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Relationship Between Refractive Error, Visual Acuity, and Postural Stability in Elite Football Players

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Abstract: This study aimed to investigate the relationship between visual system parameters (visual acuity and refractive error) and postural balance under controlled conditions in elite football players. Visual acuity (monocular and binocular) and refractive errors were assessed in 34 male athletes using retinoscopy and subjective refraction. Postural stability was assessed with the Cyber-Sabots™ platform, recording the center of pressure (CoP) metrics, including sway amplitude, velocity, and distribution area. Visual and postural parameter correlations were assessed using Pearson's test ($p < 0.05$). Athletes demonstrated good binocular visual acuity (-0.03 ± 0.09 logMAR) and were predominantly emmetropic. Visual acuity and postural parameters showed significant negative correlations, whereby visual acuity was associated with reduced CoP displacement (r = −0.352) and sway area (r = −0.367), indicating enhanced stability. Hyperopia and oblique astigmatism were moderately correlated with increased sway (r = 0.343) and antero-posterior sway amplitude in the sagittal plane (r = 0.324). Anisometropia showed moderately negative correlations with antero-posterior control (r = −0.421), suggesting a disruptive effect on postural stability. The postural analysis showed adaptations characteristic of football players, including anterior body inclination, increased forefoot loading, and medio-lateral sway. Romberg's quotients highlighted significant visual input reliance for maintaining postural balance. Visual acuity, refractive errors, and interocular refractive asymmetries significantly influence postural stability in elite football players. These results support incorporating visual function assessment into training and injury prevention in elite sports.

Keywords: visual acuity; refractive errors; stabilometry; postural stability; sports vision; football players

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1. Introduction

Posture refers to the alignment and stability of body segments in relation to gravity and the base of support. It is a dynamic process involving continuous adjustments governed by the integration of sensory inputs from the visual, vestibular, proprioceptive, and

somatosensory systems [1]. Effective postural stability is essential not only for maintaining balance in both static and dynamic conditions but also for supporting functional mobility, injury prevention, and optimal athletic performance [2,3]. Impairments in any component of the postural stability system can lead to instability, increasing the risk of falls and compromising physical capability [4,5].

Among the sensory systems involved in posture, vision plays a critical role by providing spatial orientation and anticipatory cues for motor adjustments. Its absence, especially on unstable surfaces, has been shown to significantly compromise postural stability because of delayed and amplitude-dependent motor responses [6,7]. Changes in visual acuity, whether due to refractive errors or other visual impairments, can significantly influence postural stability [8,9]. For example, refractive blur has been found to increase postural sway, particularly under conditions where somatosensory or vestibular inputs are compromised [10,11]. The relationship between visual acuity and postural stability has also been evidenced through modifications in anticipatory postural adjustments [12]. One study showed that reduced visual input delays the onset of muscle activation patterns required for maintaining balance during perturbations, leading to increased center-of-pressure displacement [13].

Beyond visual influences, the feet biomechanical function play a crucial role in maintaining posture. The foot acts as the primary interface between the body and the supporting surface, serving a central role in stabilometry and postural regulation. Its anatomical structure and sensory mechanisms are essential for preserving balance, distributing body weight, and responding to environmental changes [14]. The integration of proprioceptive inputs from the foot with visual and vestibular systems is critical for postural stability [15]. Studies have shown that foot function abnormalities, such as altered plantar pressure distribution or foot posture deviations, can significantly compromise balance and contribute to broader issues, including falls or pain in other parts of the body, such as the lower back [16,17]. The foot's contribution to postural stability is frequently evaluated via center of pressure (CoP) displacement, which reflects neuromuscular adjustments required to sustain balance [17]. These responses confirm that the foot is not a passive support but a dynamic structure capable of influencing postural stability through its mechanical and sensorimotor properties [18]. Assessing the interaction between the foot and the ground through stabilometry offers valuable insights into postural control strategies. Such information enables clinicians to identify dysfunctions and develop targeted interventions to improve balance, reduce falls, and enhance posture [16].

Posture and balance are particularly significant in the context of sports [19]. Athletes rely on optimal sensory integration and musculoskeletal coordination to achieve high performance while minimizing the risk of injury. Differences in postural stability between athletes and non-athletes suggest that long-term, high-intensity training may enhance sensory integration and motor responses. For example, volleyball players exhibit greater centre-of-pressure sway during visual deprivation tasks, indicating a reliance on visual input to maintain balance [20]. This may reflect adaptations that improve dynamic visual acuity and postural strategies in sport-specific scenarios [20]. Similarly, football players demonstrate playing position-specific differences in balance performance, with midfielders showing greater postural stability than defenders and forwards [21,22]. Given the physical demands of football and the increased incidence of muscle and anterior cruciate ligament injuries, particularly in the post-COVID-19 era, preventive exercise programs have gained renewed relevance for maintaining musculoskeletal integrity and reducing injury risk [23,24].

This study examines the relationship between visual acuity, refractive errors, and postural stability in elite football players.

Few studies have specifically targeted elite football players, a population characterized by unique visual and motor demands, such as rapid visual processing under high-speed and unstable conditions. Our integrated approach combines comprehensive optometric assessments with objective postural stability analysis using the Cyber-Sabots™ platform, evaluating participants under controlled visual conditions (eyes open and closed). This methodological approach enables a detailed examination of how refractive errors and visual acuity specifically affect postural control in elite athletes. These athletes rely heavily on visual input to guide motor responses and maintain balance. Furthermore, subtle visual impairments, such as uncorrected refractive errors, may compromise postural control and, consequently, performance. Investigating this population offers valuable insights into visuo-postural interactions under elite-level physiological and perceptual demands. This study aims to determine how visual acuity and refractive errors impact postural stability. We hypothesized that both greater refractive errors and reduced visual acuity would be significantly associated with increased postural sway, indicating reduced postural stability.

