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REVIEW ARTICLE

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Does long-term sports experience change the body balance of athletes? A systematic review and meta-analysis

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ABSTRACT

Sports practice promotes physiological adaptations influenced by the characteristics of training stimuli, and postural balance appears to play an important role in athletic performance. To analyze postural control in athletes - obtained from the displacements of the center of pressure during orthostatic posture, considering elite athletes and control groups (non-athletes or athletes with a lower competitive level). The search in electronic databases was carried out in PubMed, Scopus, and Scielo until April 2023, with works selected between 1976 and 2023. An assessment of the methodological quality of the studies was carried out. In addition, in the meta-analysis, the main center of pressure variables used were oscillation area, mean velocity, and total mean velocity. Twenty studies were included, and the meta-analysis showed differences in favor of athletes in the conditions of single-leg support with eyes open and eyes closed, with a greater difference in the second situation. Overall, athletes presented better postural balance compared to the non-athlete group and, among athletes, those with a higher competitive level presented the best postural strategy. The results suggest that sports training improves postural control and that the differences in favor of athletes are greater in more challenging/unstable postural conditions.

KEYWORDS: postural control; balance; sports.

INTRODUCTION

Physical training induces neuromuscular, cardiopulmonary, biochemical, and psychological adaptations, which are influenced by the characteristics of the diversity of motor stimuli (Olivier et al., 2019; Paillard, 2017). In this context, the postural control system appears to be crucial for successful athletic performance (Behm et al., 2010; Kibele et al., 2015) and, thus, many sports should consider training balance skills. Conceptually, postural balance depends on the organization and adequate maintenance capacity of body segments to ensure body stability and avoid possible falls (Paillard, 2017), fundamental for sporting demands. Visual, vestibular, and somatosensory information is used to plan and execute complex postural adjustments according to the context, expectations, goals, and previous experiences (Shumway-Cook & Woollacott, 2010).

Furthermore, proactive balance (anticipation of a predicted postural disturbance) and reactive balance (compensation for an unexpected postural disturbance) are related to dynamic situations in sports (Shumway-Cook & Woollacott, 2010). However, due to the methodological difficulty of studying body balance under game conditions, protocols are usually performed in non-ecological environments (Paillard, 2019). Computerized posturography (stabilometry) is the gold standard method for assessing postural balance, with measurements based on anteroposterior and mediolateral displacements of the center of pressure (COP), using a force platform during

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upright posture. This method is non-invasive, fast and easy to operate. COP displacements can be analyzed through graphical representations (statokinesiogram/stabilogram) and through variables extracted from the COP, such as area, velocity, amplitude and average frequency of body sway (Duarte & Freitas, 2010; Kiers et al., 2013).

Additionally, the demands for body adjustments during sports practice challenge the postural control system, reducing stability, increasing the likelihood of falls, increasing joint tensions and the likelihood of musculoskeletal injuries (Behm et al., 2010), which requires excellent control of gestures, postures, and movements in elite athletes. Long-term training in sports activities appears to improve postural balance by inducing positive functional adaptations of motor strategies, such as acquisition, processing and motor action, adaptations of neurophysiological components and cognitive function in relation to the spatial representation of the body (Imbiriba et al., 2020; Paillard, 2017; Zemková & Kováčiková, 2023).

Balance improvement is generally observed by reduced body sway and decreased muscle response time with training to standing posture disturbances. Thus, elite athletes appear to have reduced body sway compared to lower-level competitive athletes or non-athletes (Kiers et al., 2013; Paillard, 2017), and a meta-analysis-based approach could highlight this quantitative evidence. Thus, the aim of this study was to perform a systematic review with meta-analysis considering athletes and stabilometry to identify stabilometric variables and more sensitive protocols to infer about the postural control system in athletes from different sports modalities and non-athletes.

METHOD

The review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses - PRISMA guidelines (Liberati et al., 2009). The search was performed in the PubMed, Scielo and Scopus databases in April 2023 (papers published between 1976 and 2023), using Boolean operators and indexing terms (Table 1).

Mendeley software (version 1.19.4, Mendeley Ltd.) was used to exclude duplicate references among the articles in the search. In the next step, Start software (v. 3.3, UFSCAR) was used to analyze the title and abstract related to the study objective. Thus, two researchers (LM and LI) evaluated titles and abstracts according to the eligibility criteria. The selected studies were read and the criteria were observed again. When there was disagreement between LM and LI, a third researcher (MM) was consulted to reach a consensus.

Only observational/cross-sectional studies were evaluated. The inclusion criteria were: articles available in full in scientific databases; articles in English; sample of participants aged between 13 and 60 years; and studies that evaluated static balance in athletes using a force platform. The exclusion criteria were: systematic reviews; interventional studies; studies without a control group (only non-athletes or athletes of different levels in the same sport were accepted); articles without an acquisition method or without mean and standard deviation values for stabilometric parameters; studies with stabilometric tests lasting less than 20 seconds; studies based on experiments with therapeutic interventions (orthoses, prostheses, bandages, or accessories); and athletes with balance disorders, labyrinthitis, vestibular pathologies, musculoskeletal injuries, or in postoperative recovery.

Data extraction

Two researchers (LM and LI) extracted specific information from the selected studies: 1) publication: authors and year of publication; 2) sample: population, sample size and demographic data (age, sex, sport modality, competitive level and time of practice); 3) stabilometric protocol: support base (single-legged/bipedal), eyes open (EO) or eyes closed (EC), distance to the target with EO, head orientation, arm position, signal acquisition time, recovery time between different acquisitions and 4) the main stabilometric results.

Categorization of the analyzed groups

The included studies compared athletes and non-athletes or athletes with different competitive levels. The non-athlete

Table 1. Search key in databases.

Database	Keywords
PubMed	(postural control [tiab] OR postural sway [tiab] OR postural balance [mesh] OR postural balance [tiab] OR postural equilibrium [tiab] OR equilibrium postural [tiab]) AND (platform [tiab] OR force platform [tiab] OR force plate [tiab] OR balance system [tiab] OR stabilometr* [tiab] OR center of pressure [tiab] OR centre of pressure [tiab] OR center of foot pressure [tiab] OR centre of foot pressure [tiab]) AND (athletes [mesh] OR athlete* [tiab] OR athletic* [tiab] OR sports [mesh] OR sport* [tiab])
Scopus and Scielo	(“postural control” OR “postural sway” OR “postural balance” OR “postural equilibrium” OR “equilibrium postural”) AND (platform OR “force platform” OR “force plate” OR “balance system” OR stabilometr* OR “center of pressure” OR “centre of pressure” OR “center of foot pressure” OR “centre of foot pressure”) AND (athlete* OR athletic* OR sport*)

group was called the control group (CG). For athletes of different levels, group "A" was used for athletes with a higher competitive level in relation to group "B", with a lower competitive level. Thus, comparisons were made between Athletes x CG or Athletes A x Athletes B.

