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Dynamics of intersegmental coordination in athletes practicing karate and taekwondo

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Abstract

Aim. The purpose of the current research was to investigate the dynamics of intersegmental coordination, with respect to athletes' caliber (performance level) and gender.
Material and method. Fifty-two athletes practicing karate – 35 athletes (21 men and 14 women) and taekwondo (TKD) – 17 athletes (11 men and 6 women) took part in the study (M_{age} = 20.8 years). The RCMV test was used to measure athletes' level of intersegmental coordination. The computerized test, assessing hand-foot coordination, makes it possible to identify key aspects of athletes' psychomotor organization in various demanding situations.
Results. The Kruskal-Wallis (H) test was used, along with the DSCF (Dwass-Steel-Critchlow-Fligner) post-hoc test to examine the characteristics of intersegmental coordination in athletes with outstanding (international-level) sports results. Three coefficients of the RCMV test stood out: working memory coefficient ($p = 0.003$, $\varepsilon^2 = 0.23$), resistance to disturbing visual factors ($p = 0.006$, $\varepsilon^2 = 0.19$), and field inspection ($p = 0.030$, $\varepsilon^2 = 0.13$), in tasks requiring intersegmental coordination. Next, Mann-Whitney test (U) was used to investigate the intersegmental coordination of karate and taekwondo practitioners separately, according to gender and athletes' caliber.
Conclusions. Athletes with international performances (Tier 4) demonstrated faster coordinated movements, were able to locate relevant stimuli in the environment more quickly, while their accuracy (in tasks requiring intersegmental coordination) was, also, higher in situations involving visual distractions. Female athletes practicing karate and TKD with international sports performances registered significantly better scores, also, for the overall performance at the RCMV test, compared to female athletes having national (Tier 3) or regional/local (Tier 2) sports results.

Key words: *intersegmental coordination; sports performance; caliber; karate; taekwondo.*

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Introduction

Combat sports (such as karate and taekwondo) are characterized by a high level of motor complexity, driven by constant interaction with an opponent, the variability of the competitive context, and the need to adapt rapidly to unpredictable external stimuli (Predoiu et al., 2025). Contemporary literature highlights that the specific movements of combat sports result from complex processes of intersegmental coordination and motor control, involving the spatiotemporal synchronization of body segments within kinetic chains (Lupu et al., 2026). Current research demonstrates that practicing combat sports leads to significant improvements in motor competence, including coordination, balance, and postural control, in both athletes and non-athletes (Olhos et al., 2026; Saraiva et al., 2025). This highlights the integrative nature of these disciplines, which simultaneously engage multiple functional systems.

Karate is a martial art developed as a method of self-defense without the use of weapons; Gichin Funakoshi is considered the founder of modern karate (Piepiora et al., 2022). Karate was adapted for sports competition in the mid-20th century by the Japan Karate Association, and Olympic competition follows the rules of the World Karate Federation (Bagińska et al., 2022). Karate places great emphasis on self-discipline, technique, flexibility, and precision, as well as on traditional rules, respect for one's training partner, and character development (Litwic-Kaminska et al., 2023). It was found that karate training improves motor coordination, balance and cognitive development in children (Alesi et al., 2014), as well as motor proficiency in adolescents with coordination difficulties (Ghadiri et al., 2022).

Taekwondo (TKD) was adapted for competitive sports in the second half of the 20th century by the International Taekwondo Federation, with Olympic competition taking place in accordance with the rules of the World Taekwondo Federation (Kim et al., 2019). In TKD fighting techniques performed with the lower limbs dominate (compared to offensive or defensive techniques performed with the upper limbs). In fact, the majority of points (98% to 100%) are derived from kicks (Jakubiak & Saunders, 2008; Kazemi et al., 2006). Such kicks must be executed with high muscular power (Marković et al., 2005) and quickly/ at the right moment to take advantage of the tactical opportunities offered by an opponent (Chung & Ng, 2012). In taekwondo, reaction ability, spatial orientation and movement synchronization are critical for efficient technical and tactical execution (Pashkov, 2015). Research showed that taekwondo practitioners demonstrate superior postural control, balance, and sensory organization due to the sport's complex kicking techniques and dynamic movement patterns (Fong et al., 2012). Also, practicing taekwondo "encourages social engagement, self-control, and resilience" (Lee et al., 2025).

