BALNEO RESEARCH Balneo and PRM Research Journal
English Edition
e ISSN 2734 - 8458 p ISSN 2734 - 844X ROMANIAN ASSOCIATION OF BALNEOLOGY

Research article

Impact of Proprioceptive Strengthening Exercise on Neurotrophic Biomarkers and Dynamic Balance in Speed Skaters

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Citation: Arti W., Sari G.M., Qorib M.F., Putra H.L., Suprianto, Nugroho P.S., Abdillah O.Z. - Impact of Proprioceptive Strengthening Exercise on Neurotrophic Biomarkers and Dynamic Balance in Speed Skaters
Balneo and PRM Research Journal ***2026****, 17(1): 1005*

Academic Editor(s):
Constantin Munteanu

Reviewer Officer:
Viorela Bembea

Production Officer:
Camil Filimon

Received: 16.01.2026
Published: 31.03.2026

Reviewers:
Sebastian Giuvara
Corina Sporea

Publisher's Note: Balneo and PRM Research Journal stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Abstract: This study investigated the impact of proprioceptive-strengthening exercise on neurotrophic biomarkers and dynamic balance in adolescent speed skaters, addressing the need for evidence-based training strategies to enhance neuromuscular adaptation. A randomized pretest–posttest control group design was applied to 30 athletes aged 11–15 years, divided equally into intervention and control groups. The intervention group performed proprioceptive-strengthening exercises three times per week for eight weeks, whereas the control group continued routine training. Blood samples were analyzed for irisin and brain-derived neurotrophic factor (BDNF), and dynamic balance was assessed using single-leg squat (SLS) and overhead squat (OHS) tests. The intervention group showed a significant increase in irisin compared to controls ($\Delta = 157.93$ ng/mL vs. 56.42 ng/mL, $p < 0.05$). BDNF increased numerically ($\Delta = 179.73$ pg/mL) but did not reach statistical significance ($p = 0.107$). Dynamic balance outcomes revealed selective improvements, particularly in trunk control during SLS and OHS. Correlation analysis indicated a moderate, significant association between irisin and dynamic balance in SLS ($r = 0.508$, $p = 0.004$), whereas BDNF did not correlate with balance measures. Proprioceptive-strengthening exercise effectively enhanced irisin and dynamic balance, irisin as a potential biomarker for neuromuscular adaptation in speed skaters.

Keywords: Irisin, Brain-Derived Neurotrophic Factor (BDNF), Proprioceptive exercise, Strengthening exercise, Dynamic balance, Speed skaters, Neurotrophic biomarkers, Neuromuscular adaptation

1. Introduction

Maintaining dynamic balance and neuromuscular stability is essential for athletes in sports requiring rapid directional changes, such as speed skating. Instability of the ankle joint and insufficient neuromuscular control are recognized risk factors for performance decline and injury in adolescent athletes [1,2]. Exercise interventions that integrate proprioceptive stimulation and muscle strengthening have been proposed as effective strategies to enhance postural control, reduce injury risk, and improve athletic performance [3].

Recently, attention has shifted toward the role of myokines and neurotrophic factors as biomarkers of exercise-induced adaptation [4,5]. Irisin, a myokine cleaved from FNDC5, has been shown to increase following physical activity and is implicated in metabolic regulation, neuromuscular adaptation, and motor performance [6]. Similarly, brain-derived neurotrophic factor (BDNF) is a key mediator of neuroplasticity, synaptic function, and motor learning, with exercise reported to elevate circulating levels [7-9]. However, findings remain controversial: while some studies demonstrate significant increases in BDNF after neuromuscular or balance training [10], others report inconsistent or non-significant changes, particularly when exercise intensity or duration is moderate [11,12].

Proprioceptive exercise improves balance in youth skaters [2,13], yet the relationship between exercise-induced biomarker changes and functional outcomes remains poorly understood. Specifically, whether increases in irisin and BDNF correlate with improvements in dynamic balance is still debated. Diverging hypotheses that irisin may be more directly linked to neuromuscular adaptation, while BDNF responses may require higher-intensity or longer-duration training to manifest [6,14].

The present study evaluted the impact of an eight-week proprioceptive-strengthening exercise program on irisin, BDNF, and dynamic balance in adolescent speed skaters. Furthermore, it examined correlations between biomarker changes and balance performance. The principal findings indicate that irisin increased significantly and correlated with dynamic balance improvements, whereas BDNF showed non-significant changes and no correlation. These results highlight irisin as a potential biomarker of neuromuscular adaptation in speed skaters and suggest that BDNF may require different exercise stimuli to exert measurable effects.