2. Methods

This study included 34 male elite football players from teams competing in top professional leagues. Participants were selected following strict inclusion and exclusion criteria. The inclusion criteria comprised male elite football players actively competing in national or international leagues, aged between 18 and 35 years, regularly participating in professional training sessions (a minimum of 5 sessions per week), with no diagnosis of neurological, vestibular, or musculoskeletal disorders affecting balance, or history of ocular pathology affecting visual acuity beyond normal refractive errors. The exclusion criteria encompassed any systemic or neurological disease potentially affecting postural control, use of medications influencing the central nervous system or balance, severe uncorrected refractive errors (greater than $\pm$6.00 dioptres of spherical equivalent), history of ocular surgery (including refractive or strabismus surgery), incomplete visual or postural assessment data, and any brain concussion in the 12 months preceding the evaluation. The sample included players occupying different field positions: 14 defenders, 13 midfielders, 4 forwards, and 3 goalkeepers. The participants' professional experience ranged from 6 to 20 years (mean $\pm$ SD: 10.6 $\pm$ 3.6 years). Sixteen athletes had previously competed at the senior level for their national teams. The sample size was constrained by the availability of teams, as all participants were elite-level players from top-tier clubs. A Post hoc power analysis (exact, correlation: bivariate normal model) performed with G*Power version 3.1.9.6 [25] yielded a statistical power ($1 - \beta$) of 0.66, based on the 34 participants and the average effect size of the significant correlations (r = 0.346).

All visual assessments were performed by a single experienced optometrist (JJ), while postural evaluations were conducted by a single experienced podiatric researcher (MO), both carried out on-site within the team's training facilities. At the time of testing, neither researcher had access to each other's data, ensuring procedural independence. This study adhered to the ethical principles outlined in the Declaration of Helsinki, including the amendments adopted during the 64th WMA General Assembly, held in Fortaleza, Brazil, in October 2013, and was approved by the Ethics Subcommittee for Life and Health Sciences of the University of Minho (CEICVS 113/2020).

Informed consent was obtained from all participants prior to their inclusion in this study.

2.1. Visual Acuity and Refractive Error Measurement

Static visual acuity for distance was measured using the ETDRS chart positioned at a distance of 5 m. Each participant was instructed to read characters on the chart until they could no longer distinguish them. The right eye was assessed first, followed by the left

eye, and finally, binocular visual acuity was assessed. For the purposes of this study, good visual acuity was defined as a binocular LogMAR value of 0.00 or better (equivalent to 20/20, lower LogMAR scores indicate superior visual function).

Refractive error was assessed using a Heine Beta 200 retinoscope (HEINE Optotechnic, Munich, Germany), followed by subjective refraction to ensure the most accurate correction for each player. Subjective refraction began with monocular measurements, followed by bi-ocular balance, and concluded with binocular refinement. Objective retinoscopy served as the starting point for subjective refraction and employed the conventional endpoint of maximum plus for the best visual acuity, followed by Jackson cross-cylinder refinement to determine the axis within 5 degrees and cylinder power within 0.25 D. Spherocylindrical findings, comprising the sphere, cylinder, and axis, were transformed into vector representations using Fourier analysis, as described by Thibos et al. [26]. This approach enables a quantitative evaluation of refractive components, including the calculation of vectors J0 (horizontal and vertical astigmatism), J45 (oblique astigmatism), and M (spherical equivalent). Myopia was defined as $M \leq -0.50$ D, emmetropia as -0.50 D $< M <$ +0.50 D, and hyperopia as $M \geq +0.50$ D. Anisometropia was determined by the absolute difference in the M between the two eyes, while anisoastigmatism was evaluated by calculating the absolute differences in the J0 and J45 astigmatic components between the right and left eyes. These metrics provided a detailed assessment of binocular asymmetries in refractive components, which may influence both visual processing and postural stability.

2.2. Postural Stability Assessment Using the Cyber-Sabots™ Platform

The Cyber-Sabots™ platform (Cyber-Sabots, Innovative Technology, Marseille, France) was used to evaluate postural stability through various variables that reflect a person's stability and balance under different experimental conditions. This platform, recognized for its high precision, collects detailed biomechanical data on center of pressure (CoP) displacements across multiple planes. It operates with two independent dynamometric platforms, one for each foot, enabling the quantification of the distinct contributions of ankle and hip musculature to postural stability. The system complies with the metrological standards established by the French Association of Posturology (AFP Standards 85/2000). Calibration was performed prior to each experimental session using the manufacturer's standard software protocol entitled "unload for measurement". This procedure ensures accurate zeroing of the force plates before each trial and complies with the standard stabilometric guidelines [27].

The postural stability parameters analyzed included mean CoP position, represented by DistMean; sway area and amplitude, assessed through Surface, Length, LengthX, and LengthY; postural stability and energy expenditure, evaluated using the LFS parameter. This variable, defined as the ratio between CoP path length and sway surface area, reflects the neuromuscular effort (muscular activation required to maintain postural stability) needed to maintain balance and serves as an indirect indicator of energy expenditure. Frequency and spectral analysis were conducted using the AN02X and AN02Y variables.

Load distribution and asymmetry were assessed through the parameters RR, FeetP, LFOOT, RFOOT, and LRR. LFOOT and RFOOT correspond to the average vertical pressure (in mm) exerted on the forefoot of the left and right feet, respectively, while RR and LR indicate the load on the rearfoot. The antero-posterior ratio (APR) was calculated to assess the balance between the forefoot and rearfoot loading, with negative values indicating a predominance of anterior loading. The left–right load ratio (LRR) quantifies asymmetry in load distribution between both sides of the body, with positive values indicating a preference for the left side.