Coordination, and in particular intersegmental coordination, must be understood as a fundamental mechanism of performance in combat sports. It not only facilitates efficient technical execution but also contributes to the athlete's adaptability in complex competitive contexts. Psychomotor coordination enables the organization, regulation, and adaptation of movement in relation to task requirements and environmental constraints, representing a complex process of sensorimotor integration, in which relevant information from the visual, vestibular, and proprioceptive systems is processed and transformed into efficient motor commands (Shumway-Cook & Woollacott, 2021). Coordination is thus a complex skill that enables the execution of rapid, precise, and economical movements, contributing to the optimization of performance and the reduction of the energy cost of the action (see Predoiu et al., 2024).

Studies show that performance in combat sports is correlated not only with strength or power, but also with the efficiency of intersegmental coordination, which allows for the optimal use of neuromuscular resources (Parr, 2018). The lack of effective intersegmental coordination leads to discontinuities in the kinetic chain, resulting in energy loss and reduced execution speed. Furthermore, asynchronous activation of segments can lead to joint overload, increasing the risk of injury (Morin & Samozino, 2018). In the absence of adequate synchronization between segments, the neuromuscular system is forced to compensate through additional activations, which increases energy expenditure and reduces the overall efficiency of movement (Santuz et al., 2018). Thus, athletes with a high level of intersegmental coordination exhibit more economical muscle activation and a more efficient organization of muscle synergies.

Intersegmental coordination enables the stabilization of body segments and control of movement trajectory, contributing to increased accuracy in technical execution (Predoiu, 2015). Consequently, athletes with good coordination perform movements that are more fluid, faster, and require less energy, demonstrating superior biomechanical efficiency. This efficiency is reflected in higher performance and a better ability to maintain performance levels throughout the duration of the effort (Parr, 2018). It appears that exposure to varied performance contexts improves the robustness of coordination and the ability to transfer skills (Dhawale et al., 2017).

Intersegmental coordination plays a key role in injury prevention. Poor intersegmental control frequently leads to muscular imbalances, characterized by disproportionate activation of muscle groups. These imbalances can cause joint instability and affect movement mechanics, increasing the risk of injury (Morin & Samozino, 2018).

Furthermore, recent research highlights that neuromuscular training programs, which aim to improve intersegmental coordination and control, significantly contribute to reducing the incidence of injuries. These programs improve stability, postural control, and muscle synchronization, reducing the risks associated with complex movements (Tschopp et al., 2025). Therefore, inter-segmental coordination not only optimizes performance but can also serve as a key protective factor, helping to maintain the structural and functional integrity of the musculoskeletal system.

The current study

The aim of the current study is to investigate the dynamics of intersegmental coordination, taking into consideration athletes' performance level and gender.

Hypotheses

H1: There are significant differences between karate and TKD practitioners in terms of intersegmental coordination, taking into consideration the athletes' caliber and gender.

Materials and method

Participants

A total of 52 athletes practicing combat sports (karate and taekwondo) took part in the study. Inclusion criteria for the present study: between 18 and 30 years of age (to ensure a relatively homogeneous age group) and a minimum of 2 years of competitive experience (the study, also, included athletes with regional/local-level results – Tier 2, according to McKay et al., 2022).

The athletes (32 men and 20 women) have a mean age of 20.8 (*SD* = 3.64, Mode = 20). Regarding competitive experience, the mean is 6.25 (*SD* = 2.82, Mode = 8), for the entire sample. By sport, the following stand out: karate – 35 athletes (21 men and 14 women) and taekwondo – 17 athletes (11 men and 6 women).

