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ASSESSMENT OF STATIC BALANCE AND PROPRIOCEPTIVE CONTROL IN FEMALE JUDOKAS

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Abstracts

Background. Postural control and proprioceptive balance are essential components of performance in judo, where athletes must continuously stabilize their body under multidirectional perturbations. However, few data are available regarding the static balance characteristics of young female judokas. ***Objective.*** This study aimed to assess descriptive and correlational aspects of static proprioceptive balance by analyzing center-of-pressure average angular deviations in the anteroposterior and mediolateral directions and their relationships with overall balance performance. ***Methods.*** Fifteen junior female judokas (15–18 years), each one having at least four years of competitive experience, performed a 10-second static bipedal balance test by means of the SensaMove Balance Board (MiniBoard). Performance (%) and average deviations (°) in the front, back, left and right directions were recorded without visual feedback. Descriptive statistics (mean, SD, SEM, range, 95 % confidence level, skewness) and Pearson's correlation coefficients were calculated. *Results.* Front–back deviations showed consistently negative mean values (–0,38° to –0,89°) with moderate variability, indicating stable anteroposterior control. Left–right deviations were centered around zero (–0,83° to 0,12°) but had higher dispersion (SD = 1,76°–2,31°), reflecting greater mediolateral variability. Overall performance was relatively high (77,60 ± 8,47 %). Significant correlations revealed that performance was more strongly associated with anteroposterior stability, whereas mediolateral deviations were closely related to front–back parameters, suggesting cross-planar interactions in postural regulation. ***Conclusions.*** Young female judokas exhibit good static proprioceptive balance characterized by small center-of-pressure deviations and efficient postural stabilization. Anteroposterior control appears more stable, while mediolateral regulation shows greater variability and may represent a target for training optimization. These findings support the inclusion of multidirectional and sport-specific balance exercises in judo conditioning programs.

Key words: proprioceptive balance; postural control; center of pressure; static stability; female athletes; balance assessment.

Келін Рошу, Володимир Потоп, Лівіу Еманuел Міхайлєску, Даніель Рошу, Андрій Чернозуб, Маріус Віорел Улареану, Іліє Міхай. Оцінювання статичної рівноваги та пропріоцептивного контролю в дзюдоїсток. ***Актуальність.*** Контроль постави та пропріоцептивна рівновага є важливими компонентами спортивної підготовки в дзюдо, де атлети постійно повинні стабілізувати своє тіло під впливом багатонаправлених порушень рівноваги. Однак наявні дані щодо характеристик статичної рівноваги молодих спортсменок-дзюдоїсток є обмеженими. ***Мета.*** Метою цього дослідження було оцінити дескриптивні та кореляційні аспекти статичної пропріоцептивної рівноваги шляхом аналізу середніх кутових відхилень центра тиску в передньо-задньому та медіолатеральному напрямках і їх взаємозв'язків із загальною ефективністю підтримки рівноваги. ***Методи.*** П'ятнадцять юніорок-дзюдоїсток (15–18 років) із щонайменше чотирирічним досвідом участі в змаганнях виконували 10-секундний статичний тест на двоногій рівновазі за допомогою SensaMove Balance Board (MiniBoard). Фіксувалися показники ефективності (%) та середні відхилення (°) в передньому, задньому, лівому та правому напрямках без візуальної зворотної інформації. Обчислено дескриптивну статистику (середнє, стандартне відхилення, стандартну помилку середнього, діапазон, 95 % довірчий інтервал, асиметрію) та коефіцієнти кореляції Пірсона. ***Результати.*** Передньо-задні відхилення показали послідовно негативні середні значення (–0,38° до –0,89°) із помірною мінливістю, що свідчить про стабільний контроль у передньо-задньому напрямку. Ліво-праві відхилення були зосереджені навколо нуля (–0,83° до 0,12°), але мали більший розкид (SD = 1,76°–2,31°), що відображає більшу медіолатеральну мінливість. Загальна ефективність була

