

## Original Article

# Improvements in Static Balance Following an Oculomotor Exercise Program in Athletes

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**Objectives:** The visual system is essential for postural control, and visual input significantly affect balance. This study investigated whether a structured oculomotor exercise program improves static balance in basketball, football, and boxing. **Methods:** Of the 138 athletes initially randomized (69 per group), 128 completed the study and were included in the final analysis. Participants in the experimental group (EG, n=64) performed oculomotor exercises alongside usual training, whereas those in the control group (CG, n=64) continued usual training alone for six weeks. Static balance was assessed using the Stork test (s) and the Leonardo Mechanograph® platform, with between-group differences analyzed using adjusted post-intervention comparisons. **Results:** The EG demonstrated significantly greater improvements than the CG in both primary outcomes. Stork test standing time increased (adjusted mean difference [EG - CG] = 22.82 s, 95% CI: 19.54–26.10;  $p < .001$ ). Ellipse area during dominant-leg stance with eyes open decreased (adjusted mean difference = -4.20 cm<sup>2</sup>, 95% CI: -5.10 to -3.30;  $p < .001$ ), indicating better balance. No significant effect modification was observed for sex, years of sport experience, or weekly training volume (all  $p > 0.26$ ). **Conclusions:** Oculomotor exercises were associated with improved static balance over 6 weeks, suggesting they may be a promising addition to athletic training. ClinicalTrials.gov ID: NCT07430384.

**Keywords:** Eye Exercises, Sport, Static Balance, Vestibular System, Visual System

## Introduction

Balance is a very important component that enables motor control and body stability for individuals, both in performing daily activities, but also in sports performance<sup>1</sup>. Maintaining balance is necessary for maintaining a position, postural adaptation to voluntary movements, and reactions to external stresses<sup>2,3</sup>, which is enabled by the interaction between the vestibular, proprioceptive, and visual systems, as well as the ability of motor elements<sup>4</sup>.

In this combination, the brain's 'primary assistant'

for the perception of body position, spatial orientation, and all the initial information from the surrounding environment is the eyes, i.e., the visual system<sup>5</sup>. To maintain postural control, an interaction between central and peripheral vision is needed to determine one's spatial orientation and that of objects in an environment. As we move, the relationship between ourselves and objects in the environment changes<sup>6</sup>. This system interacts with the vestibular system, as the brain adapts the signals derived from the latter to the perceptual strategy based on their displacements. The brain integrates visual and vestibular inputs through the semicircular canals and vestibule, together with proprioceptive information, to ensure a stable perception of movement and orientation<sup>7</sup>. This produces motor reflexes that maintain posture and balance. The vestibular-ocular reflex provides eye movement for visual acuity during head movement, while the vestibular-spinal reflex helps in postural stability<sup>8,9</sup>. In the classical view, it is thought that the vestibular system and the mechanoreceptors of the feet and joints are the main ones responsible for receiving information to enable

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balance, but it has been evidenced that the visual system is more important in controlling balance, especially when the surface is unstable, as well as when learning a new posture<sup>10</sup>. The movement of the image on the retina indicates the optic flow, which provides information for orientation in space and the perception of body movement, while the movement of images during head movement causes retinal slippage, risking visual ambiguity and postural instability<sup>11,12</sup>. Visual fixations that are induced through visual training<sup>13</sup> reduce these movements on the retina by improving the optic flow and the accuracy of information to the vestibular and somatosensory systems, a mechanism that allows the central nervous system to regulate muscle tone and maintain the center of mass within the base of support, enabling visual and postural stability<sup>6</sup>. Given the importance of the visual system in the triad with the vestibular and proprioceptive systems for improved balance, training the visual-vestibular system through oculomotor exercises has been shown to improve postural stability and balance<sup>14,15</sup>. Few studies, however, have examined their effects in healthy athletic populations, as most prior research has focused on patients with static<sup>16</sup> or dynamic balance deficits<sup>17,18</sup>, employed a limited number of exercises<sup>14,19</sup> over short intervention periods<sup>17,20</sup>, or required participants to perform the exercises at home without supervision<sup>21</sup>, leaving adherence and correct execution uncontrolled. Consequently, further evidence is needed regarding the effectiveness of structured, supervised, multi-week oculomotor training programs on static balance in healthy athletes.

The present study aims to evaluate the effectiveness of a comprehensive, personally supervised oculomotor exercise program on static balance in healthy athletes. By extending previous findings to athletes practicing basketball, football, and boxing<sup>13</sup>, the study further explores whether balance adaptations following the intervention are influenced by sex, type of sport, and duration of sport participation<sup>22</sup>.

## Materials and Methods

### Study design

This is a randomized controlled study conducted in 2024–2025 with pre- and post-intervention measurements, aiming to evaluate the effects of an oculomotor exercise protocol on balance performance in athletes. The study was designed as a repeated-measures trial with two groups (experimental and control) and two assessment points, pre- and post-intervention. A priori sample size and statistical power calculations were performed using G\*Power software<sup>23</sup> (version 3.1.9.7). Based on previous oculomotor training research in healthy adults<sup>24</sup>, a medium effect size was assumed. With an alpha level of 0.05 and 80% statistical power, a total of 128 participants, 64 per group was required to detect meaningful differences between groups and across assessments.