Evaluation of the methodological quality of the studies

A checklist (Ghamkhar & Kahlaee, 2019) with a total of 14 evaluation items for cross-sectional studies was used. Studies that met less than 50% of the criteria should be classified as "low quality"; between 50–75% should be classified as "moderate quality" and above 75% as "high quality". This process was carried out by two authors independently and, in case of disagreement, a third author was consulted.

Quantitative synthesis

This quantitative analysis was performed using the Review Manager – RevMan software, version 5.3.5 (Copenhagen: The Nordic Cochrane Centre) and compared athletes and CG or athletes of levels A and B. The analysis allows estimating the effect size, the difference between the means, the heterogeneity, the level of significance of the comparison between the data and the publication bias.

The random effects model was adopted and the inconsistency method (I^2) was used to measure differences between the studies, depending on the heterogeneity of the primary studies, due to methodological differences, as well as sample characteristics and contrasts of results (Berwanger et al., 2007). The following classification values were adopted: 25% (low), 50% (intermediate) and 75% (high) (Pereira & Galvão, 2014).

RESULTS

Initially, the database search returned 2,602 studies. The search, selection and inclusion flowchart is presented in Figure 1. Twenty studies were included for the quantitative synthesis of the systematic review.

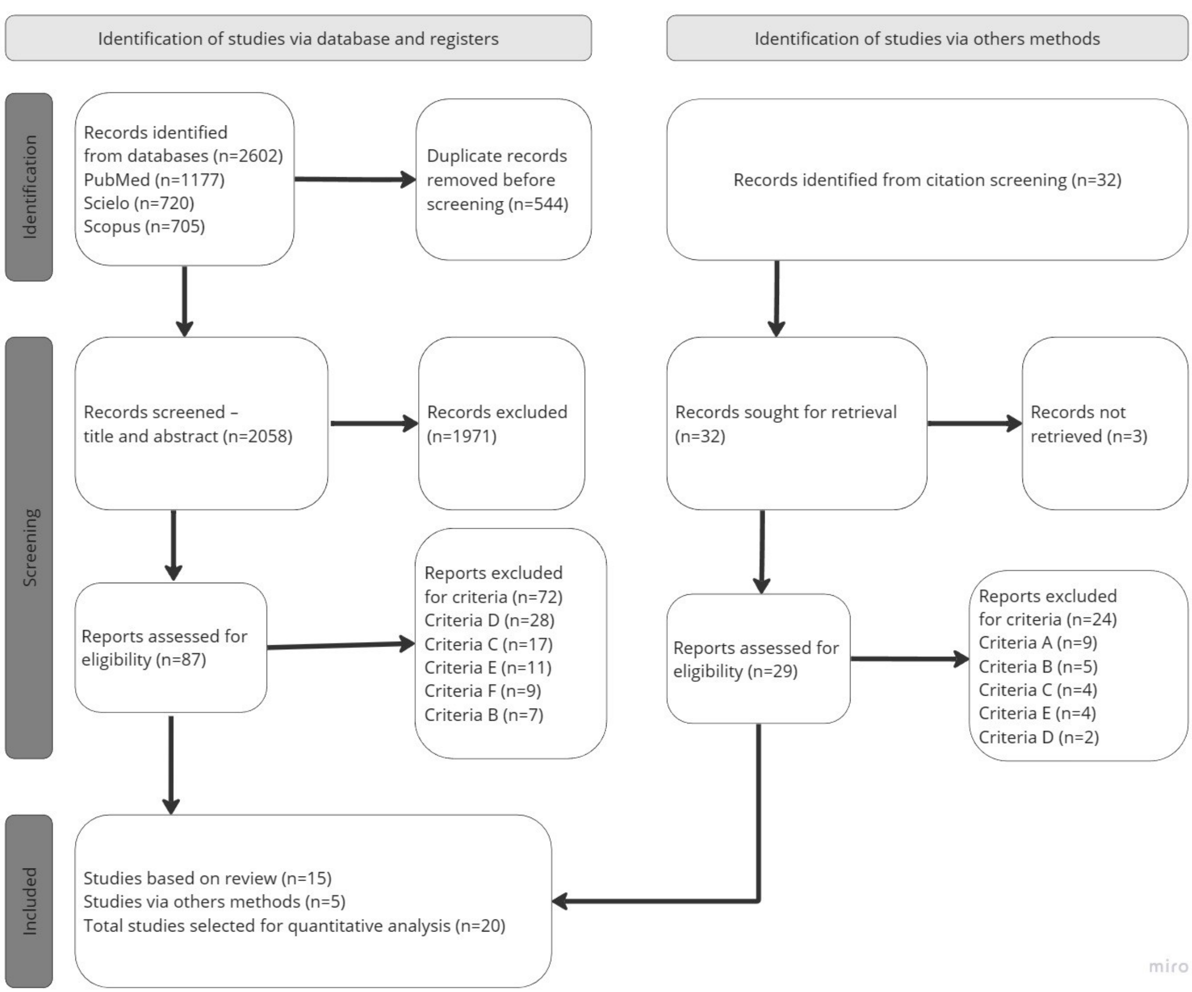


Figure 1. Study flowchart.

Regarding the analysis of methodological quality, all included studies were classified as high quality (Table 2), but only the work by Meshkati et al. (2011) achieved 13 points for presenting the intraclass correlation coefficient. The sample size in most studies was small, between 7 at least and 41 at most individuals per group.

Fifteen studies were conducted only with men, two only with women and three with both. Five studies only involved athletes; in another 15 studies, athletes and non-athletes were compared. A total of 427 athletes participated in the 20 eligible studies (74 women and 353 men), with an average number of approximately 21 athletes in each study. In the non-athletes (CG), 316 individuals were evaluated in 15 studies (86 women and 230 men), with an average number of participants of 21 individuals (Table 3). The sport most explored in the studies was football ($n = 4$), followed by volleyball ($n = 3$) and karate ($n = 3$).

Stabilometric results

Considering the experimental protocols, the bipedal position was used in 17 studies with the following variations: feet together, naturally apart, hip-width apart, heels at 30º (Table 3). The unipedal position was used in six studies (named as right and left foot; or dominant and non-dominant leg). The arms positioned along the body were used in 16 studies and, considering the visual conditions, tasks were performed with FO in 16 studies and with EO in all 20 studies, where the distance to a visual reference varied from 2 to 5 meters. Eleven articles performed experimental balance tasks only once and five studies performed three repetitions for each experimental situation. Signal acquisition lasted 20 seconds in six studies, 51.2 seconds or 30 seconds were found in five different studies, two studies used 35 seconds and also 40 seconds, 25.6 seconds and 60 seconds in one study each.