відносно високою (77,60 ± 8,47 %). Значущі кореляції показали, що ефективність більшою мірою пов'язана зі стабільністю передньо-заднього напрямку, тоді як медіолатеральні відхилення тісно взаємопов'язані з передньо-задніми параметрами, що свідчить про крос-планарні взаємодії в регуляції постави. ***Висновки.*** Молоді спортсменки-дзюдоїстки демонструють добру статичну пропріоцептивну рівновагу, яка характеризується невеликими відхиленнями центра тиску й ефективною стабілізацією постави. Контроль у передньо-задньому напрямку є більш стабільним, тоді як регуляція в медіолатеральному напрямку має більшу мінливість і може стати ціллю для оптимізації тренувань. Ці результати підтримують уключення багатонаправлених і специфічних для виду спорту вправ на рівновагу в програми фізичної підготовки дзюдоїсток.

Ключові слова: пропріоцептивна рівновага, контроль постави, центр тиску, статична стабільність, спортсменки, оцінка рівноваги.

Introduction. Judo is a high-intensity combat sport that involves rapid changes of direction, throws and ground control techniques, all of which requiring exceptional postural stability and neuromuscular coordination. Athletes must continuously maintain dynamic balance while counteracting external perturbations, making proprioceptive function and postural control essential for both performance and injury prevention [8].

Postural control in judokas relies on the integration of sensory information from visual, vestibular and somatosensory systems. Repeated exposure to destabilizing situations inherent in combat sports induces sport-specific adaptations, resulting in enhanced balance and neuromuscular coordination compared with non-athletic individuals, particularly under conditions of limited visual feedback [7; 12; 16].

Proprioception plays a critical role in maintaining joint position sense, coordinating postural responses and reducing injury risk. Deficits in proprioceptive feedback can increase postural sway, impair coordination and elevate the risk of musculoskeletal injuries, especially in the ankle and knee joints, which are subjected to mechanical stress during throws and landings [10; 14].

Instrumented balance platforms provide reliable and objective measures of postural stability through center-of-pressure (COP) analysis and tilt-based tasks. These systems enable the evaluation of dynamic balance under reduced visual conditions, highlighting the contributions of proprioceptive and vestibular inputs and serving as important tools for performance monitoring and preventive training program development [8; 15; 21].

Although most studies on combat sports postural control have focused on male athletes, the physiological and neuromuscular differences between sexes indicate that female judokas may exhibit distinct balance characteristics. Targeted research is therefore necessary to understand these adaptations in female athletes and to inform evidence-based training and injury prevention strategies [8; 9; 14].

Therefore, the *aim of the present study* was to assess dynamic balance and proprioceptive control in female judo athletes using a balance platform test. It was hypothesized that trained female judokas would demonstrate good postural stability indices, reflecting sport-specific neuromuscular adaptations.

Materials and Methods

The study sample consisted of 15 junior female judokas aged 15–18 years, enrolled at the ―Mircea Eliade‖ Sports High School in Bucharest. All participants had a minimum of four years of competitive judo experience and followed a regular training schedule of 5–6 sessions per week, including technical–tactical practice, proprioceptive and stability exercises and general physical conditioning.

Static postural balance was assessed in January 2025 using the SensaMove Balance Board (MiniBoard), a portable computerized device designed to quantify center-of-pressure (CoP) oscillations. The system recorded overall balance performance (%) and average angular deviations (°) in the front, back, left and right directions. In addition, second-by-second average deviations were obtained over a 10-second testing interval, allowing detailed analysis of front–back (anteroposterior) and left-right (mediolateral) postural control dynamics.

Each participant performed the test in a standardized bipedal stance, barefoot, with arms alongside the body and without visual feedback, maintaining an upright and stable posture. Environmental conditions were kept constant for all assessments. Device settings were configured as follows: shape size 20°, shape width 5° and maximum tilting 10°. Each trial lasted 10 seconds and a single valid attempt was recorded for analysis.

The research protocol complied with the ethical principles of the Declaration of Helsinki and was approved by the Ethics Committee of the Doctoral School of Physical Education and Sport Science (ID: 34/21.03.2025), University Center of Pitești, National University of Science and Technology ―Politehnica‖ of Bucharest. Written informed consent was obtained from all participants and from parents/guardians for minors.