2. Materials and Methods

2.1 Study design

This study was designed as a randomized controlled trial using a pretest–posttest control group framework. The trial was registered in the Indonesia Clinical Research Registry (INA-CRR) under the identifier INA-4832FDB (registration date: January 13, 2026). Ethical approval was obtained from the Faculty of Medicine, Universitas Airlangga (No. 145/EC/KEPK/FKUA/2024). Written informed consent was obtained from all participants and their parents before enrollment. The study was conducted in accordance with the Declaration of Helsinki and reported following the CONSORT guidelines [16].

2.2 Participants

Thirty adolescent speed skaters (aged 11–15 years; 15 males, 15 females) from local clubs in Sidoarjo, Indonesia, were recruited using simple random sampling. Inclusion criteria were: active club membership, age 11–15 years, ability to communicate and follow instructions, and parental consent. Exclusion criteria included: current participation in other rehabilitation programs, musculoskeletal injury or medical condition preventing training, or withdrawal of consent. Participants who missed ≥3 sessions or sustained injury during the program were considered dropouts.

Randomization and blinding Participants were randomly allocated (1:1) into intervention and control groups using a computer-generated random number sequence. Allocation was concealed using sequentially numbered, opaque envelopes prepared by an independent researcher. Due to the nature of the intervention, participants and trainers were not blinded. However, outcome assessors and data analysts were blinded to group allocation [16,17].

Sample size calculation Sample size was calculated using the formula for comparing two independent means with continuous data [18]. Assumptions included: standard deviation (σ) = 4.32, α = 0.05 ($Z\alpha/2$ = 1.96), power = 80% ($Z\beta$ = 0.84), and expected mean difference = 5. The required sample size was 12 per group. To account for potential dropout (20%), 15 participants were recruited per group, yielding a total sample of 30.