In the included studies, the variables frequently used were the velocity of the center of pressure ($n = 16$; 8 evaluating the total average velocity and 8 the average anteroposterior and mediolateral velocities); the body sway area ($n = 11$) and the COP excursion or length ($n = 3$). Other variables were also found in small numbers. Thus, the COP area and the average AP and ML velocity and the total average velocity under EO and EC were considered in the meta-analysis.

Meta-analysis

In the quantitative analysis considering Athletes vs. CG, the athletes presented a smaller COP sway area in 2

Table 2. Qualitative assessment based on the proposal by Ghamkhar and Kahlaee (2019).

Estudies	Questions														Score
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Albaladejo-García et al., 2023	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Lee et al., 2021	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Borzucka et al., 2020a	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Borzucka et al., 2020b	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Jabnoun et al., 2019	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Kochanowicz et al., 2017	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Bieć et al., 2015	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Rabello et al., 2014	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Ong and Gouwanda, 2014	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Juras et al., 2013	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Handrigan et al., 2012	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Meshkati et al., 2011	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Bieć and Kuczyński, 2010	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Meshkati et al., 2010	ok	ok	ok	ok	X	ok	ok	ok	ok	ok	ok	ok	ok	ok	13
Kuczyński et al., 2009	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Paillard and Noé, 2006	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Paillard et al., 2006	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Noé and Paillard, 2005	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Paillard et al., 2002	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12
Perrin et al., 2002	ok	ok	ok	ok	X	ok	X	ok	ok	ok	ok	ok	ok	ok	12

Criteria: Q1: Clear statement of the research objective; Q2: Use of an appropriate method to answer the survey questions; Q3: Clear specification of the study population; Q4: Pre-specification of inclusion/exclusion criteria; Q5: Sample size and its justification; Q6: Description of outcome measures; Q7: Assessment of measurement reliability; Q8: Control of confounding factors; Q9: Appropriate use of statistical tests; Q10: Missing results; Q11: Complete and clear reporting of results; Q12: Accuracy of results; Q13: Statistical summary; Q14: Consistency of conclusions and data presented. The total score corresponds to the sum of the criteria.

Table 3. Characterization and main findings of the selected studies.

Athletes vs. CG				
Reference	Group (sample size)	Protocol	COP variables	Results
Albaladejo-García et al., 2023	BMX M (12) e F (7)	Unipedal Dominant	SD	ü No significant differences
	Age: 21.9 ± 4.4 years old	2 x 40s, 30s	Total mean velocity	
	CG M (12) e F (8)	EC / EO	AP-ML Mean velocity	
	Age: 23.9 ± 3.6 years old			
Lee et al., 2021	Atlhetes: F (14) e M (15)	Bipedal 30°	Area	Atlhetes: lower values
	Age: 25 ± 5 years old	Unipedal Dominant	AP-ML Mean velocity	ü Area Conditions:
	CG: F (10) e M (3)	Rigid and Airex		ü Bipedal EC Airex
	Age: 27 ± 4 years old	3 x 30s, rec 30s EC		ü Unipedal EC Rigid
		EO/EC		
Borzucka et al., 2020a	Volleyball M INT (31)	Bipedal	DP	Atlhetes: lower values
	Age: 24.3 ± 3.3 years old	1 x 20s	Amplitude	ü Amplitude
	CG M (31)	EO	AP-ML Mean velocity	ü Peak Frequency
	Age: 22.9 ± 1.3 years old		Peak Frequency	Atlhetes: highest values
			Mean Frequency	ü Mean Velocity
			Fractal Dimension	ü Mean Frequency
				ü Fractal Dimension
Borzucka et al., 2020b	Volleyball F INT (31)	Bipedal	DP; Amplitude;	Atlhetes: lower values
	Age: 25.7 ± 7.6 years old	1 x 20s EO	AP-ML Mean velocity;	ü Amplitude
	CG F (31)		Peak Frequency;	Atlhetes: highest values
	Age: 20.7 ± 1.6 years old		Mean Frequency;	ü Mean velocity
			Fractal Dimension	ü Peak Frequency
				ü Fractal Dimension
Jabnoun et al., 2019	Parkour M AMA (10)	Bipedal 5cm 30°e Unipedal	Area	Atlhetes: lower values
	Age: 23 ± 2.6 years old	Rigid (3 x 51.2s) Airex (3 x 25.6s)		ü Area
	CG M (10)	rec 30s; EO/EC		Conditions:
	Age: 24.5 ± 2 years old			ü Bipedal Airex EC
				ü Unipedal EO/EC
Kochanowicz et al., 2017	Ginástica Artística M INT (12)	Bipedal	Area	Atlhetes: lower values
	Age: 8–25 years old	(hip width)		ü Area EO/EC
	CG M (16)	1 x 30s		
	Age: 18–25 years old	EO/EC		
Rabello et al., 2014	Tae Kwon Do M INT (9)	Unipedal	Area	Atlhetes: lower values
	Age: 24.8 ± 4.2 years old	3 x 30s, rec 30s	AP-ML Mean velocity	ü Mean VelocityAP
	CG M (10)	EO		
	Age: 23.3 ± 4.1 years old			
Ong and Gouwanda, 2014	Dance F REG (8)	Bipedal EO/EC	Area	Atlhetes e actives: lower values
	CG sedentário (8) e CG ativo (8)	1 x 60s	Total mean velocity	ü Area EC

Continue...

Table 3. Continuation.