Based on their recorded athletic performance, the investigated athletes are classified as follows (according to the typology by McKay et al., 2022): Tier 4 (Elite/International-level performance, N = 18, of whom 8 are women); Tier 3 (Highly Trained/National-Level Results, N = 16, of whom 6 are women); Tier 2 (Trained/ Regional/Local-level results, N = 18, of whom 6 are women). A balanced number of female athletes can be noted in each of the three groups, formed based on the sports results achieved.

The convenience and the purposive sampling techniques were used, as the main sampling techniques in the present research.

Measures

The RCMV test (created in Romania, by RQ Plus company) was used to measure athletes' level of intersegmental coordination. The test takes about 10 minutes and involves three working speeds. The computerized test makes it possible to identify key aspects of athletes' psychomotor organization in various demanding situations, by assessing hand-foot coordination and motor learning abilities. Depending on the number and position of the relevant stimuli (red squares) on the computer screen, the athlete "must respond through a motor reaction of his upper limbs (button pressing) and lower limbs (pedal pushing)" (Teodorescu et al., 2012). Therefore, "RCMV assesses motor coordination through bi-segmental and multi-segmental responses" (Vicol et al., 2025).

The test automatically generates the following coefficients: 1: learning ability (athletes' motor reactions in new conditions); 2: working memory (athletes' processing speed, when they need to press the appropriate buttons and pedals); 3: overall performance (take into account both athletes' speed and accuracy); 4: resistance to disturbing visual factors (athletes' coordination in situations involving visual distractions); 5: personal pace (accuracy of coordinated movements); 6: resistance to time pressure (athletes' coordination as the work speed increases); 7: field inspection (involves athletes' rapid localization of relevant stimuli and fast motor responses); 8: self-pacing coefficient (refers to the speed of coordinated movements, but only in the most dynamic parts of the RCMV test). The raw scores (for each mentioned coefficient) divide karate and TKD practitioners into classes, from 5 (maximum performance) to 1 (minimum scores for intersegmental coordination).

In the current research, the 8 coefficients (raw scores) of the RCMV test will be abbreviated using Arabic numerals, while the corresponding classes (for each coefficient) will be abbreviated using Roman numerals (see Tables, in the current study).

Procedure

The RCMV test was carried out (in the presence of the experimenters) between October 2024 - March 2026, between 10 a.m. - 5 p.m. Karate and TKD practitioners provided their written informed consent to participate in this study, while data confidentiality was ensured. Romanian athletes performed the computerized test at rest, individually, but also in groups of up to 5 athletes at a time. The athletes had no previous experience with the RCMV test (a factor that could have influenced the quality and speed of coordinated movements).

Results

To capture the characteristics of intersegmental coordination (measured under various conditions) in athletes with outstanding (international-level) sports performances, the Kruskal-Wallis (H) test was used (first, without controlling for the gender variable), along with the DSCF (Dwass-Steel-Critchlow-Fligner) post-hoc test.

Table I. Results of the H test – differences between groups (Tier 4 *vs.* Tier 3 *vs*. Tier 2)

	χ^2	df	p	ε^2
1	0.286	2	0.867	0.005
I	1.157	2	0.561	0.022
2	11.920	2	0.003	0.233
II	12.691	2	0.002	0.248
3	1.327	2	0.515	0.026
III	4.296	2	0.117	0.084
4	10.12790	2	0.006	0.198
IV	8.69964	2	0.013	0.170
5	2.79269	2	0.248	0.054
V	1.49938	2	0.473	0.029
6	2.48612	2	0.288	0.048
VI	1.52057	2	0.468	0.029
7	7.02951	2	0.030	0.137
VII	5.50749	2	0.064	0.107
8	0.00945	2	0.995	1.85e-4
VIII	0.09518	2	0.954	0.001

Note. Arabic numerals = raw scores, coefficients of the RCMV test (from 1 to 8);
Roman numerals = the corresponding classes for each coefficient (see *Measures*); χ^2 = chi-square;
ε^2 = epsilon square/ effect size (ε^2 = 0.14 represents a large effect size/difference between groups).