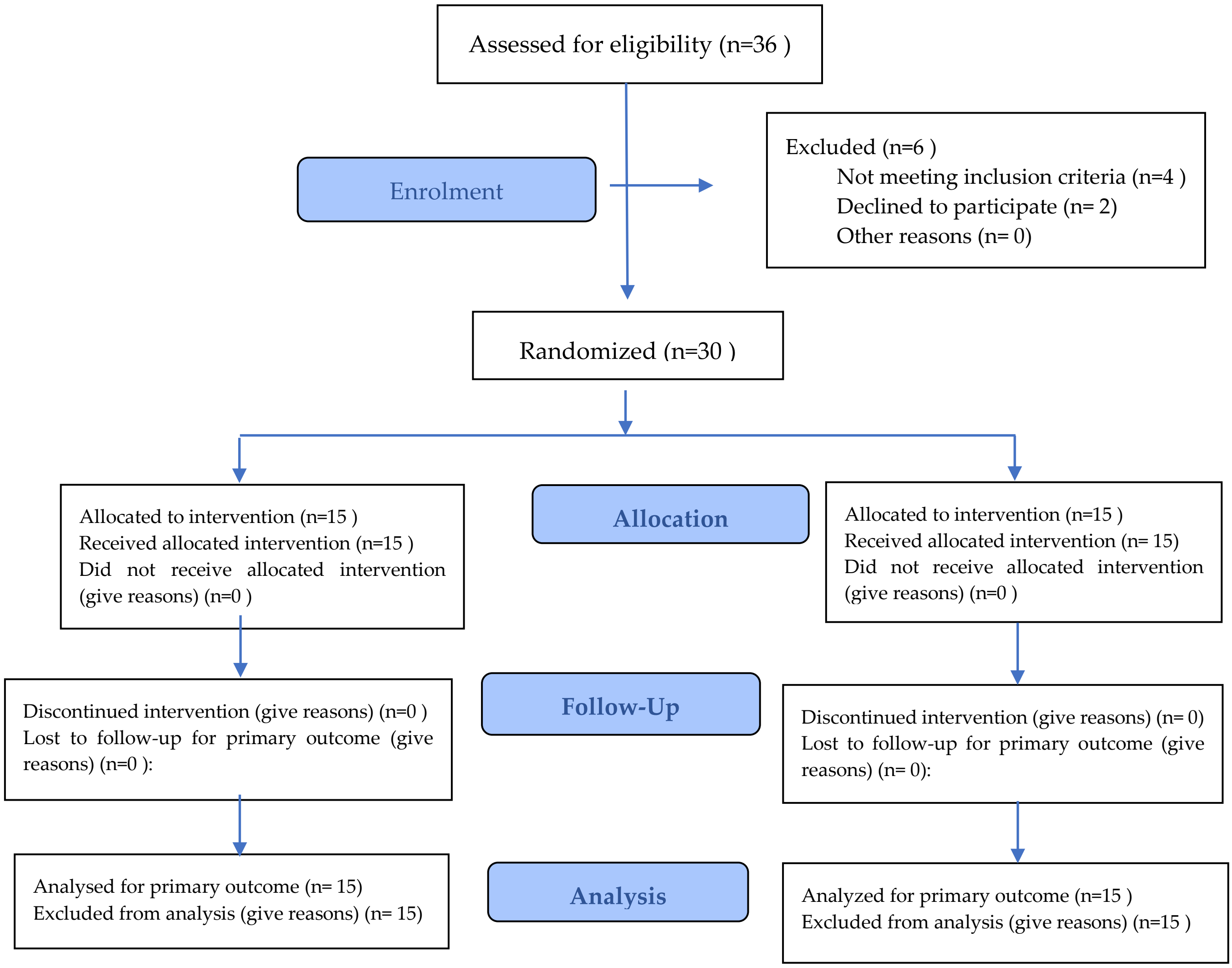

Figure 1. CONSORT 2025 flow diagram of participant recruitment, randomization, intervention allocation, follow-up, and analysis.

Intervention The intervention group received an eight-week proprioceptive–strengthening program, three sessions per week, each lasting approximately 60 minutes. Exercises included static, dynamic, and plyometric proprioceptive drills combined with strengthening exercises (squats, lunges, calf raises and interval sprints). Training by physiotherapists and sport science researchers.

Comparator The control group continued routine club training, consisting of basic skating drills, endurance running, stretching, and sprint practice, three sessions per week (~60 minutes/session). No structured neuromuscular intervention was provided.

2.3 Outcome measures

Primary outcomes: Serum irisin (ng/mL) measured using ELISA (Elabscience® Human Irisin ELISA Kit) and serum BDNF (pg/mL) measured using ELISA (BT LAB Human BDNF ELISA Kit). Secondary outcomes: Dynamic balance was assessed single-leg and overhead squat tests (Humantrak Vald). Measurements were taken at baseline (pre-intervention) and after eight weeks (post-intervention).

2.4 Data analyses

Data were analyzed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA). Normality was tested using Shapiro–Wilk. Within-group comparisons were performed using paired t-tests or Wilcoxon signed rank tests. Between-group differences were analysed using independent t-tests or one-way ANOVA. Pearson or Spearman correlation analyses were conducted to examine associations between biomarker changes and dynamic balance outcomes. Statistical significance was set at $p < 0.05$. Missing data by listwise deletion.

3. Results

Participant Characteristics

A total of 30 adolescent speed skaters successfully completed the trial, with equal allocation to the intervention group (n = 15) and the control group (n = 15). No participants dropped out during the study period. Baseline demographic and anthropometric variables—including age, sex, body mass index (BMI), leg length, and duration of club participation—were comparable between groups. Statistical testing confirmed that there were no significant differences across all measured parameters ($p > 0.05$), indicating homogeneity at baseline.

Table 1. Baseline profile of adolescent speed skaters in the intervention and control groups

Variable	Intervention (n = 15)	Control (n = 15)	p-value
Age (years, mean ± SD)	13.2 ± 1.2	13.4 ± 1.3	0.721
Age distribution	11 y: 2 (13.3%) 12 y: 3 (20%) 13 y: 4 (26.7%) 14 y: 4 (26.7%) 15 y: 2 (13.3%)	11 y: 1 (6.7%) 12 y: 3 (20%) 13 y: 5 (33.3%) 14 y: 4 (26.7%) 15 y: 2 (13.3%)	–
Sex	Male: 9 (60%) Female: 6 (40%)	Male: 8 (53.3%) Female: 7 (46.7%)	0.688
BMI (kg/m²)	19.1 ± 2.4	18.9 ± 2.3	0.812
Right leg length (cm)	85.5 ± 2.1	85.8 ± 2.3	0.693
Left leg length (cm)	85.3 ± 2.2	85.6 ± 2.4	0.711
Club participation (years)	3.5 ± 1.1	3.3 ± 1.0	0.532

Noted. *Values are expressed as mean ± standard deviation for continuous variables and n (%) for categorical variables. Independent t-tests were applied to continuous data, whereas chi-square tests were used for categorical comparisons. A p-value > 0.05 indicates no significant difference between groups.*

Table 2a. Serum Irisin Levels Before and After Proprioceptive Strengthening Training

Group	n	Pre (Mean ± SD, min–max)	Post (Mean ± SD, min–max)	Δ Change	Within-group p	Between-group p
Intervention	15	172.26 ± 156.99 (24.41–635.65)	330.19 ± 194.72 (56.51–733.29)	+157.93	0.003	
Control	15	65.17 ± 58.81 (10.61–224.58)	121.59 ± 113.22 (27.84–373.12)	+56.42	0.022	