### Participants recruitment and flow

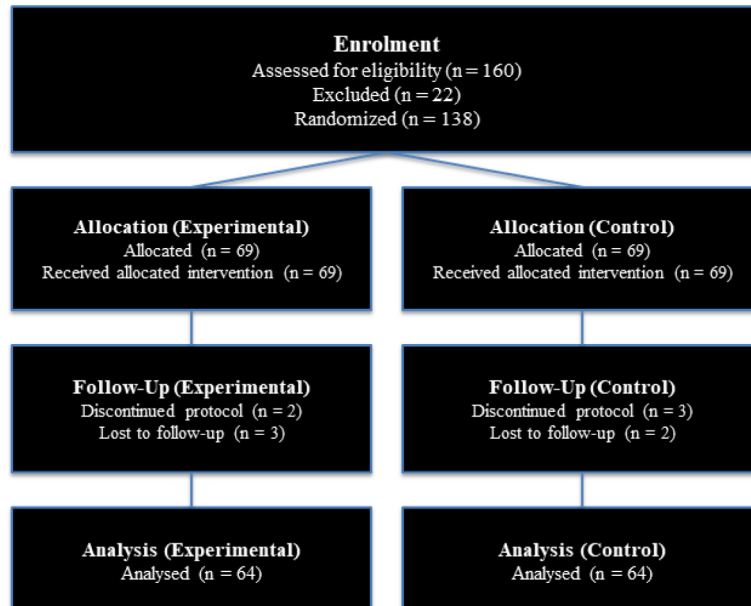
A total of 160 athletes were initially assessed for eligibility. Of these, 22 were excluded because they did not meet the inclusion criteria, leaving 138 athletes who were randomized into the study. The included participants were male and female athletes aged 15–30 years, recruited from basketball, football, and boxing disciplines. They were either students of the University of Sports of Tirana and members of the respective university sports clubs, or athletes who regularly trained at the University of Sports of Tirana facilities and were also affiliated with their respective sports clubs. These sports were selected because they are among the most represented and structurally organized at the university, allowing close supervision of the intervention and providing a relatively homogeneous training background. Furthermore, basketball, football, and boxing place substantial demands on postural control, unilateral stance, and visual-vestibular integration. During the intervention, five participants withdrew due to personal reasons or inability to complete the training protocol, and five participants did not attend the post-intervention assessment, resulting in 128 participants included in the final per-protocol analysis. All participants included in the final analysis completed the prescribed training sessions (five sessions per week for six weeks, 10 minutes per session), ensuring adherence to the intervention protocol. Participant progression, including recruitment, exclusions, withdrawals, and inclusion in the final analysis, is presented in the CONSORT flow diagram (Figure 1).

#### The inclusion criteria were:

- Age 15–30 years, as visual acuity develops between the ages of 5 and 15 years<sup>25</sup>, while the perception of object movement continues to develop beyond adolescence<sup>26</sup>.
- Be engaged in the relevant sports disciplines for a minimum of 12 months, a time considered sufficient for a sports specialization<sup>27</sup>.
- Healthy subjects without cardiorespiratory, psychological, vestibular, or oncological pathologies, as verified by self-declaration (Questionnaire, which is available as supplementary material) and their health booklet.
- Training in the relevant disciplines 5x/week.
- Having a visual acuity of 20/20 after testing, with or without glasses/contact lenses.

#### The exclusion criteria were:

- Subjects with vertigo symptoms, with divergent/convergent strabismus.
- Subjects with cardiorespiratory, psychological, vestibular, or oncological problems.
- Athletes under the age of 15.
- Subjects with injury in the last 12 months that required medical attention, concussion, and cognitive deficits.



**Figure 1.** CONSORT flow diagram illustrating participant recruitment, allocation, follow-up, and analysis. A total of 160 athletes were assessed for eligibility, of whom 22 were excluded for not meeting the inclusion criteria. The remaining 138 athletes were randomized equally into two groups (n = 69 per group). In the experimental group (EG), 2 participants discontinued the intervention and 3 were lost to follow-up. In the control group (CG), 3 participants discontinued and 2 were lost to follow-up. The remaining participants completed the study and were included in the final analysis (EG, n = 64; CG, n = 64).

### Randomisation and allocation

Participants were randomly allocated to the study groups using a pre-prepared random allocation sequence. The sequence was generated in advance by an independent therapist who was blinded to the study protocol and not involved in participant recruitment, assessment, or intervention delivery. Block randomization (blocks of 4) was used to ensure balanced group sizes. Allocation concealment was ensured using sequentially numbered, opaque, sealed envelopes. The envelopes were prepared prior to participant enrollment, were tamper-proof, and were opened sequentially only after a participant had been formally enrolled. Participants were enrolled by the study investigators, while group assignment was performed by the independent blinded therapist, ensuring separation between sequence generation, enrollment, and allocation. Outcome assessors were blinded to group assignment.

- The Experimental Group (EG) performed the oculomotor exercise protocol described below, along with their usual training.
- The Control Group (CG) continued the usual exercise routine without additional interventions.

### Materials and procedures

#### Screening

All subjects underwent several tests such as the visual acuity test<sup>28</sup>, visual field perimeter testing, specifically the confrontation test<sup>29</sup> to exclude peripheral vision impairments. To exclude the possibility of vestibular problems, we used the Dix-Hallpike maneuver<sup>30</sup>, as such issues could alter the subjects' performance during and after the training protocol. Subjects then completed a questionnaire formulated by V.SH and A.L. The questionnaire consisted of questions related to athletes' training experience, daily training hours, additional physical activity, medication use, sleep patterns, cardiovascular and other medical conditions, as well as symptoms such as dizziness or nausea. This questionnaire was distributed for evaluation to a sports doctor, a physiotherapist, a coach, and an athlete, each with over five years of experience. After reviewing their suggestions, the questionnaire was approved and piloted in its final form on five athletes. Based on their feedback, the final form was approved.

#### Measurements

After completing the questionnaire, measurements and evaluations of general anthropometric parameters

(weight, height, BMI), the dominant leg, and static balance were performed. Height was measured to the nearest 0.5 cm using a stadiometer (Health O meter® Professional Scales, Illinois, SHBA) with participants standing barefoot and upright. Dominant leg was determined based on a previous study<sup>31</sup>, which identifies the preferred leg for performing single-leg tasks such as kicking a ball. Body weight and static balance was assessed using the Leonardo Mechanograph GRFP STD device (Novotec Medical GmbH, Pforzheim, Germany), a reliable tool for quantifying postural control across different age groups<sup>32</sup>. Two key parameters were recorded during the one-leg stance test: ellipse area (StdEIA, cm<sup>2</sup>) and sway velocity (mm/s). The ellipse area (cm<sup>2</sup>) represents the 95% confidence ellipse of the center of pressure (COP) trajectory, containing approximately 95% of the COP points recorded during the trial<sup>33</sup>. Smaller ellipse area (cm<sup>2</sup>) values indicate less postural sway and better balance performance. The sway velocity (mm/s) quantifies the total distance traveled by the COP per unit time. Higher sway velocity (mm/s) values indicate greater postural adjustments and reduced stability, whereas lower values reflect a more stable stance. Together, these metrics provide complementary information about static balance, with ellipse area (cm<sup>2</sup>) capturing the overall sway magnitude and sway velocity (mm/s) reflecting the speed of postural corrections<sup>34</sup>.