Data processing was performed using KyPlot 6 software. Descriptive statistics were calculated for all variables, including mean, standard deviation (SD), standard error of the mean (SEM), range, 95 % confidence limits of the mean (CLM) and skewness, to characterize central tendency, variability and distribution normality.

Pearson's correlation analysis (r) was applied to examine the relationships between overall performance, directional average deviations (front, back, left, right) and second-by-second front-back and left-right deviations across the 10-second interval. Statistical significance thresholds were set at $p < 0,05$, $p < 0,01$, and $p < 0,001$. The strength of correlations was interpreted according to Cohen's (1988) criteria: $r = 0,10–0,29$ (weak), $r = 0,30–0,49$ (moderate), $r = 0,50–0,69$ (large), and $r \geq 0,70$ (very large/strong).

Results. The results section presents a comprehensive descriptive and correlational analysis of center-of-pressure deviations and overall performance indicators, aiming to characterize static proprioceptive balance and identify directional and cross-planar relationships in postural control among young female judoka.

Table 1

Descriptive Statistics of Front-Back Average Deviation during the Proprioceptive Balance Test in Young Female Judokas

Statistical Indicators	Seconds - avg. Deviation (°)									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Mean	-0,44	-0,38	-0,54	-0,89	-0,83	-0,52	-0,71	-0,73	-0,54	-0,64
SD	0,95	1,23	1,21	1,24	1,03	1,28	1,15	1,78	1,87	1,17
SEM	0,25	0,32	0,31	0,32	0,27	0,33	0,30	0,46	0,48	0,30
Range	3,13	5,18	5,25	5,04	3,35	4,97	3,80	6,19	7,28	4,21
CLM(0.95)	0,53	0,68	0,67	0,69	0,57	0,71	0,64	0,99	1,03	0,65
Skewness	-0,51	1,06	0,82	0,12	0,20	0,68	0,96	0,56	-1,14	0,08

Note. *N=15, Confidence level of mean (0,95) – (CLM).*

The descriptive analysis of the front–back average angular deviation recorded over the 10 consecutive seconds showed consistently negative mean values (–0,38° to –0,89°), pointed out a persistent posterior displacement tendency of the center of pressure throughout the testing period. Inter-individual variability was moderate, with standard deviations ranging from 0,95° to 1,87°, the largest fluctuations occurring in the ninth second and the lowest in the first second. The SEM values (0,25°–0,48°) and corresponding 95 % confidence intervals highlighted good precision of the estimated means. Skewness coefficients (–1,14 to 1,06) indicated only minor asymmetry and an approximately normal distribution of the data, supporting the use of parametric statistical procedures. The results reflect relatively stable and well-controlled anteroposterior postural regulation across the 10-second interval, with limited second-to-second variation and moderate inter-subject differences.

Table 2

Descriptive Results of Left-Right Average Deviation during the Proprioceptive Balance Test in Young Female Judokas

Statistical Indicators	Seconds - avg. Deviation (°)									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Mean	-0,48	-0,55	-0,38	-0,17	-0,65	-0,32	-0,83	-0,72	-0,03	0,12
SD	1,79	1,95	1,92	1,92	2,04	2,10	1,89	1,76	2,31	2,31
SEM	0,46	0,50	0,50	0,50	0,53	0,54	0,49	0,45	0,60	0,60
Range	6,73	7,85	6,99	6,92	6,83	6,57	7,44	6,90	7,93	7,99
CLM(0.95)	0,99	1,08	1,06	1,06	1,13	1,16	1,05	0,97	1,28	1,28
Skewness	-0,30	0,85	0,15	-0,10	-0,09	0,47	0,85	-0,08	0,20	-0,17

The descriptive analysis of the left–right average angular deviation recorded across the 10 consecutive seconds revealed mean values close to zero (–0,83° to 0,12°), indicating symmetrical mediolateral oscillations of the center of pressure without consistent lateral dominance. However, variability was moderate to high, with standard deviations ranging from 1,76° to 2,31°, suggesting greater fluctuations in lateral stability. The highest dispersion occurred in the final seconds (S9–S10), whereas the lowest variability

was observed at S8. The SEM (0,45°–0,60°) and 95 % confidence limits (0,97°–1,28°) showed acceptable precision of the estimates. Wide value ranges (6,57°–7,99°) confirmed substantial inter-individual differences, while skewness coefficients (–0,30 to 0,85) suggested approximately normal data distribution.

