each task by visual condition was probed over three consecutive trials. Within-task intertrial intervals lasted 15 s, with a 1-min. seated rest interval every three trials. To prevent the after-effects of the dynamic balance tasks, the quiet standing balance was evaluated first. The ensuing sequence of the two dynamic tasks was alternated across participants within the group. For the three tasks, full vision and visual occlusion were alternated between participants within the group.

Immediately preceding the probing trials, participants were familiarized with the task to be performed next. Initially, in the dynamic tasks they assumed the correct maximum hip flexion or squat posture for individually setting the visual marker height and distance. Then, the respective movements were performed in the due range of motion and rhythm, with online feedback provided by an examiner based on subjective online visual evaluation. For the dynamic tasks, the metronome was activated prior to task initiation. This allowed participants to synchronize from the outset their movements with the specified rhythm. In the conditions of visual occlusion, participants were instructed to imagine the location of the visual reference, trying to achieve the specified movement amplitude, and maintaining the head in the vertical orientation, the same way as in the performance under full vision. The performance of the probing trials was visually monitored online by a single examiner (the same across participants). In cases where the performance failed to attend to the required movement amplitude or rhythm, the trial was immediately interrupted. Following extra familiarization movements for stabilization of the required movement characteristics, the testing was reinstated. Interruption occurred in about 2% of trials; no trials were excluded from the analysis.

2.4. Data Collection and Analysis

Ground reaction force data were sampled at a frequency of 200 Hz. After a preliminary visual inspection of individual signals, raw data were processed using MATLAB version 2017b routines (MathWorks, Inc., Natick, MA, USA). Data were digitally filtered using a fourth-order zero-lag Butterworth filter with a cutoff frequency of 10 Hz. The following dependent variables based on center of pressure (center of pressure is a variable frequently used to assess postural stability, representing the point in which the resultant ground reaction force (from the anteroposterior, mediolateral and vertical components) is applied on the support base to sustain quiet stance or dynamic balance) (CoP) displacement were analyzed: peak-to-peak amplitude (delta between the highest and lowest values); root mean square (RMS); and mean velocity. Analyses were conducted separately for the anteroposterior (AP) and mediolateral (ML) directions. For the dynamic tasks, calculations were made for each movement cycle, followed by within trial average over cycles. For the quiet standing and dynamic tasks, variables were calculated for the entire period of task duration. Analysis was based on means from the three trials for each task by visual condition. As a prerequisite for parametric analysis, the Shapiro-Wilk test showed normal data distribution. Analysis was conducted individually for each task through two-way 2 (group: gymnasts X other athletes) X 2 (vision: eyes open X eyes closed) ANOVAs with repeated measures on the last factor. Significant effects ($p < 0.05$) are reported along with the respective effect sizes given by partial eta squared ($\eta_p{}^2$). Statistical analysis was performed using Statistica software (version 7.0, Statsoft, Tulsa, OK, USA). The full dataset is available as Supplementary Material.

3. Results

3.1. Quiet Stance

Figure 2 presents the results of the analysis of CoP displacement amplitude, RMS, and velocity in the AP (panels A–C) and ML (panels D–F) directions. Analysis of CoP sway in the AP direction showed significant main effects of vision. The vision effect was due to higher values for eyes closed compared to eyes open for the three dependent variables: amplitude, $F(1, 17) = 13.66$, $p < 0.01$, $\eta_p^2 = 0.45$; RMS, $F(1, 17) = 6.54$, $p = 0.02$, $\eta_p^2 = 0.28$; and mean velocity, $F(1, 17) = 16.57$, $p < 0.01$, $\eta_p^2 = 0.49$ (Figure 2A–C). Analysis of ML CoP sway showed significant main effects of vision, with higher values for eyes closed compared to eyes open for RMS, $F(1, 17) = 4.71$, $p = 0.04$, $\eta_p^2 = 0.22$; and mean velocity, $F(1, 17) = 12.88$, $p < 0.01$, $\eta_p^2 = 0.43$ (Figure 2D–F). No significant effects related to the group were found for quiet standing.