The one-leg stance test was performed barefoot on both legs, with participants tested separately on the dominant and non-dominant leg. The non-supporting leg was held in hip extension (approximately neutral to slight extension) and knee flexion (~90°) to prevent contact with the supporting leg, while the arms were maintained in the anatomical position<sup>35</sup>. Each participant completed a familiarization trial prior to formal testing. A single trained assessor, blinded to group allocation and timepoint, initiated the Leonardo test and provided scripted verbal instructions to maintain balance. Each condition, eyes open (EO) and eyes closed (EC), lasted 10 seconds as automatically timed by the Leonardo platform and was repeated three times per leg, with 30 seconds of rest between trials to prevent fatigue<sup>36</sup>. The average of three trials per condition was used for analysis. All assessments were conducted in the afternoon to minimize diurnal variations in postural control<sup>37</sup>.

Another test used to assess balance was the Stork test (s)<sup>38</sup> performed on the dominant leg. Participants were instructed on proper procedure and posture: the untested foot was placed against the side of the tested kneecap, hands on hips, and trunk upright with a forward gaze. On the assessor's standardized command "go," participants raised the heel of the tested leg to stand on their toes and attempted to maintain this position for as long as possible. Timing was recorded manually using a stopwatch and ended when the tested heel touched the ground or the untested foot moved away from the kneecap. Each participant performed three trials, with the mean time used for analysis. The test was administered by a single

trained assessor blinded to group allocation and timepoint, following scripted instructions and pre-specified stopping rules to minimize detection bias. Balance performance was categorized using the following standardized scale for Stork test standing time (s): Poor (< 20 s), Fair (20-29 s), Average (30-39 s), Good (40-49 s), Excellent (≥ 50 s). This categorization was applied consistently across all tables and text<sup>39</sup>. The categorization of the Stork test (s) before and after the intervention provides an overview of the shifts of participants across these Likert scale categories. All measurements were performed before (Week 0) and after the study protocol was incorporated (Week 6). During the period between the first and final measurements, all subjects were instructed to maintain the same training routine without additions, changes in intensity or new training programs, to avoid interfering factors that could affect the study's results.

#### *Exercise protocol and its implementation*

The oculomotor exercise protocol is based on the package of 6 exercises used in a previous study<sup>40</sup>. It includes eye stretching exercise, tracking (smooth pursuit exercises, horizontal and vertical), gaze stabilization, spatial localization, saccades, vergence and convergence exercises an effective exercise for balance<sup>41</sup>. The exercise protocol was conducted over a six-week period, with one session per day, five sessions per week, for a total of 30 sessions. Each session lasted 10 minutes and aimed to improve balance, while participants continued their regular sport practice routines throughout the study period. The exercises were performed in the afternoon before their sport training sessions. Multiple sessions within the same day were not permitted. All exercises were performed in a distraction-free environment, with each participant supervised individually by a licensed physiotherapist. Participants performed the exercises barefoot. In the first four weeks, oculomotor exercises were performed in a bipedal stance. In the final two weeks, exercises were progressed to a single-leg stance on the dominant leg, performed on a 10-mm-thick rubber mat to provide additional sensory stimulation<sup>42</sup>. This progression was implemented to promote greater improvements in balance<sup>43</sup> and to increase the challenge to the vestibular system<sup>44</sup>. Adherence to the intervention was monitored throughout the study. Participants who did not complete the full protocol were documented in the study flowchart, while all remaining participants completed all prescribed training sessions.

#### **Statistical Analysis**

Continuous variables are reported as mean ± SD and categorical variables as n (%). Baseline comparability between groups is described using standardized differences (Hedges' g for continuous variables and standardized differences in proportions for categorical

**Table 1.** Baseline Characteristics and Between-Group Standardized Differences.

Variable	Overall (n = 128)	Control group (n = 64)	Experimental group (n = 64)	Standardized difference
Sex (female), n (%)	31 (24.22%)	17 (26.56%)	14 (21.87%)	-0.11
Sport type (overall), n (%)				V = 0.40
o Basketball, n (%)	35 (27.34%)	14 (21.87%)	21 (32.81%)	0.25
o Football, n (%)	56 (43.75%)	20 (31.25%)	36 (56.25%)	0.50
o Boxing, n (%)	37 (28.91%)	30 (46.87%)	7 (10.94%)	-0.79
Age (years)	19.37 ± 2.28	19.05 ± 2.45	19.69 ± 2.07	0.28
Weight (kg)	74.31 ± 14.05	74.03 ± 14.95	74.58 ± 13.19	0.04
Height (m)	1.77 ± 0.09	1.76 ± 0.08	1.78 ± 0.09	0.21
BMI (kg/m <sup>2</sup> )	23.69 ± 3.67	23.83 ± 3.94	23.56 ± 3.41	-0.07
Weekly training (hours/week)	9.36 ± 2.22	9.38 ± 1.89	9.34 ± 2.53	-0.02
Years of sports' experience	6.06 ± 3.81	5.77 ± 3.89	6.35 ± 3.74	0.15
Stork test time (s)	19.16 ± 8.63	20.08 ± 6.33	18.23 ± 10.40	-0.21
Sway velocity LLEO (mm/s)	62.07 ± 16.48	62.09 ± 14.19	62.06 ± 18.61	-0.00
Sway velocity LLEC (mm/s)	110.76 ± 37.32	106.89 ± 40.31	114.64 ± 33.94	0.21
Sway velocity RLEO (mm/s)	59.08 ± 16.41	57.75 ± 14.78	60.42 ± 17.91	-0.16
Sway velocity RLEC (mm/s)	113.44 ± 32.64	110.09 ± 33.02	116.79 ± 32.16	0.20
Ellipse area LLEO (cm <sup>2</sup> )	5.54 ± 2.86	5.40 ± 2.58	5.67 ± 3.14	0.09
Ellipse area LLEC (cm <sup>2</sup> )	20.68 ± 21.27	17.19 ± 16.00	24.17 ± 25.12	0.33
Ellipse area RLEO (cm <sup>2</sup> )	5.84 ± 3.67	5.74 ± 3.17	5.94 ± 4.12	0.05
Ellipse area RLEC (cm <sup>2</sup> )	24.79 ± 17.36	26.54 ± 13.14	23.04 ± 20.71	-0.20