Overall, although mediolateral control remained relatively stable, it exhibited greater variability compared with the front–back direction, reflecting reduced stability and less consistent postural regulation in the lateral plane.

Table 3

Descriptive Results of Proprioceptive Balance Test in Young Female Judokas

Parameters	Statist. Ind.					
	Mean	SD	SEM	Range	CLM(0,95)	Skewness
Perf. *(%)*	77,60	8,47	2,19	31	4,69	-0,64
Front, avg. dev. (°)	1,15	0,87	0,23	2,78	0,48	0,54
Back, avg. dev. (°)	-1,40	0,89	0,23	2,89	0,49	-0,54
Left, avg. dev. (°)	-1,13	0,65	0,17	2,54	0,36	-0,56
Right, avg. dev. (°)	0,69	0,46	0,12	1,48	0,26	0,22

The descriptive results of the proprioceptive balance test in young female judokas are presented in table 3. The overall performance (Perf. %) had a mean of 77,60 %, with a standard deviation of 8,47 %, proving a relatively consistent balance performance across participants. The standard error of the mean (SEM = 2,19 %) and the 95 % confidence limit of the mean (CLM = 4,69 %) suggest reliable estimation of the group mean. Skewness (–0,64) indicates a slight negative asymmetry in performance; most participants performed above the mean.

Descriptive analysis of the proprioceptive balance test underlined a relatively high and homogeneous level of postural control among young female judokas, with an overall performance of 77,60 ± 8,47 %. The low SEM (2,19 %) and narrow 95 % confidence interval confirmed the reliability of the group mean. Directional deviations were small in both planes, with slight anterior (1,15 ± 0,87°) and posterior (–1,40 ± 0,89°) oscillations in the anteroposterior axis and reduced mediolateral displacements (left: –1,13 ± 0,65°; right: 0,69 ± 0,46°). Variability was moderately greater in the anteroposterior direction, while lateral control appeared more stable and symmetrical. Generally, the findings demonstrate good proprioceptive balance and efficient postural stabilization in both movement planes.

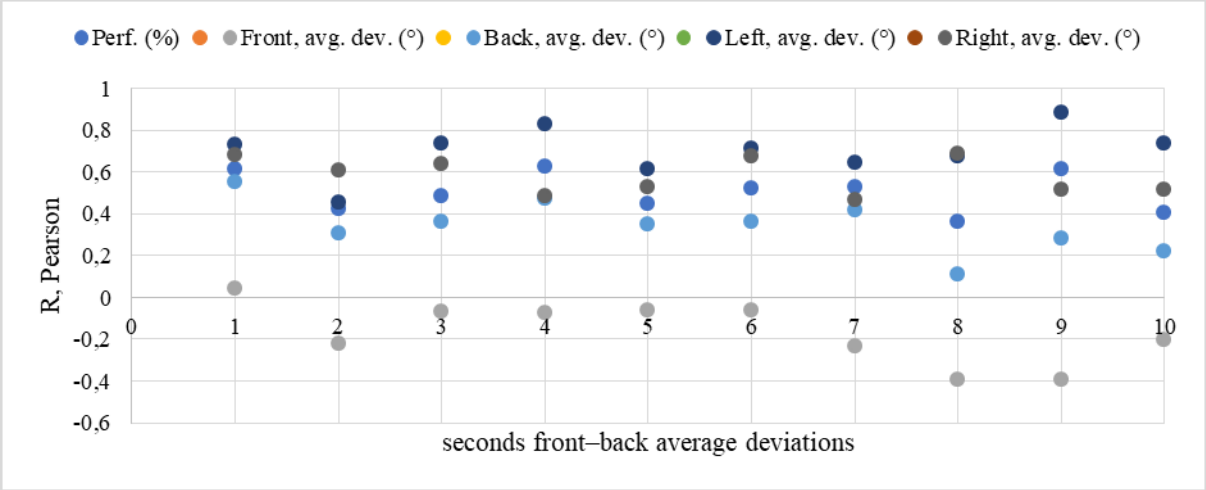

Fig. 1. *Correlation Analysis between Static Balance Parameters and Front-Back Average Deviations Across the 10-Second Testing Period*