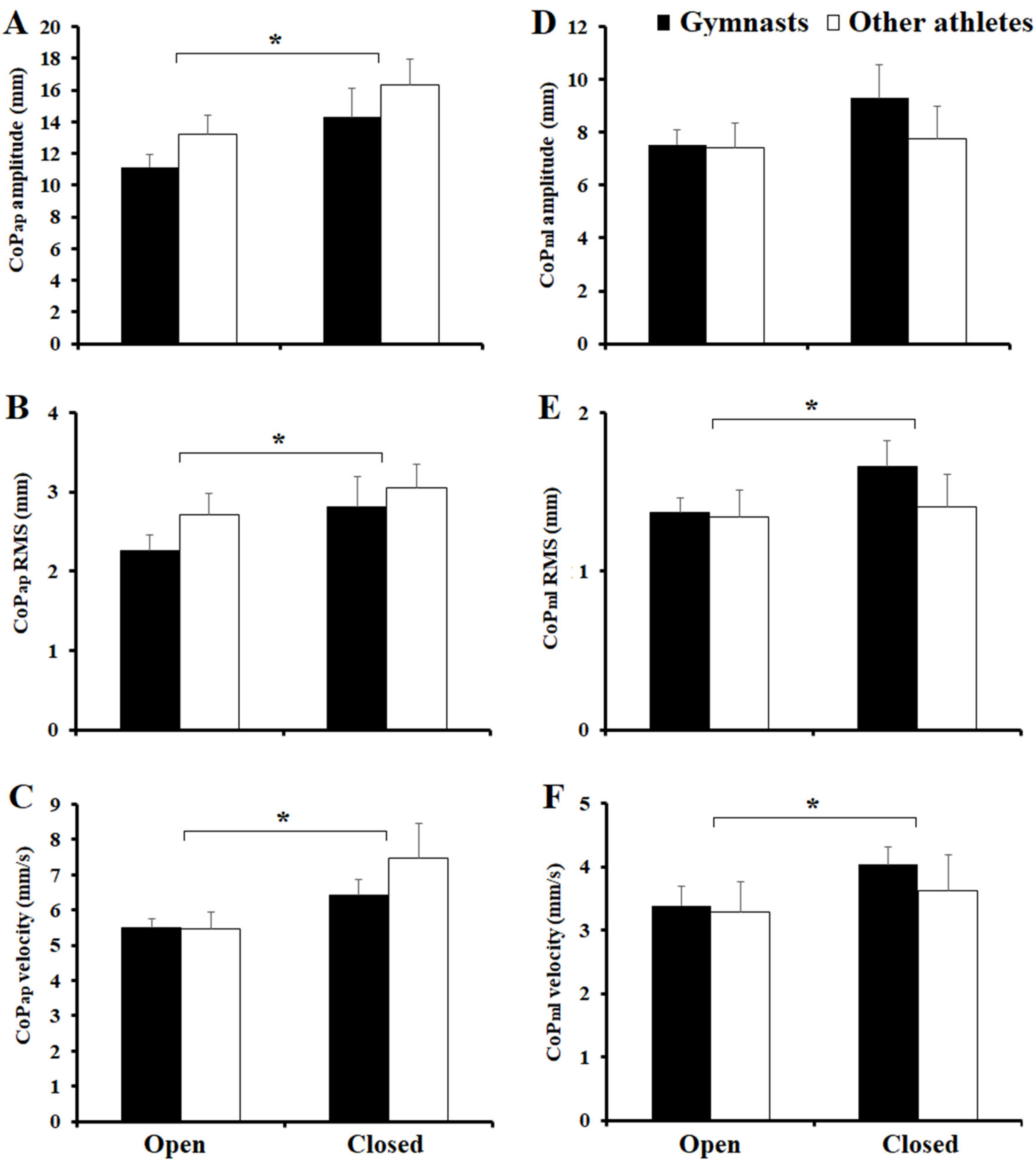

Figure 2. Quiet standing. Comparison between gymnasts and other athletes in the conditions of eyes open and eyes closed; averages (standard deviation indicated by vertical bars) of CoP amplitude (peak-to-peak), CoP root mean square (RMS), and CoP mean velocity in the AP (**A**–**C**) and ML (**D**–**F**) directions; significant effects of vision are represented by asterisks.