Athletes vs. CG				
Reference	Group (sample size)	Protocol	COP variables	Results
Juras et al., 2013	Karate M INT (9)	Bipedal OE/CE	Rambling.	Atlhetes: highest values
	Age: 24.6 ± 4.8 years old	2 x 30s, rec 60s	Trembling	ü Rambling e Trembling (EO/EC)
	CG M (11)			
	Age: NR			
Handrigan et al., 2012	Football M NAC (9)	Bipedal 10cm	Amplitude	Atlhetes e CG obese: highest values
	Age: 23.4 ± 1.3 years old	4 x 30s, rec NR	Total mean velocity	ü Velocity and Amplitude (EO/EC)
	CG Obese M (17)	EO/EC	(No mean and SD)	
	Age: 36.9 ± 7.7 years old			
	CG M (15)			
	Age: 38.5 ± 9.7 years old			
Meshkati et al., 2011	Karate M INT (15)	Bipedal	Area	Atlhetes: highest values
	Age: 21.4 ± 3.3 years old	3 x 35s, rec 25s	Total mean velocity	ü Total mean velocity EO
	CG M (16)	EO/EC	Amplitude DP;	ü SD Velocity AP ML EO
	Age: 21.1 ± 1.9 years old		SD Velocity	
Bieć and Kuczyński, 2010	Soccer M BEG (25)	Bipedal 10cm	AP-ML Mean velocity	Atlhetes: lower values
	Age: 13 years old	2 x 20s, rec 60s	Amplitude;	ü Mean velocity AP/ML EO and ML EC
	CG não Atlhetes M (19)	EO/EC	Frequency;	ü Amplitude AP/ML EC and ML EO
	Age: 13 years old		Variability	ü Variabilidade AP/ML EO and ML EC
				ü Frequency ML EO/EC
Meshkati et al., 2010	Karate M REG (25)	Bipedal pés unidos	Total mean velocity	Atlhetes: highest values
	Age: 20.6 ± 2.1 years old	3 x 35s, rec 25s	Mean VelocityDP	ü Total mean velocity EO
	CG M (25)	EO/EC	SD Amplitude	ü Velocity DP AP/ML EO
	Age: 21.5 ± 2.3 years old			
Kuczyński et al., 2009	Volleyball M REG (23)	Bipedal	AP-ML Mean velocity	Atlhetes: lower values
	Age: 22.9 ± 4.7 years old	1 x 20s	Amplitude;	ü Mean velocity
	CG M (24)	EO	Frequency;	ü Variability
	Age: 22.9 ± 1.3 years old		Variability	ü Amplitude (AP/ML)
Perrin et al., 2002	Dança F INT (14)	Bipedal 10cm	Area	Judo: lower values
	Age: 22.1 ± 4.5 years old	1 x 20s	Excursion	ü Area and Excursion (EO/EC)
	Judo M INT (17)	EO/EC		Compared to CG e Dance
	Age: 24.8 ± 4.5 years old			
	CG: F (21) e M (21)			
	Age: 23.9 ± 4.2 years old			

Continue...

Table 3. Continuation.

Atlhetes A vs. Atlhetes B				
Reference	Group (sample size)	Protocol	COP variables	Results
Bieć et al., 2015	Soccer M Sub20 (23)	Bipedal 10cm e Unipedal	AP-ML Mean velocity	U20: Highest values para
	Age: 18.8 ± 0.9 years old	1 x 20s; EO/EC	Variability	ü Variability AP/ML EC;
	Soccer M Sub14 (24)			U14: Highest values para
	Age: 13.1 ± 0.6 years old			ü Variability Bi/Unipedal EO ML
Paillard and Noé, 2006	Soccer M PRO (15)	Bipedal 5cm 30°	Area	PRO: lower values
	Age: 24 ± 3 years old	1 x 51.2s	Total mean velocity	ü Area
	Soccer M AMA (15)	EO/EC	Mean position	ü Total mean velocity (EO/EC)
	Age: 23 ± 3 years old		VVY (Velocity Variance)	
Paillard et al., 2006	Soccer M NAC (15)	Unipedal Dominant	Area	NAC: lower values
	Age: 24 ± 3 years old	1 x 51.2s	Total mean velocity	ü Area OE
	Soccer M REG (15)	EO/EC	Frequency	ü Total mean velocity EO/EC
	Age: 23 ± 3 years old			
Noé et al., 2005	Alpine skiing M NAC (7)	Bipedal knees extended	Area	Atleta: highest values
	Age: 18 ± 1 years old	1 x 51.2s	Total mean velocity	ü Area EO
	Esqui alpino M REG (7)	EO/EC		
	Age: 22 ± 3 years old			
Paillard et al., 2002	Judo M INT (11)	Bipedal	Area	No significant differences
	Age: 17.6 ± 0.3 years old	1 x 51.2s	Excursion;	
	Judo M REG (9)	EO/EC	Frequency	
	Age: 17.4 ± 0.4 years old		Mean position	

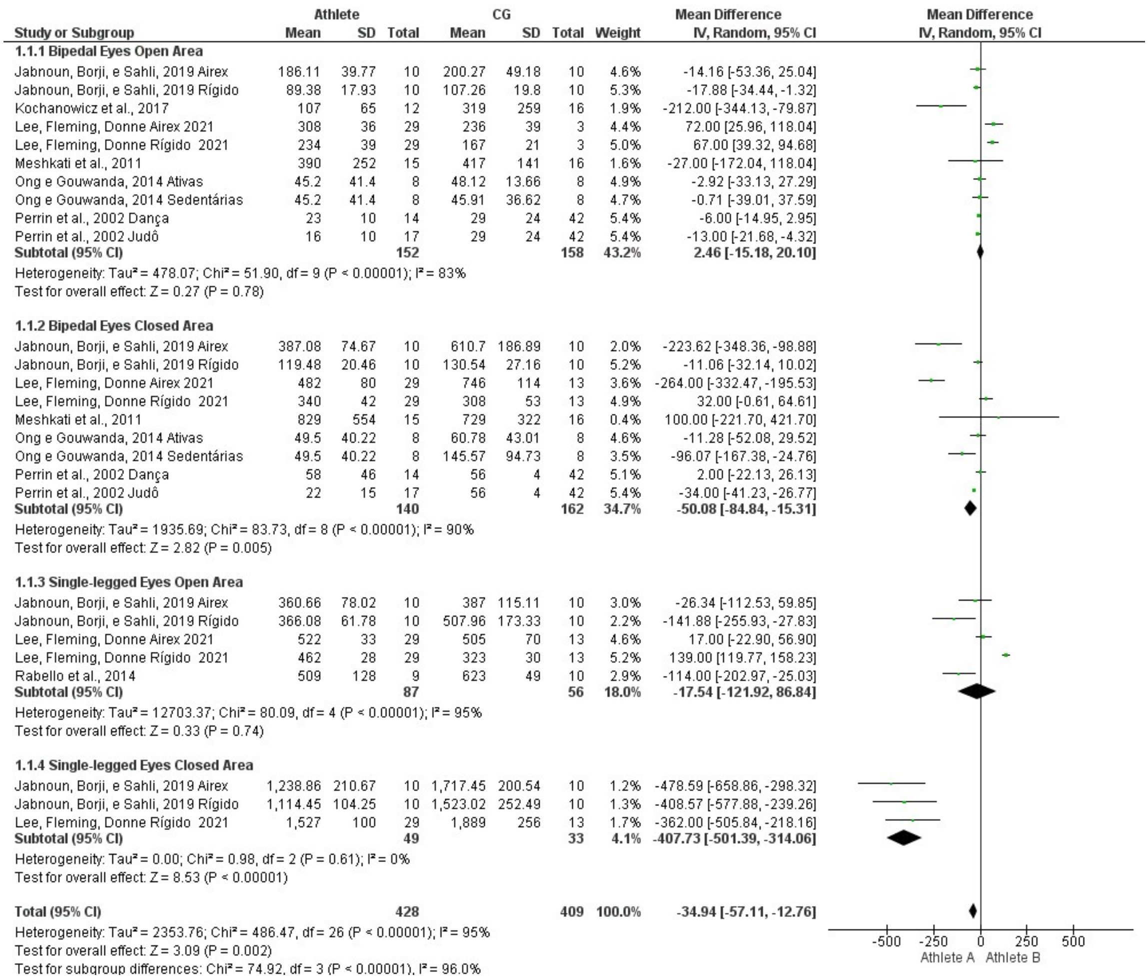
AMA: amateur; AP: anteroposterior; SD: standard deviation; F: female; CG: control group; BEG: beginner; INT: international; M: male; ML: mediolateral; NR: not reported; NAC: national; EO: eyes-open; CE: eyes-closed; PRO: professional; REC: recovery time; REG: regional; U14: to 14 years old; U20: to 20 years old.