Noted. *Values are expressed as mean ± standard deviation with ranges in parentheses. Δ Change represents post-intervention minus pre-intervention values. Paired t-tests or Wilcoxon signed-rank tests were applied for within-group comparisons, and, independent t-tests for between-group differences. Statistical significance was set at p < 0.05.*

Table 2b. Serum BDNF Levels Before and After Proprioceptive Strengthening Training

Group	n	Pre (Mean ± SD, min–max)	Post (Mean ± SD, min–max)	Δ Change	Within-group p	Between-group p
Intervention	15	368.35 ± 304.66 (101.60–959.30)	548.08 ± 174.69 (149.40–780.00)	+179.73	0.107	0.110
Control	15	451.92 ± 321.75 (103.20–896.20)	458.94 ± 158.72 (132.20–672.30)	+7.02	0.938	

Noted. *Values are expressed as mean ± standard deviation with ranges in parentheses. Δ Change represents post-intervention minus pre-intervention values. Paired t-tests or Wilcoxon signed-rank tests were applied for within-group comparisons, and independent t-tests for between-group differences. Statistical significance was set at p < 0.05.*

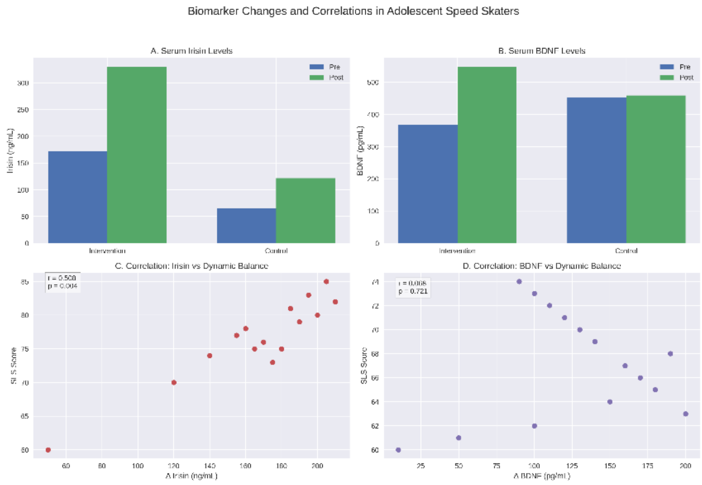

Figure 2. Irisin and BDNF Responses and Associations with Dynamic Balance Following Proprioceptive Strengthening Exercise

Table 3a. Single-leg squat assessment: Dynamic balance outcomes (left leg)

Variable (°)	Group	n	Pre (Mean ± SD, min–max)	Post (Mean ± SD, min–max)	Δ Change	p-value
Peak knee flexion	Intervention	15	76.7 ± 12.9 (47.3–94.7)	83.5 ± 11.2 (64.2–104.2)	+6.8	0.076
	Control	15	57.3 ± 6.6 (46.3–68.3)	70.4 ± 10.9 (51.3–83.4)	+13.1	
Knee displacement (total)	Intervention	15	14.0 ± 10.3 (4.2–42.7)	11.5 ± 5.3 (6.7–24.5)	−2.5	0.350
Peak knee valgus	Intervention	15	7.3 ± 5.2 (0.6–16.9)	5.1 ± 4.7 (0.1–14.3)	−2.5	0.336
Peak knee varus	Intervention	15	3.5 ± 5.3 (0.0–19.4)	9.5 ± 4.5 (0.0–15.0)	−4.0	0.180
Trunk lateral flexion	Intervention	15	2.7 ± 1.8 (0.5–5.9)	4.1 ± 1.5 (2.2–6.4)	−1.6	0.028

Table 3a. Single-leg squat assessment: Dynamic balance outcomes (right leg)

Variable (°)	Group	n	Pre (Mean ± SD, min–max)	Post (Mean ± SD, min–max)	Δ Change	p-value
Peak knee flexion	Intervention	15	80.4 ± 9.4 (66.4–95.4)	80.4 ± 9.6 (67.1–96.3)	+0.0	0.994
	Control	15	92.5 ± 21.1 (58.9–133.7)	103.9 ± 13.9 (78.1–127.6)	+11.4	0.043
Knee displacement (total)	Intervention	15	11.8 ± 7.7 (6.3–32.5)	10.2 ± 3.3 (5.4–16.3)	−1.3	0.485
Peak knee valgus	Intervention	15	3.6 ± 5.2 (0.1–19.4)	4.5 ± 3.8 (0.3–13.6)	+0.9	0.625
Peak knee varus	Intervention	15	8.8 ± 4.7 (1.4–21.7)	8.7 ± 4.2 (1.8–15.7)	−0.1	0.942
Trunk lateral flexion	Intervention	15	2.7 ± 1.8 (0.5–5.9)	1.5 ± 1.1 (0.9–10.1)	+0.2	0.597