The results show that overall performance (Perf. %) exhibited moderate and statistically significant positive correlations with front–back deviations, particularly in S1, S4, S6, S7, and S9 ($r = 0,524–0,627$, $p < 0,05$). This means that higher performance levels are associated with better control of anteroposterior oscillations. Lateral parameters (left and right average deviations) displayed the strongest correlations with front–back deviations, with consistently high and significant coefficients ($r = 0,463–0,886$, $p < 0,05–0,001$), revealing a strong functional interdependence between mediolateral stability and anteroposterior control. The

Left parameter showed particularly high associations. Conversely, the front and back deviations themselves presented weak or non-significant correlations, suggesting limited within-plane associations. Figure 1 shows that front-back stability is closely linked to lateral control mechanisms, reflecting multi-planar integration of postural regulation.

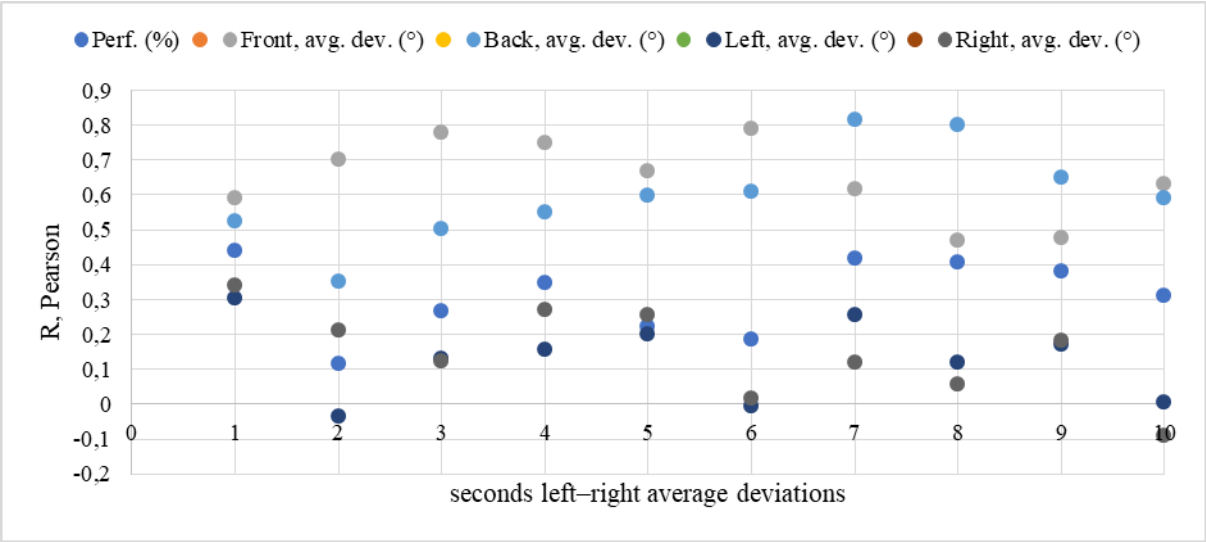

Fig. 2. *Correlation Analysis between Static Balance Parameters and Left-Right Average Deviations Across the 10-Second Testing Period*

For mediolateral deviations, overall performance presented weak and non-significant correlations, proving a limited contribution of lateral control to general performance.

In contrast, anteroposterior parameters (Front and Back) displayed moderate to very strong correlations with left–right deviations, most of them statistically significant. The Front parameter revealed consistent associations ($r = 0{,}589–0{,}788$), while the Back parameter reached the highest values in the final seconds (up to $r = 0{,}817$ and $r = 0{,}802$, $p < 0{,}001$), underscoring that lateral stability largely depends on anteroposterior control mechanisms.