In Table I significant differences can be observed between the three groups of athletes, for 3 coefficients of the RCMV test: 2 - working memory (p = 0.003, ε^2 = 0.23), 4 - resistance to disturbing visual factors (p = 0.006, ε^2 = 0.19), and 7 - field inspection (p = 0.030, ε^2 = 0.13). The DSCF post-hoc test captures the differences between groups, taken two by two (Table II).

Table II. Pairwise comparisons DSCF – intersegmental coordination

		W (2)	p (2)	W (II)	p (II)	W (4)	p (4)	W (IV)	p (IV)	W (7)	p (7)
Tier 4	Tier 3	-3.507	0.035	-3.477	0.037	-2.00	0.333	-2.98	0.089	-3.082	0.075
Tier 4	Tier 2	-4.769	0.002	-4.837	0.002	-4.48	0.004	-3.93	0.015	-3.473	0.037
Tier 3	Tier 2	-0.271	0.980	-0.640	0.893	-2.34	0.222	-1.16	0.689	-0.811	0.834

Note. Arabic numerals = raw scores, coefficients of the RCMV test (from 1 to 8); Roman numerals = the corresponding classes for each coefficient (see *Measures*); W = Wilcoxon test; p = alpha significance level

Data analysis (Table II) reveals significant differences between:

- athletes with international-level performance (Tier 4) and athletes with national-level results (Tier 3; raw scores: p = 0.035 and classes: p = 0.037), as well as regional/local results (Tier 2; raw scores: p = 0.002 and classes: p = 0.002), in the case of working memory coefficient (in tasks requiring intersegmental coordination);
- athletes with international-level performance (Tier 4) and athletes with regional/local-level results (Tier 2), in the case of resistance to disturbing visual factors (raw scores: p = 0.004 and classes: p = 0.015) in tasks requiring intersegmental coordination;
- athletes with international performances (Tier 4) and karate and TKD practitioners with regional/local-level results (Tier 2), in the case of field inspection (raw scores: p = 0.037) in tasks requiring intersegmental coordination.

Table III presents the results at descriptive level. A good to very good score is observed for resistance to disturbing factors coefficient (Tier 4, *M* = 4.44), and an average to good score for working memory coefficient (Tier 4, *M* = 3.78).

Table III. Descriptive statistics RCMV – the results for the significant differences observed

	Tier	2	II	4	IV	7
N	Tier 4	18	18	18	18	18
	Tier 3	16	16	16	16	16
	Tier 2	18	18	18	18	18
Mean	Tier 4	947	3.78	1.07	4.44	970
	Tier 3	912	3.00	1.00	3.81	921
	Tier 2	911	2.83	0.914	3.44	896
SE	Tier 4	11.0	0.222	0.040	0.232	13.4
	Tier 3	11.2	0.204	0.041	0.292	19.4
	Tier 2	6.68	0.0904	0.032	0.326	24.3
SD	Tier 4	46.6	0.943	0.172	0.984	56.9
	Tier 3	44.7	0.816	0.166	1.17	77.8
	Tier 2	28.3	0.383	0.136	1.38	103

Note. 2 and II: raw score and class (performance level) for working memory coefficient; 4 and IV: raw score and class for resistance to disturbing visual factors; 7: raw score for field inspection coefficient.

Next, Mann-Whitney test (U) was used to examine the intersegmental coordination of karate and taekwondo practitioners separately, according to gender and athletes' caliber. Due to the reduced sample size (when gender variable was considered), athletes having national performances (Tier 3) and regional/local sports results (Tier 2) formed a single group in the statistical analysis. Table IV presents the results for the U test.