Postural stability dependence on visual input was evaluated using the Romberg quotient parameters QRBG and QRBVV, calculated as the ratio between values obtained under eyes closed and eyes open conditions for total sway area (QRBG) and velocity variance (QRBVV), respectively. Elevated values in these indices indicate greater reliance on visual input to maintain balance, suggesting lower efficiency of proprioceptive and vestibular systems in the absence of vision. Conversely, lower values indicate better multisensory integration and reduced visual dependency. The Romberg quotients were specifically calculated to allow indirect comparison between eyes open and eyes closed conditions, assessing the influence of visual input on postural control without presenting separate raw data tables.

Participants were instructed to adopt a standardized bipedal stance, barefoot, with their feet aligned at an angle of 30°, without socks or shoes. The stabilometric platform was positioned at a distance of 240 cm from an optical target (a vertical line on the wall) to ensure objectivity of vertical alignment. These conditions were defined to standardize participant posture and visual focus during the measurements.

During testing, participants were exposed to two experimental conditions: eyes open and eyes closed. These variations were used to assess the influence of visual sensory input on postural stability, as recommended by standard postural assessment protocols. Stabilometric data were collected over a 51.2 s interval for each condition, with a sampling frequency of 40 Hz. The parameters analyzed included CoP total oscillation amplitude, average CoP velocity, and CoP displacement area, following best practices in stabilometric analysis. To ensure the reliability of the results, a calibration protocol was performed prior to each experimental session. Data collected were processed using the platform's native software, which generated descriptive metrics and visualizations. These processed data were then exported for statistical analysis using specialized software.

2.3. Statistical Analysis

Data from both visual and postural evaluations were stored and later exported to an Excel spreadsheet. The analysis was conducted using SPSS for Windows (version 30; IBM Corp., Armonk, NY, USA).

Most of the postural stability variables followed a normal distribution. Given that the sample size was greater than 30 participants and no significant outliers were detected, the Pearson correlation coefficient was chosen for the analysis, as recommended by several authors. Pearson's method is widely considered robust to moderate normality violations in samples over 30, maintaining validity and statistical power [28–30]. All data were analyzed using Pearson's correlation test, with the significance level set at $p < 0.05$. Correlation coefficients were interpreted as follows: negligible (0.00–0.09), weak (0.10–0.39), moderate (0.40–0.69), strong (0.70–0.89), and very strong ($\geq$0.90). In addition, 95% confidence intervals were calculated for each Pearson correlation coefficient to provide further information regarding the strength and reliability of the associations. Comparisons between the right and left eyes were conducted using the paired-samples *t*-test, with statistical significance defined as $p < 0.05$.

3. Results

3.1. Descriptive Results

This study sample comprised 34 elite male football players with a mean age of 25.5 $\pm$ 4.5 years, a mean height of 1.79 $\pm$ 0.08 m, a mean body weight of 73.4 $\pm$ 9.6 kg, and a mean body mass index (BMI) of 22.9 $\pm$ 1.5 kg/m^2. The analysis focused on parameters related to visual function and postural stability, with results presented in Tables 1 and 2. The mean logMAR static visual acuity values were -0.01 ± 0.10 for the right eye, -0.02 ± 0.10

for the left eye, and −0.03 ± 0.09 for binocular vision. No significant differences were identified between the right and left eyes (p = 0.158). The mean spherical equivalent (M) was 0.06 ± 0.44 D for the right eye and 0.07 ± 0.50 D for the left eye, with no statistically significant differences between eyes (p = 0.686). Similarly, the mean astigmatic components showed no significant interocular differences (J0: p = 0.130; J45: p = 0.059). Anisometropia, defined as the absolute difference in the spherical equivalent between the eyes, averaged 0.29 ± 0.31 D. Based on ametropia classification, 5.9% of the athletes were myopic, 79.4% were emmetropic, and 14.7% were hyperopic. Regarding postural stability, the mean medio-lateral deviation in the frontal plane (Xmean) was −1.18 ± 10.09 mm, indicating a slight leftward tilt with high variability. In the sagittal plane, the mean antero-posterior deviation (Ymean) was 43.42 ± 19.67 mm, reflecting a pronounced forward lean (anterior body inclination relative to the vertical axis of balance). The mean center of pressure (CoP) displacement from the central point (DistMean) was 6.74 ± 2.13 mm. The sway area (Surface), covering 90% of the CoP distribution, was 300.55 ± 157.07 mm^2. Total sway amplitude (Length) was 889.10 ± 270.52 mm, with medio-lateral (LengthX) and antero-posterior (LengthY) sway amplitudes averaging 729.77 ± 262.81 mm and 377.95 ± 93.63 mm, respectively.

Table 1. Summary of mean values and standard deviations for visual system parameters.

			Mean ± SD
Age (Years)			**22.20 ± 3.50**
Visual acuity (LogMAR)	Right Eye		−0.01 ± 0.10
	Left Eye		−0.02 ± 0.10
	Both Eyes		−0.03 ± 0.09
	Difference right/left eye		0.01± 0.04
Refractive error (D)	Right eye	M	0.06 ± 0.44
		J0	0.07 ± 0.24
		J45	−0.04 ± 0.15
	Anisometropia		0.29 ± 0.31
	Anisoastigmatism	J0	0.11 ± 0.15
		J45	0.10 ± 0.18
Ametropia (%)	Myopia:		5.90
	Emmetropia:		79.40
	Hyperopia:		14.70

The postural stability index (LFS), reflecting energy expenditure to maintain balance, averaged 1.75 ± 0.50 mm, while velocity variability (VarV) was 115.24 ± 56.46 mm, suggesting increased rigidity in some participants. The load distribution analysis revealed a mean load of 0.28 ± 0.07 mm on the left forefoot (LF), 0.24 ± 0.09 mm on the left rearfoot (LR), and 0.30 ± 0.07 mm and 0.18 ± 0.07 mm on the right forefoot (RF) and rearfoot (RR), respectively. These findings indicate a relatively balanced plantar distribution with slight forefoot predominance. The antero-posterior load ratio (APR) was −16.50 ± 25.19, reflecting anterior load bias, while the left–right load ratio (LRR) averaged 3.07 ± 9.53, suggesting a slight preference for the left side. The vertical variability index, representing postural asymmetry (IVV (PA)), averaged −0.01 ± 0.16 mm, suggesting minimal lateral dominance. Bilateral coordination between the feet (IntCorLR) was 0.76 ± 0.15, approaching the lower limit of normal, indicating a potential need to enhance intersegmental stability. The Romberg quotients for surface area (QRBG(Surf)) and velocity variance (QRBVV) were

125.00 ± 97.80 and 122.36 ± 43.83, respectively, underscoring the influence of visual input on postural stability.