Continuous variables are presented as mean ± SD; categorical variables as n (%). Standardized differences are Hedges' g for continuous variables and standardized differences in proportions for binary/categorical levels. Sport overall effect size is Cramér's V. Abbreviations: LL: left leg; RL: right leg; EO: eyes open; EC: eyes closed.

variables); sport type imbalance is summarized using Cramér's V.

The primary estimand was the baseline-adjusted between-group mean difference (experimental minus control: EG-CG) at Week 6 for each co-primary outcome: (1) Stork test standing time (s) and (2) dominant-leg, eyes-open (EO) ellipse area (cm<sup>2</sup>). Primary treatment effects were estimated using baseline-adjusted ANCOVA, with the Week 6 value as the dependent variable, treatment group as a fixed factor, and the corresponding Week 0 value as a covariate. Effects are reported as adjusted mean difference (MD; EG-CG) with 95% confidence intervals (CI) and p-values. To control family-wise error across the two co-primary outcomes, statistical significance was assessed at two-sided  $\alpha = 0.025$  (Bonferroni adjustment).

Standardized effects are reported as Hedges' g computed from unadjusted pre- and post-intervention change scores (Week 6-Week 0) comparing Experimental Group with Control Group; these standardized effects are provided to quantify magnitude, whereas statistical inference is based on the baseline-adjusted ANCOVA estimates. To mitigate multiplicity across instrumented postural-control outcomes, the dominant-leg EO ellipse area (cm<sup>2</sup>) was selected a priori as the primary mechanography endpoint.

All remaining ellipse-area (cm<sup>2</sup>) and sway-velocity (mm/s) outcomes were analyzed using the same ANCOVA framework, but were considered secondary/exploratory. Accordingly, no additional multiplicity adjustment was applied beyond the Bonferroni correction for the two co-primary outcomes, and p-values for secondary outcomes and subgroup interactions are reported for exploratory interpretation alongside effect sizes and CIs.

Prespecified subgroup moderation (sex, sport type, years of sport experience, weekly training volume) was assessed by adding a Group × subgroup interaction term to the baseline-adjusted ANCOVA model for each co-primary outcome. Interaction p-values tested whether the Week 6 treatment effect differed across subgroups, and partial eta squared ( $\eta^2p$ ) was reported as the interaction effect size; subgroup analyses were considered exploratory. Because a notable baseline imbalance in sport type was observed between groups, post hoc sensitivity ANCOVA analysis were additionally performed for both co-primary outcomes. For each sensitivity model, the Week 6 outcome was entered as the dependent variable, treatment group as a fixed factor, the corresponding Week 0 value as a covariate, and sport type and sex as additional fixed factors. These analyses were undertaken to assess

**Table 2.** Stork Test and the Primary Mechanography Endpoint (Dominant-Leg, Eyes-Open Ellipse Area): Descriptives and Baseline-Adjusted Treatment Effect.

Outcome	CG Week 0	CG Week 6	EG Week 0	EG Week 6	ANCOVA adjusted MD (EG-CG)	95% CI	p-value	Standardized treatment effect (Hedges' g, change)
Stork test (s)	20.08 ± 6.33 (n = 64)	19.87 ± 5.43 (n = 64)	18.23 ± 10.40 (n = 64)	40.76 ± 18.41 (n = 64)	22.82	19.54 to 26.10	<.001	2.39
Ellipse area (cm <sup>2</sup> ), dominant leg stance (EO)	5.42 ± 2.39 (n=64)	7.78 ± 3.53 (n=64)	6.15 ± 4.16 (n=64)	3.95 ± 2.51 (n=64)	-4.20	-5.10 to -3.30	<.001	-1.49

Values are mean ± SD (n) at baseline (Week 0) and Week 6. The oculomotor exercises effect was estimated using baseline-adjusted ANCOVA, reported as adjusted mean difference (MD) EG - CG, with 95% CI. Standardized treatment effect is Hedges' g computed from change scores (Week 6 - Week 0) (EG - CG). Abbreviations: EG: experimental group; CG: control group, EO: eyes open.

**Table 3.** Subgroup Moderation Analyses (Group × Moderator Interaction).

Moderator	Outcome	Interaction p values	η <sup>2</sup> p
Sex (male/female)	Stork test (s)	0.264	0.010
Sex (male/female)	Dominant-leg EO ellipse area (cm <sup>2</sup> )	0.611	0.002
Sport	Stork test (s)	0.048	0.049
Sport	Dominant-leg EO ellipse area (cm <sup>2</sup> )	0.637	0.007
Years of sport experience	Stork test (s)	0.694	0.006
Years of sport experience	Dominant-leg EO ellipse area (cm <sup>2</sup> )	0.824	0.003
Weekly training (hours/week)	Stork test (s)	0.736	0.001
Weekly training (hours/week)	Dominant-leg EO ellipse area (cm <sup>2</sup> )	0.836	0.0004

Abbreviations: EO: eyes open; η<sup>2</sup>p: partial eta squared.

whether the primary treatment estimates were robust to between-group differences in baseline sport composition. Sensitivity results are reported as adjusted mean differences (MD; EG-CG) with 95% confidence intervals (CI) and p-values.

Model assumptions were assessed using residual and Q-Q plots to evaluate normality and homoscedasticity. Robustness was examined using nonparametric bootstrap resampling (2000 samples) with bias-corrected and accelerated confidence intervals. Analyses were performed in IBM SPSS Statistics v26.0 (IBM Corp., Armonk, NY, USA).