experimental conditions: bipedal with eyes closed and single-legged with eyes closed, but there was no difference in the conditions with eyes open (Bipedal and Single-legged). It is worth mentioning that more challenging postures, such as EC and single-legged posture on the ground or on the Airex mat, increase the differences in favor of the athletes (Jabnoun et al., 2019). The average effect sizes of the studies indicate a significantly smaller area of oscillation in Athletes (Figure 2).

On the other hand, the mean AP/ML velocities were lower in the Athletes compared to the CG only in the bipedal stance (EC). Thus, no significant pooled effect size was found in this variable between the groups (Figure 3).

Furthermore, in the comparison between athletes of different levels, there was no difference for the oscillation area in the conditions of greater postural stability (bipedal). However, in more challenging tasks (postural instability), during single-leg support, with EO and EC, level A athletes presented a smaller oscillation area (Figure 4) and lower mean velocity (Figure 5), but the mean velocity (AP and ML) was different even in the bipedal stance with EO. Paillard and Noé (2006) and Paillard et al. (2006) showed the greatest differences in relation to athletes of different levels (Figure 5). Thus, in the average effect sizes of the studies, there was a significant difference for the average COP velocity, with lower velocity in level A athletes.

In the comparison between studies that analyzed athletes of different levels, the i^2 values for COP Area and Velocity were 76 and 83%, respectively. Furthermore, comparing the



CG: control group.

Figure 2. Forest plot representing meta-analysis results for body sway area used to assess postural balance in different experimental conditions, comparing athletes vs. control group: 1) biped/eyes open; 2) biped/eyes closed; 3) unipedal/eyes open and 4) unipedal/eyes closed.

athletes and the CG, the values were 95 and 76% for the same variables.

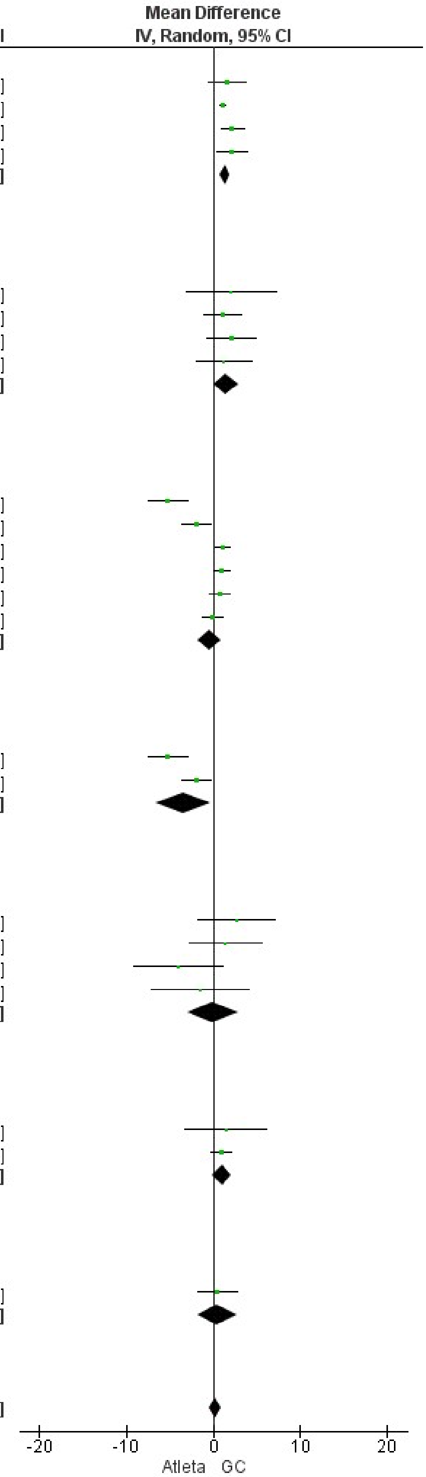
DISCUSSION

This study is a systematic review with meta-analysis to investigate the relationship between sports knowledge and body balance. Our findings corroborate previous studies (Kiers et al., 2013; Paillard, 2017), which reported that sports experience modified the postural balance of athletes, with better results for high-level athletes. Twenty articles were analyzed, most of them of high quality. The results showed that athletes had, in general, better postural balance with a smaller body sway area compared to non-athletes. In addition, athletes of a higher competitive level had a smaller sway area and COP velocity compared to athletes of a lower competitive level.

All 20 included studies were classified as high quality, with only the work by Meshkati et al. (2011) reaching 13 of the 14 points on the Ghamkhar and Kahlaee (2019) checklist for presenting the intraclass correlation coefficient. The sample size in most studies was small, between a minimum of 7 and a maximum of 41 individuals per group.

Stabilometric parameters and experimental protocols differ notably among studies involving athletes. Methodological issues should be explored to resolve the lack of standardization and reference values for stabilometric variables. In this context, the results of the present study revealed seven different test acquisition times (20 s; 25.6 s; 30 s; 35 s; 40 s; 51.2 s and 60 s), four different numbers of repetitions (1, 2, 3 or 4 repetitions), two visual conditions (EO and EC) and different postures adopted: arm position during the test (along the body or crossed), unipedal or bipedal posture with different foot positions (feet together, with heels separated by 1 cm, with heels separated by 5 cm and feet