Table 2. Summary of mean values and standard deviations for postural system parameters.

		Mean ± SD
Mean CoP position	Xmean (mm)	−1.18 ± 10.09
	Ymean (mm)	43.42 ± 19.67
	DistMean (mm)	6.74 ± 2.13
Area and amplitude of sway	Surface (mm^2)	300.55 ± 157.07
	Length (mm)	889.10 ± 270.52
	LengthX (mm)	729.77 ± 262.81
	LengthY (mm)	377.95 ± 93.63
Velocity and variability of CoP	VarV (mm^2/s^2)	115.24 ± 56.46
	VFY (mm/s)	−5.00 ± 10.00
Frequency and spectral analysis	AN02X (%)	27.35 ± 9.89
	AN02Y (%)	27.63 ± 8.19
Load distribution and asymmetry	LF (%)	0.28 ± 0.07
	LR (%)	0.24 ± 0.09
	RF (%)	0.30 ± 0.07
	RR (%)	0.18 ± 0.07
	LFOOT (%)	0.51 ± 0.05
	RFOOT (%)	0.48 ± 0.05
	Posterior (%)	0.42 ± 0.13
	Anterior (%)	0.58 ± 0.13
	APR (%)	−16.50 ± 25.19
	LRR (%)	3.07 ± 9.53
	FeetP (°)	4.20 ± 6.5
	IntCorLR	0.76 ± 0.15
Stability and postural stability	LFS	1.75 ± 0.50
	IVV (PA)	−0.01 ± 0.16
Dependence vision	QRBG(Surf) (%)	125.00 ± 97.80
	QRBVV (%)	122.36 ± 43.83

CoP: center of pressure; Xmean: medial-lateral deviation in the frontal plane; Ymean: antero-posterior deviation in the sagittal plane; DistMean: distance of the CoP from the central point; Surface: area covered by the ellipse representing 90% of the CoP distribution; Length: total sway amplitude; LengthX: medial-lateral sway amplitude with frontal plane; LengthY: antero-posterior sway amplitude in sagittal plane; VarV: velocity variability; VFY: velocity in function of sagittal plane; AN02X: frontal oscillation at 0.2 Hz frequency; AN02Y:sagittal oscillation at 0.2 Hz frequency; LF: load on the left forefoot; LR: load on the left rearfoot; RF: load on the right forefoot; RR: load on the right rearfoot; LFOOT: load on the left foot; RFOOT: load on the right foot; APR: antero-posterior load ratio; LRR: left–right load ratio; FeetP: feet position inclination; IntCorLR: coordination between the feet; LFS: postural stability index; IVV (PA): vertical variability index or postural asymmetry; QRBG(Surf): Romberg quotients for surface area; QRBVV: velocity variance.

3.2. Analysis of Correlations Between Visual Parameters and Postural Stability

Visual acuity, assessed both monocularly and binocularly, demonstrated significant correlations with key postural stability parameters, including DistMean, Surface, and Length (Table 3). For DistMean, negative correlations were observed (r = −0.318, p = 0.033 for monocular acuity; r = −0.352, p = 0.020 for binocular acuity), indicating that better

visual acuity is associated with reduced center of pressure (CoP) sway. Similarly, for Surface, negative correlations were found (r = −0.326, p = 0.030 and r = −0.367, p = 0.016 for monocular and binocular acuity, respectively), suggesting that improved acuity enhances overall postural stability. For Length, significant negative correlations (r = −0.289, p = 0.048 and r = −0.370, p = 0.016) indicated greater efficiency of postural control with better visual acuity. Additionally, binocular acuity showed significant negative correlations with medio-lateral sway (LengthX: r = −0.350, p = 0.021) (side-to-side displacement of the center of pressure (CoP) in the frontal plane) and antero-posterior sway (LengthY: r = −0.343, p = 0.024), reflecting reduced body sway in both planes. These findings highlight the crucial role of visual acuity in modulating postural stability in elite athletes. Refractive errors, including the spherical equivalent (M), astigmatic components (J0 and J45), and ametropia, were significantly associated with various postural stability parameters, illustrating their combined influence on balance control. Ametropia, derived from the spherical equivalent, categorizes refractive states from myopia (negative values) to hyperopia (positive values), providing a unified framework for analyzing the impact of refractive error. For DistMean, moderate positive correlations with M (r = 0.437, p = 0.005) and J45 (r = 0.412, p = 0.008) and a weak positive correlation with ametropia (r = 0.325, p = 0.030), indicated that higher refractive errors, particularly hyperopia and oblique astigmatism, are associated with reduced stability. Figure 1 presents the positive correlation between the spherical equivalent and the mean CoP position. Similarly, weak positive correlations with Surface for M (r = 0.329, p = 0.029), J45 (r = 0.343, p = 0.024), and ametropia (r = 0.361, p = 0.018) suggest that greater hyperopic errors result in increased sway area, thereby compromising overall stability. For LengthY, significant correlations with M (r = 0.346, p = 0.045), J0 (r = −0.372, p = 0.015), J45 (r = 0.324, p = 0.031), and ametropia (r = 0.421, p = 0.013) reveal that refractive errors influence antero-posterior sway (front-to-back displacement of the center of pressure (CoP) in the sagittal plane). Greater hyperopic errors are associated with worsened stability, whereas orthogonal astigmatism appears to have a stabilizing effect; with-the-rule astigmatism seems more beneficial for postural stability than against-the-rule astigmatism. Additionally, weak correlations between M and foot position inclination (r = −0.316, p = 0.034) reflect improved plantar load distribution with increased spherical error. Furthermore, correlations between M, ametropia, and QRBG(Surf) (r = −0.347, p = 0.022; r = 0.361, p = 0.018) suggest that hyperopia compromises stability under surface-based conditions.