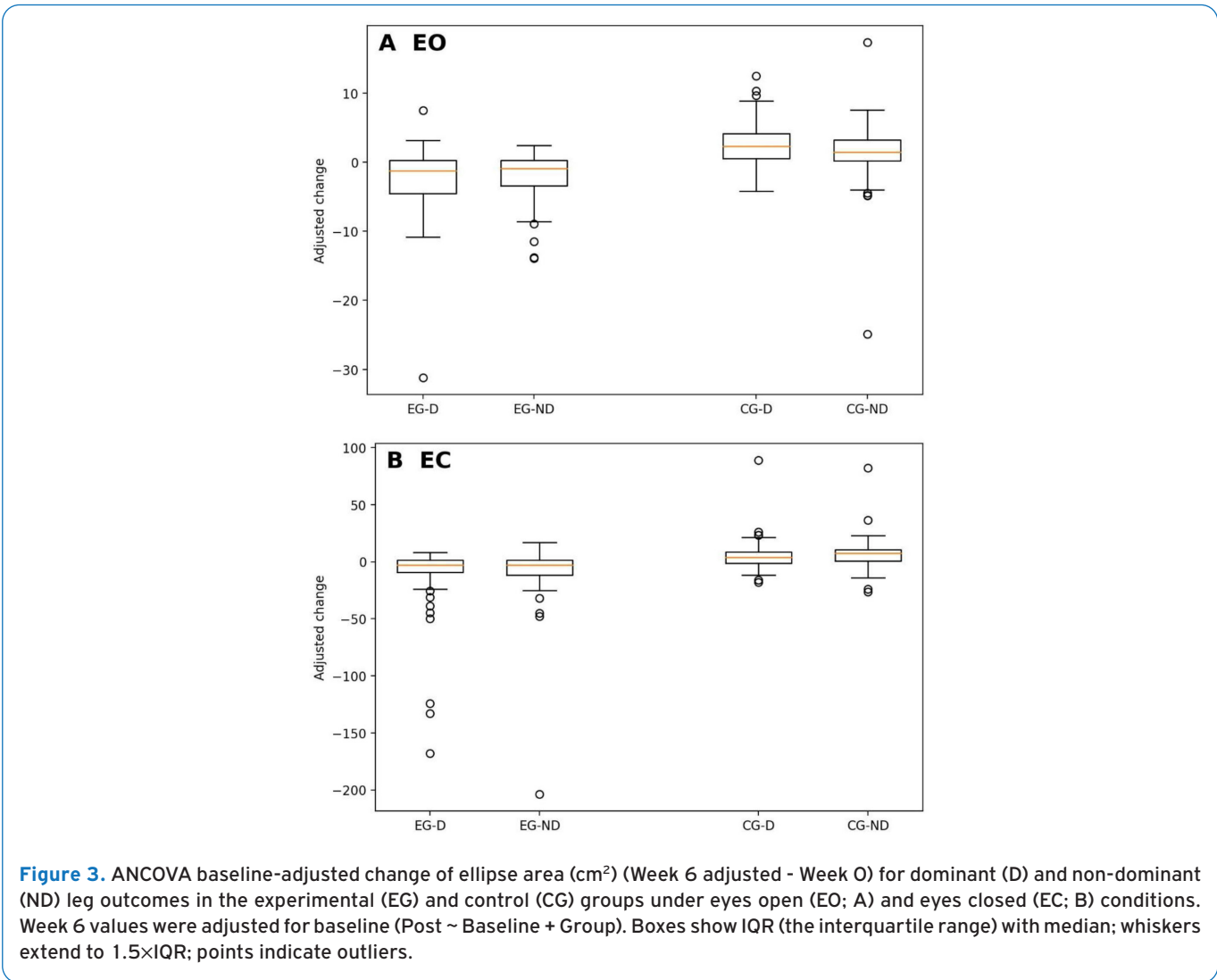
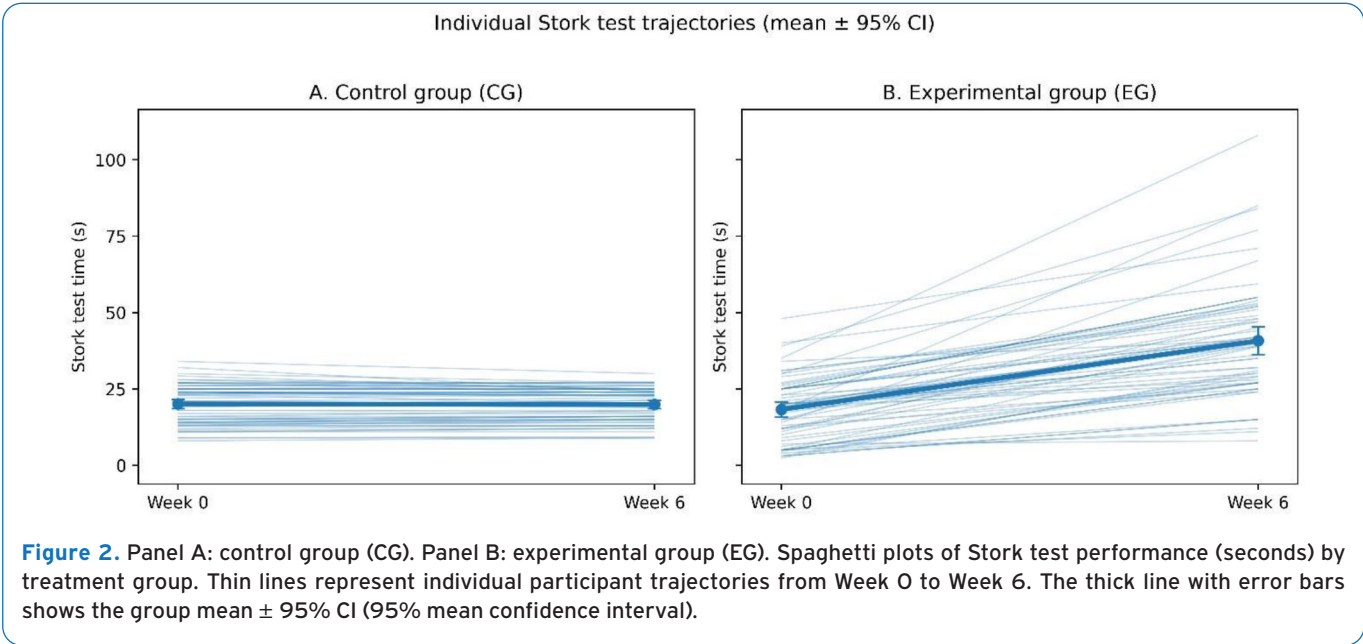
## Results