Table 4. Overhead squat assessment (lower body dynamic performance, degrees)

Variable	Group	n	Pre (Mean ± SD, min–max)	Post (Mean ± SD, min–max)	Δ Change	p-value
Peak Knee Flexion–Left	Intervention	15	94.18 ± 18.29 (60.40–121.20)	100.18 ± 18.49 (49.50–125.90)	+6.00	0.315
	Control	15	93.00 ± 13.37 (60.20–112.40)	92.98 ± 13.31 (60.20–112.40)	−0.02	0.921
Between-group p-value						0.195
Peak Knee Flexion–Right	Intervention	15	96.58 ± 15.69 (63.50–120.30)	110.11 ± 9.15 (98.20–127.60)	+13.58	0.001
	Control	15	96.00 ± 14.81 (96.00–117.20)	95.86 ± 14.84 (65.00–117.80)	−0.14	0.451
Between-group p-value						0.000
Trunk Flexion	Intervention	15	8.95 ± 4.78 (2.60–19.67)	11.52 ± 4.46 (4.71–20.13)	+2.57	0.000
	Control	15	8.83 ± 3.69 (2.10–17.60)	8.62 ± 3.69 (2.30–18.10)	−0.21	0.267
Between-group p-value						0.010
Trunk Lateral Flexion	Intervention	15	1.44 ± 0.86 (0.30–3.50)	1.67 ± 1.16 (0.10–4.80)	+0.23	0.452
	Control	15	5.09 ± 2.04 (1.50–10.10)	2.66 ± 1.81 (0.50–5.90)	−2.43	0.000
Between-group p-value						0.073

Notes: Values are presented as mean ± standard deviation with ranges in parentheses. Δ Change = post-intervention minus pre-intervention values. p-values were calculated using: a. Paired t-test for normally distributed data ($\alpha = 0.05$) b. Wilcoxon signed-rank test for non-parametric data c. One-way ANOVA for between-group comparisons. $p < 0.05$ indicates statistical significance.

Table 5. Correlation between irisin levels and dynamic balance (single-leg squat and overhead squat)

Variable	Irisin	Dynamic Balance–Single-Leg Squat (SLS)	Dynamic Balance – Overhead Squat (OHS)
Irisin	Pearson correlation = 1 Sig. (2-tailed) = – N = 30	r = 0.508** p = 0.004 N = 30	r = 0.068 p = 0.721 N = 30
Dynamic Balance – SLS	r = 0.508** p = 0.004 N = 30	Pearson correlation = 1 Sig. (2-tailed) = – N = 30	r = 0.508** p = 0.004 N = 30
Dynamic Balance – OHS	r = 0.068 p = 0.721 N = 30	r = 0.068 p = 0.721 N = 30	Pearson correlation = 1 Sig. (2-tailed) = – N = 30

Notes: Correlations were calculated using Pearson's test (r) with significance level set at $p < 0.05$. A significant positive correlation was observed between Irisin levels and dynamic balance in the Single-Leg Squat test ($r = 0.508$, $p = 0.004$). No significant correlation was found between Irisin levels and dynamic balance in the Overhead Squat test ($r = 0.068$, $p = 0.721$).

Table 6. Correlation Between Brain-Derived Neurotrophic Factor Levels and Dynamic Balance

Variable	BDNF	Dynamic Balance – Single-Leg Squat (SLS)	Dynamic Balance – Overhead Squat (OHS)
BDNF	Pearson correlation = 1 Sig. (2-tailed) = – N = 30	r = 0.128 p = 0.502 N = 30	r = −0.194 p = 0.304 N = 30
Dynamic Balance – SLS	r = 0.128 p = 0.502 N = 30	Pearson correlation = 1 Sig. (2-tailed) = – N = 30	r = 0.128 p = 0.502 N = 30
Dynamic Balance – OHS	r = −0.194 p = 0.304 N = 30	r = 0.194 p = 0.304 N = 30	Pearson correlation = 1 Sig. (2-tailed) = – N = 30

Notes: Correlations were calculated using Pearson's test (r) with significance level set at $p < 0.05$. No significant associations were found between BDNF levels and dynamic balance, either in the Single-Leg Squat ($p = 0.502$) or Overhead Squat ($p = 0.304$) assessments.