	Atlhete			CG				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
2.1.1 Bipedal Eyes Open Mean Velocity								
Lee, Fleming, Donne Airex 2021	11.5	3.9	29	9.9	2.9	13	4.5%	1.60 [-0.52, 3.72]
Lee, Fleming, Donne Rígido 2021	9.6	0.8	29	8.5	0.5	13	7.5%	1.10 [0.70, 1.50]
Meshkati et al., 2010	14.2	2.8	25	12	2	25	6.0%	2.20 [0.85, 3.55]
Meshkati et al., 2011	14.2	3	15	12	2	16	5.1%	2.20 [0.39, 4.01]
Subtotal (95% CI)			**98**			**67**	**23.1%**	**1.40 [0.83, 1.98]**
Heterogeneity: Tau² = 0.08; Chi² = 3.62, df = 3 (P = 0.31); I² = 17%								
Test for overall effect: Z = 4.81 (P < 0.00001)								
2.1.2 Bipedal Eyes Closed Mean Velocity								
Lee, Fleming, Donne Airex 2021	22.5	10.2	29	20.4	6.8	13	1.5%	2.10 [-3.14, 7.34]
Lee, Fleming, Donne Rígido 2021	13.7	3.3	29	12.6	3.2	13	4.5%	1.10 [-1.01, 3.21]
Meshkati et al., 2010	20.6	5	25	18.5	5	25	3.5%	2.10 [-0.67, 4.87]
Meshkati et al., 2011	19.8	5.4	15	18.6	3.4	16	3.0%	1.20 [-2.00, 4.40]
Subtotal (95% CI)			**98**			**67**	**12.4%**	**1.46 [0.03, 2.89]**
Heterogeneity: Tau² = 0.00; Chi² = 0.40, df = 3 (P = 0.94); I² = 0%								
Test for overall effect: Z = 2.00 (P = 0.05)								
2.1.3 Bipedal Eyes Open AP ML Mean Velocity								
Biec et al,, 2010 AP	5.7	1.9	25	10.9	4.7	19	4.3%	-5.20 [-7.44, -2.96]
Biec et al,, 2010 ML	7.5	2.1	25	9.4	3.3	19	5.3%	-1.90 [-3.60, -0.20]
Borzucka et al., 2020a AP	6.7	1.9	31	5.6	1.6	31	6.8%	1.10 [0.23, 1.97]
Borzucka et al., 2020a ML	7.6	1.5	31	6.6	1.9	31	6.9%	1.00 [0.15, 1.85]
Kuczynski, Rektor e Borzucka, 2009 AP	7.5	2.1	23	6.7	2.1	24	6.3%	0.80 [-0.40, 2.00]
Kuczynski, Rektor e Borzucka, 2009 ML	8.7	2.3	23	8.8	2	24	6.2%	-0.10 [-1.33, 1.13]
Subtotal (95% CI)			**158**			**148**	**35.8%**	**-0.45 [-1.78, 0.89]**
Heterogeneity: Tau² = 2.30; Chi² = 36.43, df = 5 (P < 0.00001); I² = 86%								
Test for overall effect: Z = 0.66 (P = 0.51)								
2.1.4 Bipedal Eyes Closed AP ML Mean Velocity								
Biec et al,, 2010 AP	5.7	1.9	25	10.9	4.7	19	4.3%	-5.20 [-7.44, -2.96]
Biec et al,, 2010 ML	7.5	2.1	25	9.4	3.3	19	5.3%	-1.90 [-3.60, -0.20]
Subtotal (95% CI)			**50**			**38**	**9.6%**	**-3.47 [-6.70, -0.24]**
Heterogeneity: Tau² = 4.42; Chi² = 5.30, df = 1 (P = 0.02); I² = 81%								
Test for overall effect: Z = 2.10 (P = 0.04)								
2.1.5 Single-legged Eyes Open AP ML Mean Velocity								
Albaladejo-Garcia 2023 AP	24.1	7.4	19	21.4	6.9	20	1.9%	2.70 [-1.80, 7.20]
Albaladejo-Garcia 2023 ML	26.3	6.5	19	24.9	7	20	2.0%	1.40 [-2.84, 5.64]
Rabello et al,, 2014 AP	19.5	3	9	23.5	7.7	10	1.5%	-4.00 [-9.16, 1.16]
Rabello et al,, 2014 ML	22.4	7.5	9	23.9	4.4	10	1.3%	-1.50 [-7.11, 4.11]
Subtotal (95% CI)			**56**			**60**	**6.7%**	**-0.06 [-2.97, 2.86]**
Heterogeneity: Tau² = 2.80; Chi² = 4.38, df = 3 (P = 0.22); I² = 32%								
Test for overall effect: Z = 0.04 (P = 0.97)								
2.1.6 Single-legged Eyes Open Mean Velocity								
Lee, Fleming, Donne Airex 2021	27.2	6.2	29	25.7	7.6	13	1.7%	1.50 [-3.21, 6.21]
Lee, Fleming, Donne Rígido 2021	24.4	1.2	29	23.4	2	13	6.3%	1.00 [-0.17, 2.17]
Subtotal (95% CI)			**58**			**26**	**8.0%**	**1.03 [-0.11, 2.17]**
Heterogeneity: Tau² = 0.00; Chi² = 0.04, df = 1 (P = 0.84); I² = 0%								
Test for overall effect: Z = 1.77 (P = 0.08)								
2.1.7 Single-legged Eyes Closed Mean Velocity								
Lee, Fleming, Donne Rígido 2021	53.6	2.1	29	53.1	3.8	13	4.4%	0.50 [-1.70, 2.70]
Subtotal (95% CI)			**29**			**13**	**4.4%**	**0.50 [-1.70, 2.70]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.44 (P = 0.66)								
Total (95% CI)			**547**			**419**	**100.0%**	**0.24 [-0.47, 0.94]**
Heterogeneity: Tau² = 1.68; Chi² = 92.53, df = 22 (P < 0.00001); I² = 76%								
Test for overall effect: Z = 0.66 (P = 0.51)								
Test for subgroup differences: Chi² = 14.86, df = 6 (P = 0.02), I² = 59.6%								



CG: control group.

Figure 3. Forest plot for meta-analysis results based on mean velocity in different experimental conditions in athletes vs. control group.

forming a 30º position). Regarding the unipedal posture, data acquisitions were collected from both the dominant limb and the preferred limb. This scenario led to significant heterogeneity, and inconsistency values (i^2) ranged from 76 to 95%.