Astigmatic components exhibited distinct associations with specific postural metrics. J0 showed significant correlations with LFS (r = −0.392, p = 0.011) and LengthX (r = −0.352, p = 0.021), suggesting that orthogonal astigmatism enhances both global and medio-lateral postural stability. Conversely, J45 demonstrated weak positive correlations with FL (r = 0.329, p = 0.029) and QRBG(Surf) (r = 0.361, p = 0.018), indicating that oblique astigmatism increases sway and reduces stability under surface-based conditions. These findings highlight the nuanced impact of refractive errors, particularly the spherical equivalent and astigmatic components, on postural control. Ametropia offers a comprehensive framework for interpreting these effects, revealing that hyperopic athletes tend to show poorer postural stability and load distribution compared with myopic athletes.

Table 3. Pearson correlation coefficients with confidence intervals between visual system parameters and postural system metrics.

			Visual Acuity Right Eye	Binocular Visual Acuity	M	J0	J45	Anisometropia	Ametropia	Anisoastigmatism J0	Anisoastigmatism J45
Mean CoP position	DistMean	*r*	−0.318 [−0.592, 0.023]	−0.352 [−0.616, −0.015]	0.437 [0.116, 0.676]		0.412 [0.086, 0.659]	−0.343 [−0.610, −0.005]	0.325 [−0.014, 0.598]		−0.502 [−0.718, −0.197]
		p-value	0.033	0.020	0.005		0.008	0.024	0.030		0.001
Area and amplitude of sway	Surface	*r*	−0.326 [−0.598, 0.014]	−0.367 [−0.627, −0.032]	0.329 [−0.010, 0.601]		0.343 [0.006, 0.611]	−0.306 [−0.583, 0.036]			−0.471 [−0.697, −0.157]
		p-value	0.030	0.016	0.029		0.024	0.039			0.002
	Length	*r*	−0.289 [−0.571, 0.055]	−0.370 [−0.629, −0.036]	0.328 [−0.011, 0.600]	−0.363 [−0.624, −0.028]					
		p-value	0.048	0.016	0.029	0.017					
	LengthX	*r*		−0.350 [−0.615, −0.013]	0.317 [−0.023, 0.592]	−0.352 [−0.616, −0.015]					
		p-value		0.021	0.034	0.021					
	LengthY	*r*		−0.343 [−0.610, −0.005]			0.324 [−0.015, 0.597]	−0.421 [−0.664, −0.096]		−0.291 [−0.572, 0.053]	−0.372 [−0.630, −0.038]
		p-value		0.024			0.031	0.007		0.047	0.015
Stability and Postural stability	LFS	*r*				−0.392 [−0.644, −0.062]					
		p-value				0.011					
Frequency and spectral analysis	AN02X	*r*								0.297 [−0.045, 0.578]	
		p-value								0.044	
	AN02Y	*r*						−0.289 [−0.571, 0.055]			
		p-value						0.049			
Load distribution and asymmetry	LF	*r*					0.329 [−0.010, 0.601]				
		p-value					0.029				
	RR	*r*							0.311 [−0.030, 0.588]		
		p-value							0.036		
	FeetP	*r*			−0.316 [−0.591, 0.025]				−0.374 [−0.632, −0.041]		
		p-value			0.034				0.015		
	LFOOT	*r*							−0.309 [−0.585, 0.033]		
		p-value							0.038		

Table 3. *Cont.*

			Visual Acuity Right Eye	Binocular Visual Acuity	M	J0	J45	Anisometropia	Ametropia	Anisoastigmatism J0	Anisoastigmatism J45
Load distribution and asymmetry	RFOOT	*r*							0.309 [−0.032, 0.586]		
		p-value							0.037		
	LRR	*r*							−0.309 [−0.585, 0.033]		
		p-value							0.038		
Dependence Vision	QRBG (Surf)	*r*			−0.347 [−0.613, −0.010]		−0.338 [−0.606, 0.001]		−0.307 [−0.584, 0.035]		0.361 [0.027, 0.624]
		p-value			0.022		0.025		0.038		0.018
	QRBVV	*r*								−0.307 [−0.584, 0.035]	
		p-value								0.039	