4. Discussion

This randomized controlled trial examined the effects of an eight-week proprioceptive–strengthening program on serum irisin, brain-derived neurotrophic factor (BDNF), and dynamic balance performance in adolescent speed skaters. The principal findings indicate that irisin levels increased significantly in the intervention group, accompanied by improvements in dynamic balance, whereas BDNF changes were not statistically significant. These results provide novel evidence that irisin may serve as a biomarker of neuromuscular adaptation, whereas BDNF responsiveness appears less consistent under moderate-intensity proprioceptive training.

Irisin response and functional outcomes

The significant elevation of irisin following training supports the hypothesis that this myokine is a mediator of exercise-induced neuromuscular adaptation. Irisin is known to be released during muscular contraction and has been linked to metabolic regulation, neuroplasticity, and motor performance [18-20]. Our correlation analysis revealed a positive association between irisin changes and dynamic balance in the Single-Leg Squat (SLS) test, that irisin may reflect functional improvements in postural control. These findings are consistent with previous reports that exercise-induced irisin contributes to enhanced motor learning and neurotrophic signaling [15,21].

BDNF response and controversy

In contrast, BDNF levels did not show significant changes after the intervention, nor did they correlate with dynamic balance outcomes. This finding reflects the ongoing debate in the literature [22,23]. Metaanalyses in adolescents have reported inconsistent effects of exercise on BDNF, with increases observed primarily under high-intensity or prolonged aerobic protocols [24-26]. Our results suggest that moderate-intensity proprioceptive–strengthening may not provide sufficient stimulus to elicit measurable BDNF changes, highlighting the need for further research on exercise dose–response relationships.

Dynamic balance performance (SLS vs. OHS)

Functional assessments revealed distinct patterns between SLS and overhead squat (OHS). Improvements in knee flexion and trunk control were evident in the intervention group, particularly in SLS, which is highly sensitive to neuromuscular adaptations in the lower limb [27-30]. The significant correlation between irisin and SLS performance underscores the relevance of this test as a marker of postural control improvements. In contrast, OHS did not show significant correlations with irisin or BDNF [31-34]. This may be explained by the complexity of OHS, which involves multijoint movements and requires shoulder mobility, trunk stability, and coordination beyond lower-limb control. Thus, OHS may be less sensitive to short-term biomarker changes, although it remains valuable as a screening tool for identifying compensatory movement patterns and injury risk [35,36].

Integration with previous studies

Our findings extend prior research on balance determinants in skating athletes. Arti et al. [14] demonstrated that age, BMI, and singleleg/tandem stand performance significantly affect balance in inline skaters, while Widiarti et al. [15] reported correlations between singleleg stand and tandem stand in roller skate athletes. By incorporating biomarkers such as irisin and BDNF, the present study advances this line of inquiry, showing that neuromuscular adaptations can be captured not only through functional tests but also at the molecular level.

Implications and future directions

Taken together, the results highlight irisin as a promising biomarker of neuromuscular adaptation, whereas BDNF responses remain equivocal in adolescent populations. From a practical perspective, integrating proprioceptive–strengthening drills into training routines may enhance dynamic balance and reduce injury risk in speed skaters. Future studies should explore: Longer intervention durations or higher-intensity protocols to clarify BDNF responsiveness and Multi-modal biomarker panels (e.g., irisin, BDNF and IGF-1) to capture broader neuroplastic adaptations.

5. Conclusions

This study demonstrated that an eight-week proprioceptive strengthening program significantly increased serum irisin levels and improved dynamic balance performance in adolescent speed skaters, whereas BDNF changes were not statistically significant. The positive correlation between irisin and single-leg squat performance highlights irisin as a potential biomarker of neuromuscular adaptation. In contrast, the absence of significant associations with Overhead Squat and BDNF that these measures may be less sensitive to short-term proprioceptive training. Taken together, the findings emphasize the importance of integrating proprioceptive exercises into training routines to enhance functional stability and reduce injury risk. Future research should explore longer interventions, higherintensity protocols, and multimodal biomarker panels to further clarify the mechanisms underlying exercise-induced neuroplasticity.

6. Patents

No patents are associated with the work reported in this manuscript.

Author Contributions: Conceptualization, **WA** and **S**; methodology, **WA**; software, **OZA**; validation, **WA**, **GMS**, and **MFQ**; formal analysis, **WA**; investigation, **WA** and **HLP**; resources, **PSN**; data curation, **WA**; writing—original draft preparation, **WA**; writing—review and editing, **WA**, **GMS**, and **MFQ**; visualization, **OZA**; supervision, **S**; project administration, **WA**; funding acquisition, **GMS**.

Funding: This research received no external funding

Institutional Review Board Statement: The study was conducted following the principles of the Declaration of Helsinki and received ethical approval on October 21, 2024, from the Health Research Ethics Committee, Faculty of Medicine, Airlangga University, Surabaya, Indonesia (Approval No: 145/EC/KEPK/FKUA/2024). The clinical trial was prospectively registered in the Indonesia Clinical Research Registry (INACRR) under the identifier INA-4832FDB, with the registration date of January 13, 2026.