Only five (Albaladejo-García et al., 2023; Bieć & Kuczyński, 2010; Bieć et al., 2015; Meshkati et al., 2010, 2011) of the 20 articles considered a transient period as a postural problem. This time is not accounted for in the stabilometric calculations,

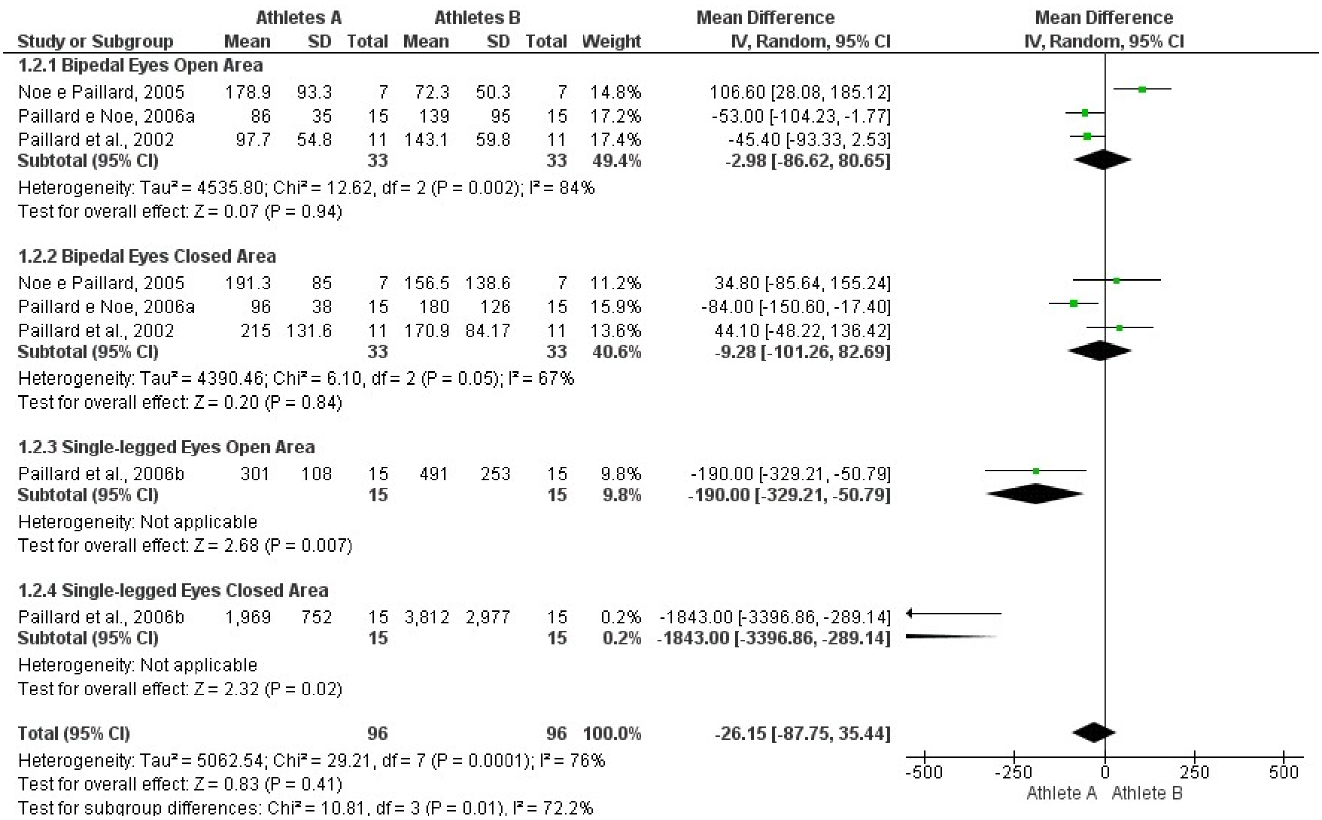


Figure 4. Forest plot representing meta-analysis results for oscillation area in different experimental conditions, comparing the groups: Level A Athletes vs. Level B Athletes..

due to a minimal adaptation of the individual after climbing onto the equipment, adapting to the experimental procedures and starting the test. This transient period can vary from 5 to 10 seconds and should be disregarded. From the initial screening, 11 articles were excluded due to the criterion of performing the test with a duration equal to or less than 20 seconds. Jabnoun et al. (2019) and Noé and Paillard (2005) used dynamic tests, but only the results of the static conditions of these studies were used (lasting 51.6 s). For better reliability of stabilometric parameters in the time domain, a transient period of 5 seconds should be observed and the tests should last at least 30 seconds (Scoppa et al., 2013).

There seems to be a certain consensus among authors that the ability to maintain body balance under specific challenging conditions would be a prerequisite to become an elite athlete (Jabnoun et al., 2019; Kiers et al., 2013; Kochanowicz et al., 2017), especially in the most challenging conditions such as unipedal, in airex or bipedal with eyes closed (Jabnoun et al., 2019; Kochanowicz et al., 2017; Ong & Gouwanda, 2014; Perrin et al., 2002). Athletes present high neural efficiency, better motor strategies and less dependence on the visual system (Borzucka et al., 2020a; Meshkati et al., 2010; Paillard, 2017; Perrin et al., 2002). In this sense, Ong and Gouwanda (2014) stated that tasks in static conditions with eyes open would not challenge the postural system enough to identify possible differences between groups.

This scenario was confirmed by the meta-analysis, where significant differences were observed when comparing the body sway area between athletes and non-athletes and between athletes of different levels, in the different experimental conditions (single-legged and bipedal with EC). Therefore, sports training appears to result in better postural control through sensorimotor adaptations (Paillard, 2017). For balance purposes, the use of visual information is reduced and somatosensory information is improved, especially in modalities that involve changes in the environment and dynamic interactions with other athletes (Paillard, 2017). Thus, higher-level competitive athletes would use vision predominantly for sports disputes, tactical issues, and scoring (Bieć et al., 2015; Paillard & Noé, 2006).

Forest Plot analysis in the subgroups confirmed that athletes presented a smaller oscillation area compared to non-athletes, as expected. A more significant difference was observed using single-leg stance protocols (Jabnoun et al., 2019; Lee et al., 2021), that is, the differences between the groups were accentuated in more challenging postures.