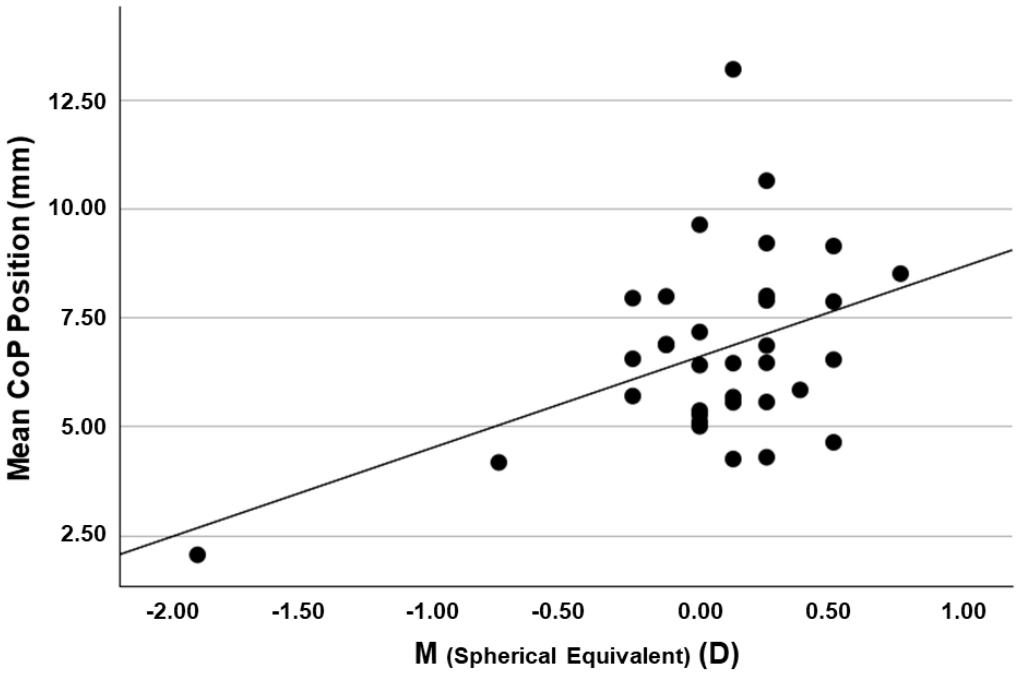


Figure 1. Scatter plot showing the correlation between the spherical equivalent (M) and mean center of pressure (CoP) position (DistMean) in elite football players.

Binocular refractive asymmetries, including anisometropia and interocular astigmatic differences (J0 and J45 components), showed statistically significant correlations with key parameters of postural stability. For DistMean, significant moderate negative correlations were observed with anisometropia (r = −0.502, p = 0.001) and J45 anisoastigmatism (r = −0.471, p = 0.002), indicating that larger interocular differences in spherical equivalent and oblique astigmatism are associated with impaired postural control. Surface exhibited similar correlations (r = −0.471, p = 0.002 for anisometropia; r = −0.307, p = 0.038 for J45 anisoastigmatism), reflecting increased sway due to binocular refractive imbalances. Figure 2 shows the negative correlation between J45 anisoastigmatism and sway surface area.

For LengthY, significant negative correlations were observed for anisometropia (r = −0.421, p = 0.007), J0 anisoastigmatism (r = −0.291, p = 0.040), and J45 anisoastigmatism (r = −0.372, p = 0.015), highlighting exacerbated antero-posterior instability. Anisometropia correlated negatively with the normalized amplitude at 0.2 Hz along the antero-posterior axis (AN02Y) (r = −0.289, p = 0.049), while J0 anisoastigmatism correlated with medio-lateral displacement (AN02X: r = 0.297, p = 0.044) and negatively with velocity variability (QRBVV: r = −0.307, p = 0.039), emphasizing their influence on postural control. J45 anisoastigmatism also correlated positively with QRBG(Surf) (r = 0.361, p = 0.018), suggesting that larger J45 differences, resulting from oblique perpendicular astigmatism, may contribute to a more balanced postural system, whereas oblique parallel astigmatism (similar axes in both eyes) leads to smaller J45 differences and greater instability.

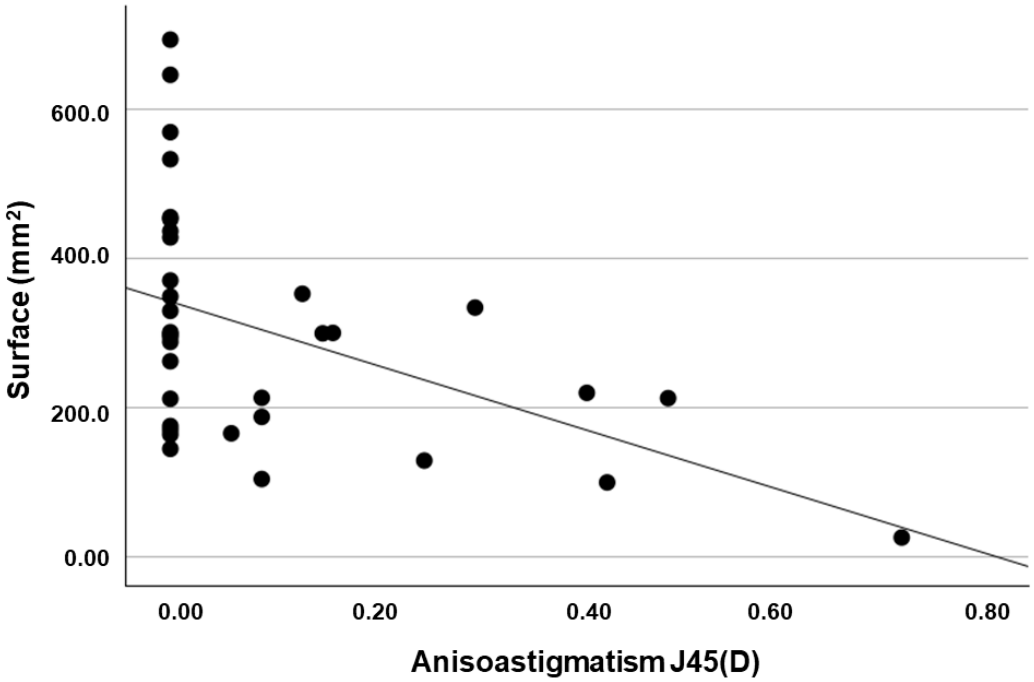


Figure 2. Scatter plot showing the correlation between anisoastigmatism J45 (difference in oblique astigmatism between eyes) and sway surface area (Surface) in elite football players.