Informed Consent Statement : Informed consent was obtained from all subjects involved in the study.

Data Availability Statement : Not applicable.

Acknowledgments: The authors would like to thank the Faculty of Medicine, Universitas Airlangga, for ethical approval and institutional support. Special gratitude is extended to the coaches and athletes from inline skating clubs in Sidoarjo for their participation, as well as to the Physiotherapy Laboratory and Pojok Statistik of Universitas Muhammadiyah Sidoarjo for providing facilities, technical assistance, and statistical guidance essential to the completion of this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Yılmaz O, Soylu Y, Erkmen N, Kaplan T, Batalik L. Effects of proprioceptive training on sports performance: a systematic review. BMC Sports Science, Medicine and Rehabilitation. 2024. doi:10.1186/s13102-024-00936-z
2. Constantin Munteanu, Cristina Popescu, Diana Munteanu, Mihail Hoteteu, et al. Biological Evaluation of Balneotherapeutic Mud and Sulfurous Mineral Waters: Insights from In Vivo and In Vitro Studies. Balneo and PRM Research Journal. 2024;15(2):702. doi:10.12680/balneo.2024.702Leger C, Quirié A, Méloux A, et al. Impact of exercise intensity on cerebral BDNF levels: role of FNDC5/Irisin. Int J Mol Sci. 2024;25(2):1213.
3. Adam AM. Assessment of physical activity levels and sedentary behavior in students using the Global Physical Activity Questionnaire. Balneo and PRM Research Journal. 2025;16(1):815. doi:10.12680/balneo.2025.815
4. Berković-Šubić M, Marunica Karšaj J, Hofmann G, Grazio S. Catastrophization, pain and disability in patients with chronic low back pain. Balneo and PRM Research Journal. 2025;16(2):824. doi:10.12680/balneo.2025.824
5. Yılmaz O, Soylu Y, Erkmen N, Kaplan T, Batalik L. Effects of proprioceptive training on sports performance: a systematic review. BMC Sports Sci Med Rehabil. 2024;16(1):149. doi:10.1186/s13102-024-00936-z. PMID: 38965588; PMCID: PMC11225257
6. Tang Z, Yin M, Xu K, et al. Exercise-Induced Changes in Brain-Derived Neurotrophic Factor in Neurodegenerative Diseases: A Bayesian Network Meta-Analysis. J Geriatr Psychiatry Neurol. 2025;0(0). doi:10.1177/08919887251409415
7. Romero Garavito A, Díaz Martínez V, Juárez Cortés E, Negrete Díaz JV, Montilla Rodríguez LM. Impact of physical exercise on the regulation of brain-derived neurotrophic factor in people with neurodegenerative diseases. Front Neurol. 2025;15:1505879. doi:10.3389/fneur.2024.1505879
8. Azevedo KP, de Oliveira VH, Silva GC, et al. The effects of exercise on BDNF levels in adolescents: A systematic review with meta analysis. Int J Environ Res Public Health. 2020;17(17):6056.
9. García DA, Guillén Martínez D, Leitão JC, et al. Exercise and BDNF in adolescence: gaps and future directions. Eur PMC. 2020.
10. Azevedo KP, de Oliveira VH, Silva GC, et al. The effects of exercise on BDNF levels in adolescents: A systematic review with meta analysis. Int J Environ Res Public Health. 2020;17(17):6056.
11. Leger C, Quirié A, Méloux A, et al. Impact of exercise intensity on cerebral BDNF levels: role of FNDC5/Irisin. Int J Mol Sci. 2024;25(2):1213.
12. García DA, Guillén Martínez D, Leitão JC, et al. Exercise and BDNF in adolescence: gaps and future directions. Eur PMC. 2020.
13. Arti W, Putra HL, Sari GM, Suprianto. Factors affecting balance in inline skating athletes based on components of single leg stand, tandem stand, age and body mass index (BMI). Balneo PRM Res J. 2025;16(3):8315.