A total of 128 participants were included (mean age 19.41 ± 2.55 years; range 15-30), of whom 31 (24.22%) were female. Participants were members of basketball (n

= 35, 27.34%), boxing (n = 37, 28.91%), and football (n = 56, 43.75%) clubs. Baseline characteristics by group are presented in Table 1. Standardized differences indicated small/negligible imbalances for most variables, with the largest baseline imbalance observed for sport type (Cramér's V = 0.40).

Co-primary outcome results are shown in Table 2. The experimental group demonstrated substantially greater improvement in Stork test standing time (s) from baseline to Week 6 than the CG (adjusted mean difference (MD) [EG - CG] = 22.82 s, 95% CI: 19.54 - 26.10; p < .001), meeting the Bonferroni-adjusted threshold. The standardized effect size based on change scores was very large (Hedges' g = 2.39). Bootstrap resampling indicated stable ANCOVA estimates (2000 samples: 95% CI: 19.64 - 26.26), and diagnostic plots showed no major departures from normality or homoscedasticity.

For the dominant-leg EO ellipse area (cm<sup>2</sup>), baseline-



**Table 4.** BSPI/ASPI Descriptives and Oculomotor Exercises Effects Across Stance Conditions A: Ellipse Area Outcomes (cm<sup>2</sup>); B: Sway Velocity Outcomes (mm/s).

Condition	CG Week 0	CG Week 6	EG Week 0	EG Week 6	ANCOVA Adj. MD (EG-CG)	95% CI	Std effect (Hedges' g)
<b>A: Ellipse area outcomes (cm<sup>2</sup>)</b>							
LLEO	5.40 ± 2.58 (n=64)	7.21 ± 3.96 (n=64)	5.67 ± 3.14 (n=64)	3.46 ± 1.77 (n=64)	-3.90	-4.81 to -2.99	-1.40
LLEC	17.19 ± 16.00 (n=64)	21.71 ± 20.42 (n=64)	24.17 ± 25.12 (n=64)	13.73 ± 8.88 (n=64)	-10.83	-15.53 to -6.13	-0.82
RLEO	5.74 ± 3.17 (n=64)	7.80 ± 3.39 (n=64)	5.94 ± 4.12 (n=64)	3.94 ± 2.61 (n=64)	-3.94	-4.87 to -3.01	-1.17
RLEC	26.54 ± 13.14 (n=64)	32.60 ± 17.63 (n=64)	23.04 ± 20.71 (n=64)	13.49 ± 8.62 (n=64)	-17.70	-21.92 to -13.47	-0.98
<b>B: Sway velocity outcomes (mm/s)</b>							
LLEO	62.09 ± 14.19 (n=64)	71.21 ± 17.67 (n=64)	62.06 ± 18.61 (n=64)	60.29 ± 21.31 (n=64)	-10.90	-17.22 to -4.59	-0.54
LLEC	106.89 ± 40.31 (n=64)	124.89 ± 45.95 (n=64)	114.64 ± 33.94 (n=64)	101.87 ± 33.71 (n=64)	-27.35	-39.53 to -15.17	-0.80
RLEO	57.75 ± 14.78 (n=64)	73.25 ± 18.71 (n=64)	60.42 ± 17.91 (n=64)	57.25 ± 17.97 (n=64)	-17.69	-23.01 to -12.37	-1.14
RLEC	110.09 ± 33.02 (n=64)	135.15 ± 38.35 (n=64)	116.79 ± 32.16 (n=64)	101.93 ± 37.33 (n=64)	-37.95	-48.56 to -27.33	-1.26

Values are mean ± SD (n) for baseline (Week 0) and Week 6. The primary model is baseline-adjusted ANCOVA (Week 6 as dependent variable; group as fixed factor; Week 0 as covariate), reporting adjusted mean difference (MD) as EG-CG with 95% CI. Secondary outcomes are exploratory; 95% confidence intervals: CI are presented without multiplicity adjustment. Standardized treatment effects are reported as Hedges' g based on change scores (EG-CG). Abbreviations: EG-experimental group; CG: control group; LL: left leg; RL: right leg; EO: eyes open; EC: eyes closed.

adjusted ANCOVA showed a significant between-group effect favouring the EG (adjusted MD [EG-CG] = -4.20 cm<sup>2</sup>, 95% CI: -5.10 to -3.30;  $p < .001$ ), also meeting the Bonferroni-adjusted threshold. The standardized effect based on change scores was large (Hedges'  $g = -1.49$ ), consistent with improved postural stability (lower values indicate better stability).

Individual Stork test standing time (s) trajectories from Week 0 to Week 6 are presented in Figure 2. Thin lines represent individual participant trajectories; the thick line shows the group mean with 95% CI.

Transitional (ordinal) analysis of Stork ranking (Table S1.) showed minimal category shifts in the CG, but substantial upward transitions in the EG. Within-group marginal homogeneity assessed by the Stuart-Maxwell test indicated a significant change in marginal distributions over time in the experimental group ( $\chi^2(4) = 54.77$ ,  $p < .001$ ), but not in the control group ( $\chi^2(4) = 3.00$ ,  $p = 0.558$ ). This analysis was exploratory and is provided as supportive evidence of improved performance distribution.