Table IV. Mann-Whitney U test – Tier 4 *vs.* Tier 3 and Tier 2

	U – men	p	r	U – women	p	r
1	104.5	0.837	-0.05	36.5	0.370	0.240
I	107.5	0.926	-0.02	30.0	0.107	0.375
2	48.0	0.012	-0.56	18.5	0.024	-0.615
II	62.0	0.018	-0.43	18.5	0.020	-0.615
3	107.0	0.919	0.02	23.0	0.058	-0.521
III	103.0	0.748	-0.06	20.0	0.010	-0.583
4	69.0	0.100	-0.37	21.0	0.041	-0.563
IV	64.0	0.044	-0.41	25.5	0.065	-0.469
5	93.0	0.499	-0.15	27.0	0.111	-0.438
V	105.5	0.857	0.04	30.5	0.134	0.365
6	73.5	0.139	-0.33	41.0	0.610	-0.146
VI	90.0	0.366	-0.18	42.5	0.681	-0.115
7	66.0	0.063	-0.40	32.0	0.139	-0.333
VII	72.0	0.100	-0.34	34.0	0.190	-0.292
8	97.0	0.611	0.11	39.0	0.512	-0.188
VIII	88.0	0.331	-0.20	38.0	0.398	0.208

Note. r: effect size for U test (r = 0.5 refers to a moderate difference between groups); Arabic numerals = raw scores, coefficients of the RCMV test (from 1 to 8); Roman numerals = the corresponding classes for each coefficient (see *Measures*).

Data analysis (Table IV) reveals significant differences between male athletes with international-level performance and those with national or regional/local-level results (2: p = 0.012, II: p = 0.018 and IV: p = 0.044). In the case of women athlete significant differences could be found for: 2 (working memory coefficient, p = 0.024), II (class/ performance level for working memory, p = 0.020), III (class/ performance level for the overall performance at the RCMV test, p = 0.010), and 4 (resistance to disturbing visual factors coefficient, p = 0.041). Table V shows the results at descriptive level.

Table V. Descriptive statistics – only the results for the significant differences observed, according to gender and athletes' caliber

		Men athletes			
	Group	N	Mean	SD	SE
2	Tier 4	10	943.1	46.64	14.75
	Tier 3 and 2	22	910.7	30.82	6.57

II	Tier 4	10	3.60	0.96	0.30
	Tier 3 and 2	22	2.90	0.42	0.09
4	Tier 4	10	4.3	1.25	0.39
	Tier 3 and 2	22	3.59	1.29	0.27
	Group	Women athletes			
		N	Mean	SD	SE
2	Tier 4	8	951.88	49.18	17.39
	Tier 3 and 2	12	914.33	46.36	13.38
II	Tier 4	8	4.00	0.92	0.32
	Tier 3 and 2	12	2.91	0.90	0.25
3	Tier 4	8	728.50	74.50	26.34
	Tier 3 and 2	12	666.16	46.06	13.29
III	Tier 4	8	3.00	0.00	0.00
	Tier 3 and 2	12	2.41	0.51	0.14
4	Tier 4	8	1.09	0.11	0.04
	Tier 3 and 2	12	0.96	0.15	0.04

Note. Arabic numerals = raw scores, coefficients of the RCMV test (from 1 to 8);
Roman numerals = the corresponding classes/ performance level for each coefficient (see *Measures*).

Discussions

Intersegmental coordination emerges as a key determinant of performance in combat sports, representing a functional expression of the integration between neuromotor control, biomechanical organization, and cognitive-perceptual adaptation to the competitive environment. Intersegmental coordination reflects the central nervous system's ability to organize movement through muscular synergies and to efficiently integrate feedforward and feedback control mechanisms. This organization allows not only for stability in execution but also for flexibility, facilitating rapid adaptation to task demands (Santuz et al., 2018).

Direct interaction with an opponent in karate and TKD involves constantly adjusting motor strategies in response to the opponent's actions, which requires a high level of intersegmental coordination. Rapid transitions between offensive and defensive phases require an efficient reorganization of kinetic chains so that movements are executed with precision and optimal speed (Chaabene et al., 2012). The efficiency of a motor action is defined by the ratio between the mechanical result obtained and the energy cost involved, and this ratio is optimized through a coordinated organization of the body segments (Morin & Samozino, 2018).