14. Arti W, Suprianto, Abdillah OZ, Hanum SMF, Setyadi A, Firdaus NZ. Correlation analysis of postural balance in roller skate athletes between single leg stand and tandem stand. J Sport Sci Fit. 2025;11(1):9–16. doi:10.15294/jssf.v11i1.24778.
15. Schulz KF, Altman DG, Moher D. CONSORT 2010 Statement: updated guidelines for reporting parallel group randomised trials. BMJ. 2020;340:c332.
16. World Medical Association. Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA. 2020;324(13):1231–1239.
17. Chan AW, Tetzlaff JM, Gøtzsche PC, et al. SPIRIT 2020 explanation and elaboration. BMJ. 2020;370:m3210.
18. Heinzle K, Habig J, Pröglhöf M, et al. Immersive virtual reality upper-limb exercises in people with Parkinson's disease: an observer-blinded randomised controlled trial. J Neuroeng Rehabil. 2025;23:9.
19. Lwanga SK, Lemeshow S. Sample size determination in health studies: a practical manual. Geneva: WHO; 1991. p. 1–80.
20. Wrann CD, White JP, Salogiannis J, et al. Exercise induces hippocampal BDNF through irisin. Cell Metab. 2021;33(2):338–350.
21. Leger C, Quirié A, Méloux A, et al. Impact of exercise intensity on cerebral BDNF levels: role of FNDC5/irisin. Int J Mol Sci. 2024;25(2):1213.
22. Mialkowskyj D, Koehnke J, Hendrixson V. Exercise intensity dependent effects of BDNF and irisin on cardiovascular regulation. Health Sci East Eur. 2025;35(3):70–77.
23. Rico-González M, González-Devesa D, Gómez-Carmona CD, Moreno-Villanueva A. Exercise as modulator of brain-derived neurotrophic factor in children: a systematic review of randomized controlled trials. Life (Basel). 2025;15(7):1147. doi:10.3390/life15071147
24. Zhu Y, Tianbi L, Wentao S, Yun L, Guodong Z. The optimal type and dose of exercise for elevating brain-derived neurotrophic factor levels in patients with depression: a systematic review with pairwise, network, and dose–response meta-analyses. Depress Anxiety. 2024;41(6):5716755. doi:10.1155/da/5716755
25. Tang Z, Yin M, Xu K, et al. Exercise-induced changes in brain-derived neurotrophic factor in neurodegenerative diseases: a Bayesian network meta-analysis. J Geriatr Psychiatry Neurol. 2025;0(0). doi:10.1177/08919887251409415
26. Moreno-Infantes F, Díaz-Quesada G, Radesca-Fabiano K, Muñoz-Andradas G, Domínguez-Balmaseda D. Impact of high-intensity exercise on BDNF levels and its implications in high-performance sport: a systematic review. Physiologia. 2024;4(4):27. doi:10.3390/physiologia4040027
27. Currier BS, McLeod JC, Banfield L, Beyene J, Welton NJ, D'Souza AC, et al. Resistance training prescription for muscle strength and hypertrophy in healthy adults: a systematic review and Bayesian network meta-analysis. Br J Sports Med. 2024;57(18):1095–1107. doi:10.1136/bjsports-2023-1095
28. George J, Maqsood M, Ahmed HS, Muhammad AS, Abdelrehim ZM, Ezzi J, et al. The efficacy of proprioceptive neuromuscular facilitation techniques in improving range of motion and strength: a systematic review. SEEJPH. 2025;XXVI(S1). ISSN: 2197-5248
29. MDPI Study Group. Effect of a short-term combined balance and multidirectional plyometric training intervention on postural balance ability and lower limb explosive performance in U-13 soccer athletes. Int J Environ Res Public Health. 2025;22(3):246. doi:10.3390/ijerph22030246
30. Faigenbaum AD, Kraemer WJ, Blimkie CJR, Jeffreys I, Micheli LJ, Nitka M, Rowland TW. Youth resistance training: updated position statement from the National Strength and Conditioning Association. J Strength Cond Res. 2024;38(4):765–778. doi:10.1519/JSC.0000000000004260
31. Hopewell S, Chan AW, Collins GS, Hróbjartsson A, Moher D, Schulz KF, et al. CONSORT 2025 statement: updated guideline for reporting randomized trials. BMJ. 2025;389:c332. doi:10.1136/bmj-2025-081234
32. Hróbjartsson A, Boutron I, Hopewell S, Moher D, Schulz KF, Collins GS, et al. SPIRIT 2025 explanation and elaboration: updated guideline for protocols of randomized trials. BMJ. 2025;389:e081660. doi:10.1136/bmj-2024-081660
33. Lloyd RS, Oliver JL. The youth physical development model: a new approach to long-term athletic development. Strength Cond J. 2025;47(2):15–27. doi:10.1519/SSC.0000000000001234
34. Etnier JL, Kibildis SW, DuBois SL. Exercise and acute cognitive enhancement. In: Exercise and Mental Health. Current Topics in Behavioral Neurosciences. Springer; 2024. p.79–102. doi:10.1007/978-3-031-56789-0_5
35. Hotz I, Ernst N, Brenneis C, et al. Barriers and facilitators to conducting RCTs in neurorehabilitation centres. BMC Med Res Methodol. 2024;24:258.