3.2. Voluntary Dynamic Balance I: Hip Flexion-Extension

Results from CoP analysis for the hip flexion-extension task are presented in Figure 3. Analysis of AP CoP sway showed significantly higher values for eyes closed than eyes open for CoP amplitude, $F(1, 17) = 11.13$, $p < 0.01$, $\eta_p^2 = 0.40$; and CoP mean velocity, $F(1, 17) = 23.00$, $p < 0.01$, $\eta_p^2 = 0.57$ (Figure 3A–C). Analysis of CoP sway in the ML direction revealed higher values for eyes closed than eyes open for the three CoP-related variables, as follows: amplitude, $F(1, 17) = 50.42$, $p < 0.01$, $\eta_p^2 = 0.75$; RMS, $F(1, 17) = 71.95$, $p < 0.01$, $\eta_p^2 = 0.81$; and mean velocity, $F(1, 17) = 57.79$, $p < 0.01$, $\eta_p^2 = 0.77$ (Figure 3D–F). No significant effects related to the group were found for the hip flexion-extension task.

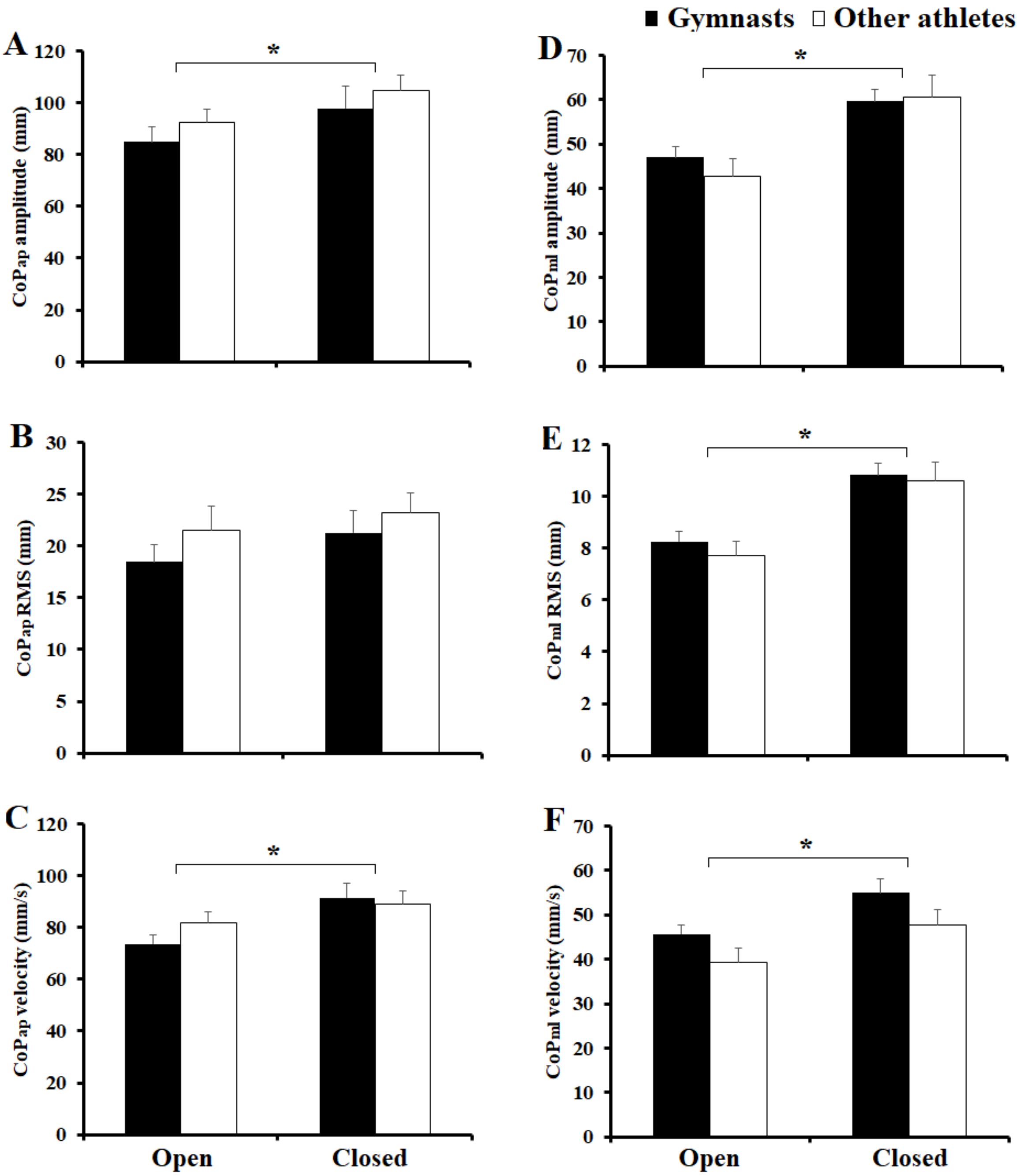

Figure 3. Hip flexion-extension task. Comparison between gymnasts and other athletes in the conditions of eyes open and eyes closed; averages (standard deviation indicated by vertical bars) of CoP amplitude (peak-to-peak), CoP root mean square (RMS), and CoP mean velocity in the AP (**A**–**C**) and ML (**D**–**F**) directions; significant effects of vision are represented by asterisks.