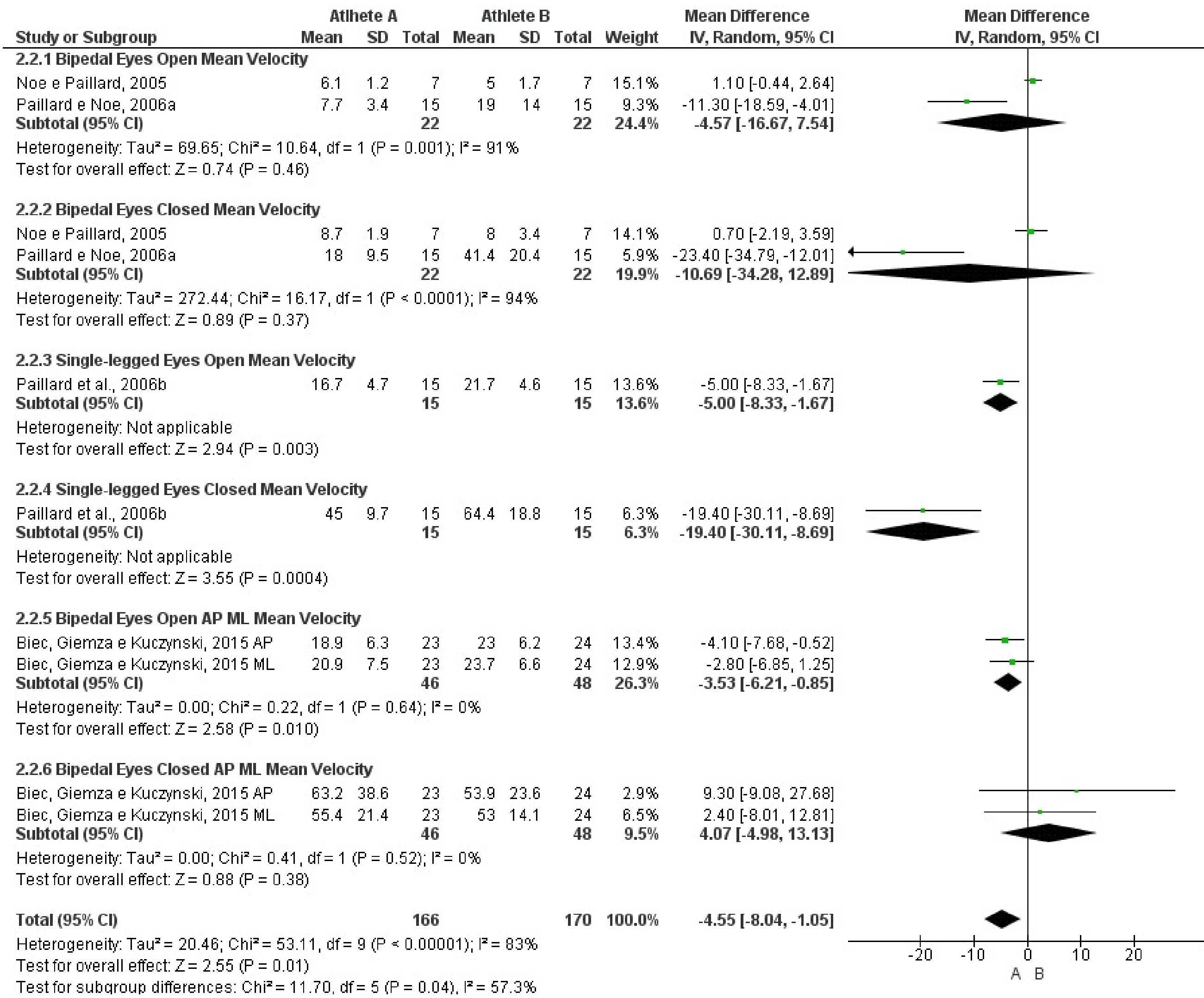


Figure 5. Forest plot representing meta-analysis results for mean center of pressure velocity in different experimental situations, comparing level A vs. level B athletes..

On the other hand, for the average COP velocity between athletes and non-athletes, there were conflicting results in the Forest Plot. Karate athletes (Meshkati et al., 2010, 2011), for example, presented a higher average velocity than the CG (Figure 3). This finding could be justified by a greater exploratory behavior during postural adjustments. In this sense, Borzuka et al. (2020a) suggested that the higher COP velocity of athletes can provide faster information about the body position based on specific changes and that these muscle synergies in response to unexpected external perturbations exhibited low co-contraction between ankle agonists and antagonists, which makes them much less vulnerable to fluctuations and/or postural disturbances.

The analysis addressed in this study also confirmed a significant difference in postural control between athletes of different levels of sports performance. Experienced athletes use the visual system less to maintain postural balance, and athletes with a higher competitive level appear to use sensory information more efficiently, based on the predominance of the vestibular and proprioceptive systems. Thus, differences between high- and low-level athletes were observed mainly during single-leg stance and eyes closed. Paillard and Noé (2006) and Paillard et al. (2006) showed that athletes with a higher competitive level efficiently weigh vestibular and proprioceptive stimuli while performing unstable tasks. However, in less challenging situations, no significant differences were observed between the groups of athletes.

Paillard and Noé (2006) considered that the greater number of challenging tasks could explain this improvement in behavior. However, the physiological interpretation of these stabilometric parameters is an open debate. Kiers et al. (2013) contested, in a systematic review, that some authors claimed that a lower velocity and oscillation area would correspond to better postural control. Instead, Borzucka et al. (2020a, 2020b) and Kuczyński et al. (2009) argued that a higher velocity associated with a lower COP amplitude was related to better postural stability and injury prevention, suggesting a faster response to postural and environmental inconsistencies, with a shorter reaction time, during sports performance.

Regarding methodological aspects, few studies met the study inclusion criteria, considering only athletes during static tests and without injuries or interventions. Furthermore, more than half (66%) of the studies used only one repetition in the acquisitions, which does not allow analysis of the reliability of the stabilometric parameters. Significant variation was also observed in the COP acquisition times and some studies were excluded because the tasks were performed with dual tasks or dynamic platforms.

The different protocols and variables considering sports specificity could be further explored. However, the sample of 20 studies was relatively small to address these issues, due to the variety of protocols, sports, and parameters. Some studies were also excluded because the authors did not present the mean and standard deviation of the stabilometric parameters. Therefore, these numerous limitations reflect the difficulty in reaching a consensus and the need for methodological standardization of the studies, as pointed out in other systematic reviews (Duarte et al., 2022). All these methodological variations also prevent, for now, the establishment of reference values and strata, which would be of great applicability for sports training. Future studies could address how the findings directly impact sports training, injury prevention, and improvement of athletic performance. In addition, possible practical applications of the results in the assessment and monitoring of postural balance in athletes of different competitive levels could be discussed.

Considering only static, non-ecological conditions during stabilometric tests, there is a challenge in proposing advanced protocols or dynamic tests to improve the possibility of reproducing sports actions as a simulation of a specific sports gesture. A transient period of 5s and at least 30s of testing, EO and EC, bipedal and unipedal, different foot positions in bipedal and randomized postures must be adopted so that there is no increasing difficulty or learning during the test, in addition to the presentation of the results with mean and standard deviation values in future works.

It was evident that sports experience modified body balance, increasing the ability to maintain body balance in challenging conditions, which is essential for offering faster adjustments to postural and environmental inconsistencies, strongly suggesting that this developed valence is one of the prerequisites for becoming an elite athlete. Greater neural efficiency, with greater use of sensory information and less dependence on the visual system, also induces that these adaptations are related to injury prevention and improved sports performance.

CONCLUSIONS

This systematic review and meta-analysis identified essential differences in postural balance comparing athletes and non-athletes and, among athletes of different levels, evidencing better performance in athletes and in athletes of higher competitive level, through the lower COP area. Athletes of higher competitive level presented smaller COP area and also different postural strategies involving COP velocity. The results highlighted that more challenging conditions should be considered to study athlete performance, for example, the unipedal posture could also be used, with eyes open and eyes closed, which are closer to specific sporting gestures and sporting demands, being more ecological to test athletes.

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