4. Discussion

This study demonstrated that elite football players exhibit good static visual acuity and a predominance of emmetropia, with low levels of anisometropia and symmetrical refractive components between the eyes. Postural stability metrics indicated overall good balance, although some medio-lateral and antero-posterior variability was observed, likely reflecting sport-specific neuromuscular adaptations. Crucially, significant correlations were found between visual acuity, refractive errors, binocular asymmetries, and key postural stability parameters, highlighting the central role of visual function in maintaining balance in this athletic population. The primary aim of this study was to explore the relationships between visual acuity, refractive errors, and postural stability in elite football players, addressing a critical gap in the understanding of visual–postural interactions in this specific population. Previous research has consistently shown that athletes typically exhibit good visual acuity and low refractive errors, with the majority being emmetropic [31–33]. However, the specific role of refractive status and visual acuity in influencing postural stability has remained insufficiently investigated. Our results confirmed that elite football players not only exhibit excellent static visual acuity, consistent with previous studies describing above-average visual performance in athletes, thereby reinforcing the notion that optimal visual function is a characteristic of high-level sporting populations.

Moreover, refractive status—particularly hyperopia and binocular asymmetries—was significantly associated with variations in postural stability. These results confirm that this study's primary objective was successfully achieved, offering new evidence that supports the integration of comprehensive vision assessments into strategies aimed at optimizing performance and preventing injuries in high-level athletes. Additionally, the low prevalence of anisometropia and the symmetry in refractive components between eyes further underline the importance of maintaining optimal binocular function for precise spatial awareness and stability during dynamic activities.

Moreover, the observed postural parameters indicated a relatively balanced overall stability, with some variability in specific metrics that may reflect sport-specific adaptations. Among the most relevant stabilometric findings, Xmean revealed a slight leftward tilt,

while Ymean indicated a pronounced forward lean. These patterns may reflect postural adaptations specific to football, where forward movements and lateral shifts are essential. The metric "mean distance of the center of pressure from the central point" suggested moderate overall stability, whereas Surface highlighted greater instability in some players, emphasizing variability in postural stability strategies.

The stabilometric path lengths of the CoP (Length, LengthX, and LengthY) provided further insights into postural dynamics. The total CoP path length (Length) reinforced the trend of moderate instability observed in some participants. In the frontal plane (LengthX), the mean value was higher compared with the sagittal plane (LengthY), indicating that medio-lateral sway was more pronounced than antero-posterior sway. This may reflect the demands of lateral movements inherent to football and is consistent with previous studies reporting increased medio-lateral sway in athletes from sports requiring frequent lateral shifts and directional changes [34,35].

Energy expenditure required to maintain balance (measured as the ratio of CoP path length to sway surface area, LFS) was found to be efficient and close to optimal, suggesting that most participants demonstrated effective neuromuscular control. In addition, considerable variability in CoP velocity (VarV) was observed, which may indicate postural rigidity or the presence of excessive compensatory mechanisms in some athletes, potentially linked to elevated soleus muscle activity. These findings align with previous studies reporting similar patterns of balance control efficiency and compensatory strategies in athletic populations [36,37].

Recent evidence indicates that visual input predominantly affects postural control at low frequencies (0.125–0.5 Hz), whereas proprioceptive and vestibular systems contribute more substantially at higher frequencies [38,39]. The present findings regarding normalized amplitude at 0.2 Hz support the idea that vision contributes significantly to postural adjustments in football players.

The analysis of load distribution revealed a balanced plantar pressure, with a slight predominance in the forefoot compared with the rearfoot, a pattern typically observed in sports requiring dynamic and rapid movements. A greater load was observed on the left rearfoot compared with the right, while the forefoot showed a slightly more even distribution. Additionally, there was a tendency for weight to shift forward, a slight preference for anterior weight shift, and a slight preference for loading on the left side, potentially reflecting sport-specific postural adaptations aimed at optimizing performance during gameplay. These results are consistent with findings from a previous study, which suggest that forefoot loading patterns are common in dynamic sports that require rapid accelerations and changes in direction [40]. Moreover, recent research indicates that such adaptations may be linked to the heightened demand for postural stability required in football, where maintaining balance while executing complex motor actions is essential [41]. The role of vision in postural stability is particularly relevant in high-demand sports environments, such as football, where rapid changes in direction and spatial awareness are essential. The visual system provides crucial information for body positioning and balance adjustments, allowing athletes to anticipate movements and react to external stimuli efficiently. Several studies, including Bae et al. (2020), have demonstrated that uncorrected refractive errors, including myopia and astigmatism, may compromise postural stability by altering spatial perception and increasing postural sway [8]. Additionally, athletes with visual impairments often rely more on proprioceptive and vestibular inputs, which can lead to increased compensatory mechanisms and greater instability, particularly under visually challenging conditions [42].

The analysis of postural asymmetry revealed a slight tendency toward lateralization, albeit minimal, while foot coordination approached the lower limit of normality. These

findings suggest potential areas for improvement in intersegmental stability (Coordination between body segments (feet, legs, trunk) to maintain balance), which could enhance balance and postural stability in elite athletes.

The influence of vision on postural stability was evidenced by the Romberg quotients, highlighting the critical role of vision in maintaining balance. The QRBG(Surf), which quantifies postural sway area by comparing eyes-open and eyes-closed conditions, reflects greater visual dependence when elevated values are observed, indicating reduced efficiency of the proprioceptive and vestibular systems in the absence of vision. Similarly, the QRBVV, which measures the velocity variance of postural sway, indicates that dynamic postural control relies more heavily on vision under similar conditions. These findings underscore the critical integration of vision with other sensory systems to maintain postural stability, particularly in more complex motor situations. Football requires not only static but also dynamic balance, as players frequently change posture during motion, requiring rapid adjustments based on visual cues. Stabilometric studies have demonstrated that football players tend to have superior postural stability compared with non-athletes, primarily because of sport-specific training adaptations in the proprioceptive and vestibular systems [42,43]. However, when visual input is compromised, either by refractive errors or binocular dysfunctions, postural stability may be negatively affected, leading to slower reaction times and greater instability. This is particularly concerning in situations that demand rapid decision-making, such as avoiding tackles or adjusting body positioning while striking the ball [44].