3.3. Voluntary Dynamic Balance II: Squat-Lift Task

Analysis of CoP sway for the squat-lift task in the AP direction indicated significant main effects for both the group and vision factors. The group effects were due to lower CoP values in the gymnasts than the athletes from other sports for the three CoP-related variables, as follows: amplitude, $F(1, 17) = 16.42$, $p < 0.01$, $\eta_p^2 = 0.49$; RMS, $F(1, 17) = 9.61$, $p < 0.01$, $\eta_p^2 = 0.36$; and mean velocity $F(1, 17) = 9.69$, $p < 0.01$, $\eta_p^2 = 0.36$. Greater values for the eyes closed than eyes open were found for CoP sway amplitude $F(1, 17) = 6.97$, $p = 0.02$, $\eta_p^2 = 0.29$ (Figure 4A–C). Analysis of CoP sway in the ML direction indicated significant main effects of vision. Greater values were found in the eyes closed condition for the three dependent variables, as follows: amplitude, $F(1, 17) = 36.12$, $p < 0.01$, $\eta_p^2 = 0.68$; RMS, $F(1, 17) = 41.73$, $p < 0.01$, $\eta_p^2 = 0.71$; and mean velocity, $F(1, 17) = 78.48$, $p < 0.01$, $\eta_p^2 = 0.82$ (Figure 4D–F).