Correlations within the same lateral plane (Left and Right with left–right) were weak or absent, indicating limited directional specificity. Figure 2 highlights that mediolateral balance is more strongly influenced by anteroposterior mechanisms than by isolated lateral factors.

Comparatively, front-back deviations were more closely associated with overall performance, whereas left-right deviations showed stronger relationships with anteroposterior parameters. This means that postural regulation relies on cross-planar interactions, with a dominant influence of anteroposterior control on overall balance stability.

Discussion. The present study aimed to examine the characteristics of static proprioceptive balance and the interrelationships between anteroposterior and mediolateral postural control mechanisms in young female judokas. Altogether, the findings underline a good level of balance performance, characterized by small center-of-pressure deviations, moderate variability and consistent stability throughout the 10-second testing period.

The descriptive analysis of front–back deviations revealed consistently negative mean values across all seconds, indicating a slight but stable posterior displacement tendency of the center of pressure. Despite this directional bias, the magnitude of oscillations remained small and relatively homogeneous, as reflected by moderate standard deviations and low SEM values. These findings are consistent with previous reports that judokas demonstrate refined anteroposterior postural control and reduced sway due to sport-specific neuromuscular adaptations [1; 16]. The observed stability further aligns with studies showing that judo practice enhances proprioceptive integration, enabling athletes to maintain posture under challenging conditions without abrupt corrective movements [8; 14]. Additionally, previous research emphasizes that COP oscillations in the anteroposterior plane are sensitive indicators of postural regulation and reflect the efficiency of sensorimotor control in experienced combat sport athletes [22]. Collectively, these results support the observation that trained judokas possess automated balance strategies, minimizing postural sway while maintaining readiness for rapid directional changes.

Mediolateral deviations demonstrated mean values near zero, indicating symmetrical weight distribution between the left and right sides [4]. However, variability was higher, with greater standard deviations, wider ranges and increased dispersion toward the end of the trial, suggesting that lateral stability was less consistent and required more frequent corrective adjustments [1; 16]. This pattern reflects the lower inherent mechanical stability of the body in the frontal plane and the heightened demands on hip and trunk stabilizers for maintaining equilibrium [13; 20; 23].

The overall proprioceptive balance performance of the participants (approximately 78 %) demonstrated a relatively homogeneous level of postural control. Directional averages showed small angular deviations in both the anteroposterior and mediolateral planes, confirming that the athletes maintained efficient stabilization with minimal center-of-pressure displacement [8; 14]. Although slight increases in anteroposterior variability were observed at specific moments, mediolateral deviations remained more symmetrical, reflecting the use of complementary stabilization strategies between planes [1; 16]. These findings align with previous evidence pointing out that judo training promotes sensorimotor adaptations that enhance dynamic balance and optimize postural regulation [8; 18; 25].

Correlational analyses highlighted significant functional relationships between balance parameters in judokas. Specifically, front–back (anteroposterior) deviations were moderately correlated with overall performance; therefore, stability in this plane directly contributes to general balance efficiency [2]. Athletes with superior anteroposterior control tended to achieve higher performance scores, demonstrating the critical role of forward–backward stabilization in maintaining effective posture during static stance tasks [3; 16]. Additionally, the relationship between training adaptations and balance performance indicates that structured judo practice enhances anteroposterior postural control, revealing sport-specific neuromuscular integration [13]. Comprehensive assessments combining anteroposterior measures with overall stability indices can improve the prediction of performance outcomes and injury risk in judokas [8].

A notable observation made in this study was the strong and consistent cross-planar associations between mediolateral (ML) and anteroposterior (AP) parameters. Lateral deviations, both left and right, exhibited high correlations with front–back oscillations, while mediolateral second-by-second variations were closely linked to anterior and posterior components. This shows that postural control operates through integrated, multi-planar mechanisms rather than independently within each plane [6; 14; 17]. The findings highlight that adjustments in one direction can influence or compensate for movements in the other, reflecting coordinated neuromuscular strategies and emphasizing the importance of multi-directional training to enhance overall balance stability in judo athletes [5; 19].