4.1. Correlations Between Visual Parameters and Postural Stability

This study identified significant correlations between visual acuity and key postural parameters. Better binocular visual acuity was associated with reduced antero-posterior displacement and sway area, emphasizing the critical role of visual clarity in maintaining postural stability. Similarly, moderate correlations were observed between visual acuity and decreased medio-lateral and antero-posterior sway, underscoring the importance of visual input in fine-tuning balance control.

Refractive errors, particularly hyperopia and oblique astigmatism, showed moderate correlations with antero-posterior displacement and sway area, suggesting that higher refractive errors are linked to increased postural instability. These findings align with previous research indicating that refractive errors can impair depth perception and visual stability, leading to greater postural sway [10].

Binocular refractive asymmetries, such as anisometropia, demonstrated strong correlations with postural stability metrics, being associated with greater antero-posterior displacement and increased medio-lateral instability. These results highlight the disruptive effects of refractive discrepancies between the eyes on postural stability. These findings demonstrate the critical role of binocular refractive discrepancies, both spherical and cylindrical, in modulating postural stability, with anisometropia and anisoastigmatism contributing to instability through distinct mechanisms.

Moreover, these findings suggest that correcting refractive errors and managing binocular asymmetries could enhance postural stability and athletic performance, particularly in athletes with significant hyperopia or anisometropia. However, further research is required to confirm the efficacy of such interventions and to determine the most effective strategies for different visual profiles.

A crucial factor in the relationship between vision and posture is the exploratory role of postural sway. Recent evidence suggests that CoP displacement may serve as a mechanism for acquiring sensory information rather than merely reflecting postural instability. Studies have demonstrated that when the centre of mass is externally stabilized

without the individual's awareness, postural sway increases, implying that CoP fluctuations may play an active role in optimizing sensory input and postural adaptation [45].

This perspective provides further insight into why athletes with visual impairments or binocular discrepancies may rely more heavily on proprioceptive and vestibular inputs, potentially leading to excessive compensations and increased energy expenditure. In individuals with strabismus, for instance, the absence of binocular fusion has been linked to greater dependence on vestibular and proprioceptive cues, resulting in increased postural instability, particularly under conditions of reduced visual input [11].

Finally, the observed forward lean and forefoot load dominance in athletes may reflect specific postural adaptations to the demands of football, where rapid movement and lateral stability are essential. The interplay between postural asymmetry and visual processing is particularly relevant for injury prevention. Football players often develop postural imbalances because of the sport's high physical demands, and these asymmetries may be exacerbated by uncorrected visual deficiencies. Research has shown that athletes with asymmetric visual processing experience greater postural instability, increasing their susceptibility to non-traumatic musculoskeletal injuries, particularly in the lower limbs [44]. These findings suggest that conventional clinical approaches to balance control deficits should be reconsidered, as postural sway may not solely be a consequence of impaired balance control but rather an adaptive and functional mechanism.

These findings have important clinical implications. Regular vision screening in elite athletes could play a critical role in identifying refractive errors or binocular asymmetries that may otherwise compromise postural control and increase injury risk. Early correction of refractive anomalies, including subtle hyperopia, astigmatism, and anisometropia, may enhance postural stability and optimize motor performance. Incorporating visual assessments into routine sports medical evaluations could, therefore, contribute to both injury prevention and the enhancement of athletic performance. Future research should explore the effectiveness of targeted visual interventions and corrective strategies in improving postural control and functional outcomes in athletic populations.

While these findings provide important insights into the visuo-postural control of elite football players, caution is needed when generalizing them to other sports or non-athlete populations. The specific physical and perceptual demands of football may influence the observed associations. Future research should extend this analysis to athletes from different disciplines and to non-athletes to clarify the broader applicability of these results.

4.2. Limitations of This Study

Despite the relevant findings of this study, several limitations must be acknowledged when interpreting the results. Although the sample comprised 34 elite male football players, yielding a statistical power of 0.66, the confidence intervals associated with the correlation coefficients were relatively wide. The exclusive inclusion of elite male athletes enhanced the internal consistency of the sample; however, it limits the external validity and generalizability of the findings to broader populations, such as female athletes, amateur players, or athletes from other sports. To increase the robustness and generalizability of the findings, future research should involve a larger, more diverse group of players across different categories and experience levels. The absence of a control group of athletes from other sports or non-athletes restricts our ability to determine if the observed associations are specific to elite football. Additionally, we did not control for other variables that might affect postural stability, such as proprioceptive or vestibular disorders and muscle fatigue. Moreover, this study focused on static postural stability, while football involves dynamic control. Future research should incorporate tests that simulate real-game conditions. Lastly, the influence of ocular dominance was not examined, representing another potential source

of variability. Addressing these limitations in future studies will enhance the understanding of the link between visual function and postural stability in high-performance athletes. Furthermore, the cross-sectional design of the present study precludes any conclusions about causal relationships between visual function and postural stability. Future research should employ longitudinal designs to clarify the directionality of these associations. Additionally, intervention studies evaluating the effects of optical correction on postural control in athletes with refractive errors are warranted to explore potential benefits for performance and injury prevention.

5. Conclusions

This study examined the relationship between refractive error, visual acuity, and postural stability in elite football players. The findings indicated that good static visual acuity and a predominance of emmetropia were common in this population, suggesting that optimal visual function may aid in meeting the postural demands of football. Additionally, specific refractive errors and binocular asymmetries were found to significantly influence postural control, especially under conditions that required visual input.

These results emphasize the importance of comprehensive visual assessments for elite athletes, highlighting the potential role of vision in enhancing postural stability and performance in dynamic sports such as football.

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Institutional Review Board Statement: The study adhered to the Declaration of Helsinki and was approved by the Ethics Subcommittee for Life and Health Sciences of the University of Minho (CEICVS 113/2020, approved at: 20 November 2020).

Informed Consent Statement: Informed consent was obtained from each athlete before evaluation.

Data Availability Statement: Data that support the findings of this study are available from the corresponding author, upon reasonable request.

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