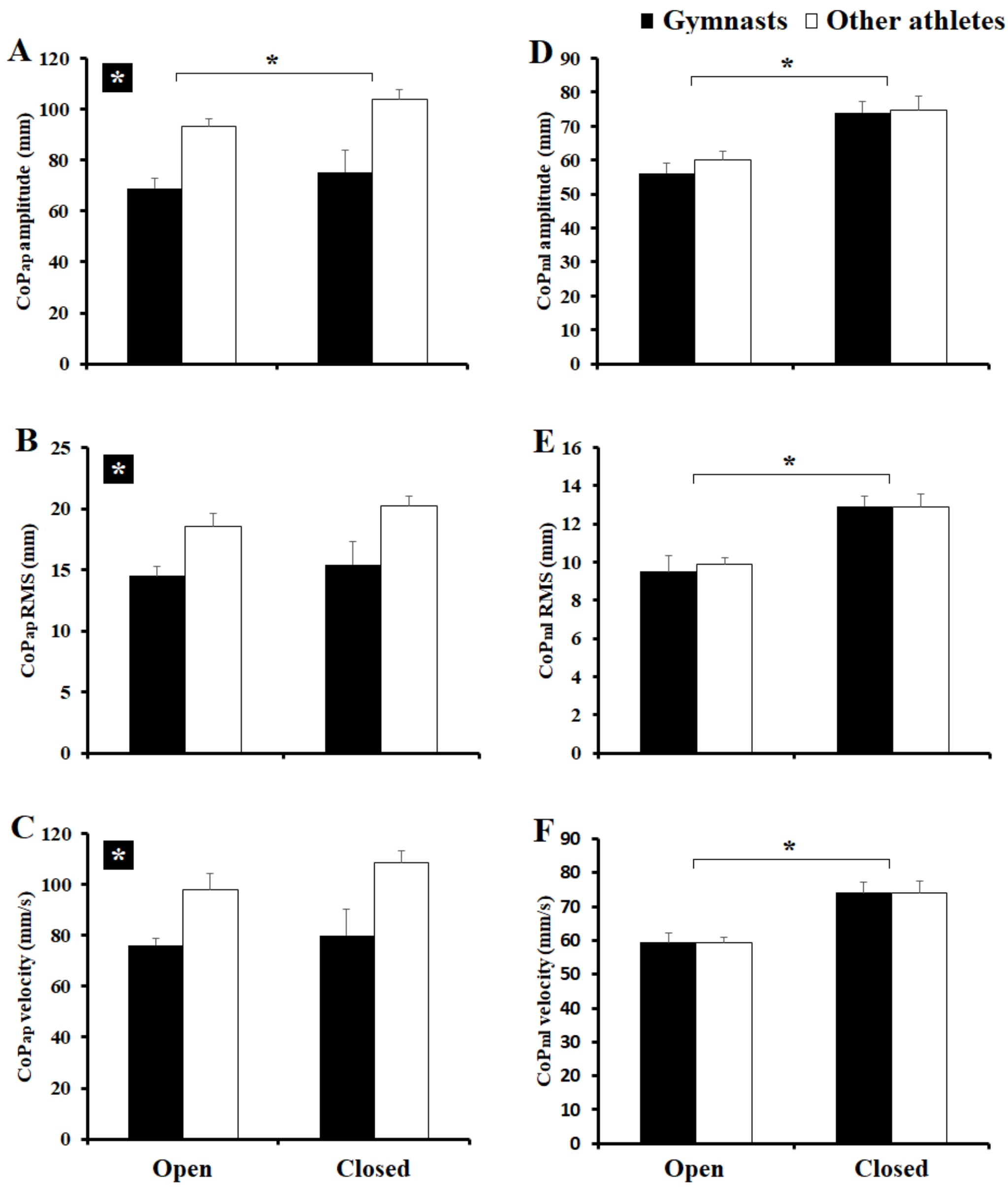

Figure 4. Squat-lift task. Comparison between gymnasts and other athletes in the conditions of eyes open and eyes closed; averages (standard deviation indicated by vertical bars) of CoP amplitude (peak-to-peak), CoP root mean square (RMS), and CoP mean velocity in the AP (**A**–**C**) and ML (**D**–**F**) directions; significant effects of vision are represented by black asterisks, while significant effects of group are represented by white asterisks against a black background at the top left corner of the panels.

4. Discussion

In the current investigation, we aimed to analyze the sensitivity of balance evaluation in the performance of quiet standing and two voluntary dynamic tasks by comparing gymnasts and athletes from other sports. The rationale for this comparison is that the expected better balance control in voluntary tasks by gymnasts should be reflected in the performance of tasks with a high demand for voluntary balance. A comparison between the gymnasts and athletes from other sports showed that dynamic balance was task-specific. In the quiet standing and the dynamic hip flexion-extension tasks, no significant differences were found between the gymnasts and the athletes from other sports. Conversely, in the squat-lift task results revealed the expected better performance of the gymnasts over the other athletes, as represented by the reduced amplitude and velocity of CoP displacement during the task execution. Availability of visual information affected the groups similarly, with an equivalent decline of balance stability between the groups in the eyes closed compared to the eyes open condition.