Subgroup moderation analyses (Table 3) showed no evidence of effect modification by sex, years of sport experience, or weekly training volume for either co-

primary outcome (all interaction  $p > 0.26$ ;  $\eta^2 p \leq 0.010$ ). A group and sport interaction was observed for the Stork test time (s) ( $p = 0.048$ ;  $\eta^2 p = 0.049$ ), suggesting modest variation in response across sport categories; no corresponding interaction was observed for dominant-leg EO ellipse area (cm<sup>2</sup>) ( $p = 0.637$ ;  $\eta^2 p = 0.007$ ). Subgroup findings are exploratory.

Given the observed baseline imbalance in sport type, post hoc sensitivity ANCOVA models were fitted for both co-primary outcomes with additional adjustment for sport type and sex. The treatment estimates remained materially unchanged. For the Stork test, the adjusted mean difference (EG-CG) was 23.40 s (95% CI: 19.79 - 27.01;  $p < .001$ ). For dominant-leg eyes-open ellipse area, the adjusted mean difference was -4.35 cm<sup>2</sup> (95% CI: -5.34 to -3.35;  $p < .001$ ). These findings support the robustness of the main treatment effects despite the baseline imbalance in sport composition.

Dominant and non-dominant leg responses under EO and EC conditions for ellipse area (cm<sup>2</sup>) were explored using baseline-adjusted ANCOVA-derived adjusted changes, visualised in Figure 3. Across EO and EC testing, adjusted-change distributions were broadly similar for dominant and non-dominant legs within each group, providing no

clear evidence that leg dominance materially altered the response pattern to the intervention regarding the ellipse surface area (cm<sup>2</sup>).

Secondary mechanography outcomes are summarised in Table 4. Across stance conditions, estimates generally favoured the EG and were directionally consistent with the co-primary findings; however, these analyses are exploratory and are presented to describe the broader pattern of postural-control changes rather than to support confirmatory inference.

## Discussion

This study showed that a 6-week oculomotor exercise program may be consistent with changes in sensory contribution to postural control; however, sensory integration mechanisms were not directly measured in this study, and the results should be interpreted with caution. The recent study demonstrated that after completing the 6-week oculomotor exercise protocol, the Stork test standing time (s) increased significantly, while the ellipse area (cm<sup>2</sup>) during dominant-leg stance with EO decreased. In contrast, the CG showed no changes in balance levels between the pre- and post-study protocol implementation. This trend supports the idea that activation and training of the visual system play an important role in balance optimization, consistent with previous findings<sup>18,20</sup>.

Beyond the effect of oculomotor exercises on balance, it is also important to explore factors that may influence postural control following oculomotor training. Previous studies have suggested that sex-related differences may affect postural control<sup>45</sup> and sensorimotor integration<sup>46</sup>.

In the present study, sex did not modify the effect of the intervention on either Stork test standing time (s) or dominant-leg EO ellipse area (cm<sup>2</sup>), as no statistically significant Group  $\times$  Sex interactions were observed. The recent findings should be interpreted with caution, as the study was not designed to control for hormonal status, menstrual cycle phase, or pubertal stage. Consequently, the absence of observed sex-related differences in this sample does not preclude the existence of underlying biological influences on balance performance, as previously suggested in the literature<sup>47</sup>. Future studies incorporating appropriate hormonal and maturational controls are therefore warranted.

On the other hand, some authors have concluded that athletes with more years of sports experience or longer training duration<sup>48</sup> may have better postural control, and it varies between sports disciplines<sup>49,50</sup>. Theoretically, this could modify the effect of oculomotor training, but contrary to these findings, our study showed no significant correlation between the outcomes of oculomotor training and the number of hours spent weekly in the athlete's training. Moreover, athletes with more years of experience in their respective sports, such as basketball, football, and boxing, did not achieve higher balance test scores than

those with fewer years of experience. Previous research<sup>51</sup> also corroborates these results.

Different sports vary significantly in postural demands and differ in balance performance. In sports with high balance demands, such as gymnastics or martial arts, equilibrium is better than in basketball and football players<sup>52</sup>; however, football players demonstrate better balance, especially in anterior-posterior and horizontal sway, compared to basketball players<sup>53,54</sup>. Similarly, boxers show slightly better balance compared to football players<sup>55</sup>, whereas compared to basketball players, boxers demonstrate better balance in rightward body orientation, suggesting that each sport affects specific balance parameters differently.

The current study observed a Group  $\times$  Sport interaction for Stork test time (s), suggesting modest variation in response across sport categories. In contrast, no significant differences were found across sports regarding the Leonardo platform's ellipse area (cm<sup>2</sup>) on dominant-leg EO stance. This pattern may be consistent with shared visual/vestibular contributions to postural control across sports; mechanistic pathways (e.g., sensory reweighting) were not directly assessed and should be examined in future studies<sup>19,56</sup>. In this study, the aim of switching to oculomotor exercises during single-leg stance in the last two weeks of the protocol was to challenge the vestibular system, since unipedal stance increases vestibular input demand<sup>57,58</sup>. However, our data showed no relationship between the dominant leg stance during oculomotor exercises and better balance performance, both in EO and EC testing, confirming previous findings<sup>59,60</sup>. However, there is a gap in the literature regarding the role of oculomotor exercises during dominant or non-dominant leg stance in improving postural stability, which could provide opportunities for further research and structured experimentation among athletes.

This study demonstrates a significant relationship between oculomotor exercises and improvement in static balance, confirming the important role of this training in optimizing equilibrium and postural control. The results of this study may encourage modifications to traditional training sessions by adding oculomotor exercises as an integral part of the training plan, especially in football, basketball, and boxing, where balance is a crucial component for maximizing sports performance<sup>61</sup>.

Furthermore, this study has some limitations, including the lack of dynamic balance assessment alongside static balance and the lack of follow-up beyond the 6-week training period to evaluate the sustainability and duration of the effects of oculomotor exercises on static and dynamic balance. Although the sample included athletes from different sports disciplines, the findings may not be generalizable to all athletic populations or to sports with different balance and visual-vestibular demands. Future studies should incorporate dynamic balance assessments, longer follow-up periods, broader sport representation, and larger sample sizes to enhance generalizability. The

relatively low proportion of female athletes in the sample (24.22%) represents a limitation of the study. However, this reflects the current sex distribution in organized competitive sports in Albania<sup>62</sup>, particularly within the selected disciplines, rather than a methodological exclusion of female participants. Future study should prioritize the inclusion of sports with higher female participation to improve gender balance and strengthen the generalizability of the findings.