The results of the current study showed significant differences between karate and TKD practitioners in terms of intersegmental coordination, taking into consideration athletes' caliber and gender. Athletes with international-level performance (Tier 4) demonstrated significantly better scores for the working memory coefficient (in tasks requiring intersegmental coordination), as well as for the resistance to disturbing visual factors and in the case of field inspection, in tasks requiring intersegmental coordination (compared to karate and TKD practitioners with lower sports results - Tiers 2). In other words, athletes with international performances registered a better processing speed in tasks requiring intersegmental coordination, demonstrated faster coordinated movements, while their accuracy was, also, higher in situations involving visual distractions. Specialized literature asserted that athletes with higher technical experience in taekwondo demonstrated better coordination abilities (Boutios et al., 2021), while coordination was found, also, to strongly correlate with karate performance (Blažević et al., 2006). Not least, coordination abilities are considered fundamental for technical efficiency in TKD, more exactly "the sense of rhythm, the sense of time and distance, balance and vestibular stamina" (Lyuchkova et al., 2022).

When intersegmental coordination of karate and taekwondo practitioners was examined separately, according to gender, significant and interesting differences were, also, emphasized. Male athletes with international-level performance obtained significantly better results for the working memory coefficient and for the resistance to disruptive visual factors (athletes' coordination in situations involving visual distractions), compared to karate and TKD practitioners with lower sports results. In the case of female athletes, significant differences were observed for the working memory coefficient, for the overall performance at the RCMV test (an indicator that takes into account both athletes' speed and accuracy in tasks requiring intersegmental coordination), and for the resistance to disturbing visual factors.

The study's findings are of interest to specialists in the field, highlighting the need to develop intersegmental coordination under various environmental conditions. Therefore, exercises involving complex kinetic chains, such

as strike combinations, are essential for developing inter-segmental coordination. These require the sequential and synchronized activation of body segments, promoting the optimization of force transfer and neuromuscular timing (Lenetsky et al., 2013). Additionally, training based on external stimuli (visual or auditory) develops motor reaction and adaptation abilities. These exercises stimulate the integration of perception with action, improving coordination under conditions of uncertainty. At the same time, the use of unstable surfaces or single-leg positions increases the demand on postural and proprioceptive control systems. Such exercises improve segmental stability and overall movement coordination, contributing to the development of intersegmental control. Last but not least, training in contexts that simulate the variability of competition (e.g., changes in pace, direction, or position) contributes to the development of adaptive coordination and the ability to rapidly reconfigure kinetic chains. These principles are supported by the literature on motor learning, which highlights that optimal performance is not the result of rigid repetition of a movement, but of the ability to adapt execution according to the context (Dhawale et al., 2017).

Limitations and future directions

The main limitation of the study concerns the relatively small sample size of karate and TKD athletes. Also, the statistical analysis of the data did not take into account a specific weight class, therefore the results may vary in a different setting. Further studies should separately address each sport branch, and a specific age (including juniors). At the same time, future research should thoroughly explore the relationship between athletes' intersegmental coordination and sports performances using advanced methods of biomechanical and neurophysiological analysis (EMG, 3D kinematic analysis, muscle synergy modeling). Such an approach could contribute to the development of more effective and better-tailored training programs, aimed at optimizing performance and reducing the risks associated with sports practice.

Conclusion

The current study emphasized that a good to very good score for resistance to disturbing visual factors (athletes' coordination in situations involving visual distractions), and an average to good score for working memory coefficient (athletes' processing speed in tasks requiring intersegmental coordination) are specific to karate and TKD practitioners with international sports performances (Tier 4). Athletes with international performances demonstrated faster coordinated movements, were able to locate relevant stimuli in the environment more quickly, while their accuracy (in tasks requiring intersegmental coordination) was, also, higher in situations involving visual distractions. When gender and athletes' caliber were investigated, female athletes having international sports results registered significantly better scores, also, for the overall performance at the RCMV test – an indicator that takes into account both athletes' speed and accuracy in tasks requiring intersegmental coordination.

Authors' Contributions

The last author had equally contributed to this study as the first author.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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