4.1. Effect of Visual Deprivation

The effect of deprivation of visual information on body stability is well known in the control of quiet standing, leading to increased amplitude and velocity of balance sway as compared to performance under full vision (e.g., [32,33]), as observed in our results. The effect of vision has also been reported in tasks requiring dynamic balance on an oscillatory support base, with visual occlusion provoking increased amplitudes of head and trunk sway in comparison with performance under full vision [34]. Relevance of visual information has also been shown in reactive balance responses, with visual occlusion leading to a higher velocity of CoP displacement to recover from an extrinsic mechanical stance perturbation [35]. In these balance tasks, visual information is thought to provide a reference of head and trunk stability in space for balance control. In the absence of vision, other sensory sources like the vestibular apparatus [36], plantar cutaneous afferents [37], and proprioceptive receptors [38] may be used as feedback sources for balance control. Our results bring original information on this topic by showing that in both the voluntary hip flexion-extension and squat-lift dynamic tasks amplitude of AP and ML CoP displacement were increased when visual information was suppressed. Lack of vision led to increased CoP velocity in the ML direction for the two dynamic tasks while affecting AP CoP velocity in the hip flexion-extension task only. A point worth noticing is that, differently from other balance tasks, in the execution of the dynamic tasks under examination the head exhibited rapid and continuous movement, encompassing a wide range of motion. This finding suggests that the visual flow, in the focal and/or peripheral vision [39], resulting from voluntary head movements can be employed to stabilize dynamic balance in whole body movements. It seems that the anticipated visual flow resulting from the voluntary head movements, in association with online proprioceptive and plantar cutaneous signals, can be used by the central nervous system for balance regulation while moving. This effect contrasts with the balance perturbation induced by generating a visual flow through a moving room in a quiet stance [40]. In this regard, it can be assumed that the ability to use anticipatory visual flow information in conditions of voluntary head motion is a requirement in our daily living activities, being of paramount importance in the performance of most sports skills.

4.2. Better Gymnasts' Balance Control in the Squat-Lift Task

Previous results have shown an effect of task-specificity in the comparison between reactive balance and quiet posture control [9,14]. Specificity in such balance tasks could be explained due to their particular requirements. While quiet standing is regulated through small-scale automatic adjustments to natural body sway, reactive balance responses require identification of the nature, direction and magnitude of an extrinsic stance perturbation and then the generation of a specific response to recover balance stability within a short time interval (cf. [41]). In Ringhof and Stein's [15] investigation, task-specificity was found in gymnasts in a comparison between three tasks, with better gymnasts' balance being detected in a voluntary task requiring a one-legged landing after jumping but not in tasks requiring reactive balance control. While this preliminary study suggested better voluntary balance control in gymnasts specifically for voluntary balance tasks, this result might be due to the extensive practice of gymnasts on landing tasks in their ordinary sport training. Our results revealed that task-specificity can also be seen between two voluntary dynamic tasks, as indicated by better balance performance in gymnasts in the squat-lift but not in the hip flexion-extension task (Figure 3A–C vs. Figure 4A–C). This finding suggests that the squat-lift task was more sensitive to the expected improved voluntary dynamic balance of gymnasts.