## Conclusions

Oculomotor exercises may represent a promising approach for improving static balance in athletes practicing football, basketball, and boxing over a 6-week intervention period. In this short-term per-protocol trial, improvements were observed in the measured static balance outcomes, whereas the underlying sensory mechanisms were not directly assessed. Although the protocol required minimal time and physical effort, its feasibility within routine athletic training should be further evaluated. Longer-term follow-up and preventive outcomes were not assessed in this study.

### Ethics approval

*This study was approved by the Ethics Committee of University of Sports of Tirana, protocol number Prot. No. 3373/1. All procedures were conducted in accordance with the Declaration of Helsinki 1964 and its later amendments, and all data were anonymous.*

### Consent to participate

*Written informed consent was obtained from all participants prior to their inclusion in the study. For participants aged 15–17 years, assent was obtained from the minor and written consent was obtained from a parent or legal guardian. Participants aged 18 years or older provided their own written consent.*

### Authors' contributions

*A.L. led the study conception, design, data acquisition, analysis, interpretation, drafted the manuscript, approved the final version, and takes full responsibility for the work. V.SH. contributed to study conception and design, data analysis and interpretation, critically revised the manuscript, approved the final version, and takes full responsibility for all aspects of the work.*

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## Supplementary Materials

**Table S1.** Transitional Table for Stork Test Categorization by Group (Before Study Implementation Protocol to After Study Protocol Implementation: Weeks 0 To 6); A: Control Group, B: Experimental Group.

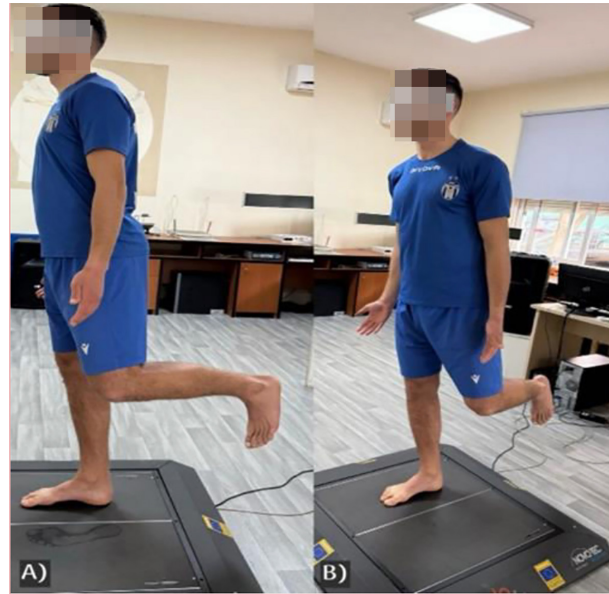
A: Control group (n = 64)					
Week 0 /Week 6	Poor	Fair	Average	Good	Excellent
Poor	4 (6.2%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Fair	0 (0.0%)	42 (65.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Average	0 (0.0%)	3 (4.7%)	15 (23.4%)	0 (0.0%)	0 (0.0%)
Good	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Excellent	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
B: Experimental group (n = 64)					
Week 0 /Week 6	Poor	Fair	Average	Good	Excellent
Poor	1 (1.6%)	6 (9.4%)	8 (12.5%)	1 (1.6%)	0 (0.0%)
Fair	0 (0.0%)	1 (1.6%)	13 (20.3%)	10 (15.6%)	4 (6.2%)
Average	0 (0.0%)	0 (0.0%)	0 (0.0%)	8 (12.5%)	11 (17.2%)
Good	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (1.6%)
Excellent	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)

*Cells show n (%), where percentages are calculated within each group total. Within-group marginal homogeneity was assessed using the Stuart-Maxwell test (Control:  $\chi^2(4) = 3.00, p = 0.558$ ; Experimental:  $\chi^2(4) = 54.77, p < .001$ ).*

**Table S2.** Baseline-Adjusted Estimated Marginal Mean Change (Week 6 - Week 0) in Co-Primary Outcomes by Sport and Treatment Group (ANCOVA; Group  $\times$  Sport Interaction Tested).

Outcome	Sport	Control Group	Experimental Group
Stork test time change (Week 6-Week 0, s)	Basketball	-0.40 (-5.19, 4.40)	16.49 (12.47, 20.51)
Stork test time change (Week 6-Week 0, s)	Boxing	-0.07 (-3.35, 3.22)	27.46 (20.67, 34.24)
Stork test time change (Week 6-Week 0, s)	Football	-0.48 (-4.50, 3.53)	25.18 (22.19, 28.18)
Dominant leg EO ellipse area change (Week 6-Week 0, cm <sup>2</sup> )	Basketball	1.77 (0.42, 3.13)	-2.04 (-3.16, -0.92)
Dominant leg EO ellipse area change (Week 6-Week 0, cm <sup>2</sup> )	Boxing	1.85 (0.92, 2.77)	-2.50 (-4.42, -0.59)
Dominant leg EO ellipse area change (Week 6-Week 0, cm <sup>2</sup> )	Football	2.97 (1.83, 4.11)	-1.92 (-2.76, -1.08)

*A significant Group  $\times$  Sport interaction was observed for Stork change ( $p = 0.048, \eta^2p = 0.049$ ), whereas no interaction was detected for dominant-leg eyes-open ellipse area change ( $p = 0.637, \eta^2p = 0.007$ ).*



**Figure S1.** Demonstration of the one-leg stance test performed on the Leonardo Mechanograph platform measuring sway area ( $\text{cm}^2$ ) and sway velocity ( $\text{mm/s}$ ). Panel A shows the testing position primarily from a lateral view. Panel B presents an anterolateral view of the same position, allowing clearer visualization of hip (coxafemoral) extension of the non-supporting limb.



**Figure S2.** Demonstration of the Stork Balance Test (s) on the dominant leg: (A) anterior plane view and (B) lateral plane view