Interestingly, correlations within the same directional plane were weaker or even absent, suggesting that balance regulation is not strictly direction-specific but relies on a more global sensorimotor integration. This cross-planar interdependence emphasizes the complexity of postural control and indicates that effective balance depends on the coordinated action of multiple muscle groups and the integration of sensory inputs, rather than on isolated corrective movements [11; 20; 24].

From a practical standpoint, the results prove that young female judokas exhibit well-developed static proprioceptive control, which likely stems from the specific demands of judo, including rapid stabilization, continuous weight shifts and frequent postural adjustments during contact situations. The increased variability in the mediolateral plane suggests that targeted interventions – such as lateral stability exercises and hip–trunk strengthening – could further enhance postural consistency and balance performance [4; 16; 18]. These findings underscore the importance of incorporating sport-specific proprioceptive and neuromuscular training to optimize postural control in young athletes.

In summary, the results prove that young female judokas have good overall balance performance, stable anteroposterior control and symmetrical, but more variable, mediolateral regulation. The strong cross-planar correlations confirm that postural stability is achieved through integrated control mechanisms rather than independent directional processes. These findings underline the importance of multidirectional balance training to optimize proprioceptive efficiency and postural stability in combat sport athletes.

Conclusion. The present study demonstrates that young female judokas exhibit a good level of static proprioceptive balance, characterized by high overall performance scores, small angular deviations of the center of pressure, and relatively stable postural control throughout the 10-second testing period. Anteroposterior oscillations indicated consistently low variability and a stable posterior tendency, reflecting efficient forward–backward stabilization mechanisms. In contrast, mediolateral control remained symmetrical but displayed greater variability, suggesting increased corrective demands in the lateral plane.

Correlation analyses revealed that overall balance performance was more strongly associated with front–back stability, while mediolateral deviations showed stronger relationships with anteroposterior parameters. These findings highlight the existence of cross-planar interactions and confirm that postural regulation relies on integrated, multi-planar neuromuscular strategies rather than independent directional control.

Taken together, the results point out that young female judokas possess well-developed proprioceptive and postural control abilities, likely influenced by the specific motor demands of judo practice.

Practical Applications

From a practical perspective, the present findings provide useful implications for coaches and specialists in strength and conditioning who work with combat sports athletes.

1) since anteroposterior stability appears closely linked to overall performance, training programs should maintain exercises that reinforce forward–backward control, such as single-leg stance tasks, perturbation training and unstable-surface drills. These methods may help preserve the already efficient stabilization mechanisms observed in this plane;

2) the greater variability identified in the mediolateral direction suggests that lateral stability represents a relative weakness and a potential area for improvement. Therefore, targeted exercises focusing on hip abductors/adductors, trunk stabilizers and lateral weight-transfer control (e.g., side lunges, lateral balance tasks, dynamic stepping drills and reactive stabilization exercises) may enhance frontal-plane postural consistency;

3) the strong cross-planar correlations emphasize the importance of multidirectional and sport-specific balance training. Integrating complex tasks that simultaneously challenge both planes (e.g., rotational movements, partner perturbations or judo-specific stance transitions) may better reflect competitive demands and promote functional postural adaptations.

Finally, periodic assessment using portable balance systems can be useful for monitoring athletes' proprioceptive status, identifying asymmetries and evaluating the effectiveness of training interventions.

Limitations

Several limitations of this study should be acknowledged.

1) The relatively small sample size limits the generalizability of the findings. Although the group was homogeneous in age and training level, larger samples would allow stronger statistical power and broader applicability.

2) Only static bipedal balance was assessed. Since judo performance predominantly involves dynamic and reactive postural adjustments, future studies should include dynamic, unilateral or sport-specific balance tests to better reflect real competition conditions.

3) The short testing duration (10 seconds) may not fully capture fatigue-related or long-term stabilization mechanisms. Longer trials or repeated measurements could provide additional insights into postural endurance and consistency.

4) The cross-sectional design prevents causal interpretation of the relationships observed. Longitudinal or interventional studies would be necessary to determine how training influences proprioceptive balance over time.

Despite these limitations, the study provides relevant baseline data and contributes to understanding the postural control characteristics of young female judokas.

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