A plausible explanation for the increased sensibility of the squat-lift task for balance control evaluation is related to its higher demand for interjoint coordination. The hip flexion-extension task required that the knees were maintained stretched while focal movements were made mainly at the hip. In this action, the hip had to be simultaneously flexed and projected backward to keep the center of mass in a stable position over the support base delimited by the feet support area. This action can be conceived to be relatively simple and overly automatized in movement control. From this perspective, this finding is consistent with previous results showing that better performance of gymnasts over other groups is seen only in tasks imposing higher balance demands given by unipedal stance and malleable support base [19,20]. On the other hand, the squat-lift task involves more complex coordination between the simultaneous motions at the hip and knees to generate the required global movements while preserving balance stability. Our results indicated that the gymnasts had lower values than the athletes from other sports for amplitude and velocity in the AP but not in the ML CoP sway direction. Although balance control in the ML direction has been shown to be associated with performance on the analogous sit-to-stand task in older individuals [28], our results suggest that balance in the frontal plane is insensitive to discriminate interindividual differences of balance control. Supposedly, the demand for symmetric movements between the legs makes the balance demand relatively low in the ML direction for a young sportsperson. We propose that better results of gymnasts than the other athletes in the AP sway direction are due to the high interjoint coordination demand mainly between the hip and knee movements leading to back-and-forth trunk displacements for the squat-lift motion while maintaining the center of mass stably over the support base. Generalizing from upper limb between-joint coordination in reaching actions [42,43], we conceptualize that in the squat-lift task, the central nervous system anticipates and finely regulates through online feedback the interactive torques between the lower limb joints to attenuate the sway magnitude and velocity of the center of mass over the support base. During the cyclic squat-lift movements, dynamic torque variation at the hip, knees and ankles, as well as the reciprocal effects on the adjacent joints, have to be accurately anticipated in the control system to attenuate self-produced balance perturbations by the voluntary movements. An additional point worth noting was that the superior balance performance of gymnasts in the squat-lift task was also observed when vision was suppressed. This finding suggests that the main sensory feedback sources leading to better dynamic balance control in the gymnasts were nonvisual, possibly guided by the myriad of somatosensory signals relevant for balance control which are generated during voluntary whole-body movements (cf. [36–38]).

4.3. Methodological Strengths and Weaknesses

We highlight as the most original methodological advancement in our study the evaluation of voluntary dynamic balance with standardization of movement amplitude and rhythm during the performance of cyclic whole-body movements. With this procedure, we assumedly prevented high intra and interindividual movement variability during the performance of the dynamic tasks as it can occur in protocols in which participants are allowed to perform movements with self-selected spatial and temporal characteristics. This procedure can be thought to favor sustainable conclusions on the interpretation of center pressure values between groups and experimental conditions. The use of gold standard measurements based on the center of pressure provided valid and reliable results in the evaluation of dynamic balance. On the other hand, the lack of kinematic measurements to document the effective amplitude and rhythm of trunk movements across participants represents a limitation in this investigation. It should be acknowledged that performing the tested tasks without vision makes standardizing movement amplitude challenging due to the absence of visual reference. An additional limitation is represented by between-group differences in anthropometric measures (see Table 1). On average, athletes from other sports were approximately 11 cm taller and 16 kg heavier than the gymnasts. It should be noted that anthropometric measures could impact center pressure measurements (cf. [44]).

5. Conclusions and Implications

Our results showed no significant differences in balance control between high-level gymnasts and athletes from different sports for quiet standing and voluntary whole-body movements. The main finding was lower amplitude and velocity displacement of the anteroposterior center of pressure sway in gymnasts compared to athletes from different sports during the voluntary cyclic squat-lift task but not in the hip flexion-extension task. This conclusion was valid for both vision and no-vision conditions. In terms of practical application, these findings suggest that the employed protocol using the squat-lift task could serve as a potentially sensitive method for assessing voluntary dynamic balance. As squat-lifting is a relatively easy task, we speculate that this assessment could apply not only to young individuals but also to older adults, serving as an objective tool for assessing voluntary dynamic balance. To validate this assumption, future studies should incorporate the squat-lift task to evaluate dynamic balance across different age groups.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/biomechanics4030030/s1, The full dataset is available as supplementary material.

Author Contributions: J.W.F.B., conceptualization, methodology, investigation, analysis, writing—original draft preparation; D.B.C., data curation, analysis, investigation; L.A.T., conceptualization, supervision, writing, review and editing. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki. Approval number by the local ethics committee: CAAE: 85093718.2.0000.5391.

Informed Consent Statement: Participants provided written informed consent.

Data Availability Statement: The full data set will be available as Supplementary Material.

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