EVALUATION OF NEUROMUSCULAR ASYMMETRIES IN ELITE KARATE ATHLETES USING TENSIOMYOGRAPHY

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Abstract:

This study aimed to evaluate the functional symmetry of the lower limbs in female karate athletes using tensiomyography (TMG). Five high-performance athletes were analyzed based on existing TMG reports, and functional symmetry indices were calculated for key anatomical segments, including the knee joint (quadriceps–hamstrings), ankle joint (dorsiflexors–plantarflexors), Achilles tendon (medial–lateral gastrocnemius), patellar ligament (vastus medialis–vastus lateralis), and overall leg function (anterior–posterior muscle groups). The results revealed a segment-specific distribution of functional symmetry. The highest mean symmetry values were observed in the patellar ligament (approximately 74%), while symmetry in the ankle joint showed consistently moderate-to-low values (approximately 50%) across all participants. The knee joint and Achilles tendon exhibited the greatest variability, indicating substantial inter-individual differences in neuromuscular organization. Overall leg symmetry displayed moderate values (approximately 67%) with noticeable variability. These findings suggest that functional symmetry in karate athletes is not uniformly distributed but rather reflects localized neuromuscular organization. A higher competitive level was not associated with uniformly greater symmetry; instead, it related to more organized and segment-specific symmetry patterns. The results support the idea that asymmetry in elite athletes may represent functional adaptation rather than dysfunction. Tensiomyography appears to be a useful tool for identifying neuromuscular imbalances and supporting individualized training strategies aimed at optimizing performance and preventing injuries.

Keywords:

Assessment, Imbalances, Functional Adaptation, TMG.

INTRODUCTION

Functional symmetry in sports refers not only to the similarity between the left and right sides of the body but also to the balance between functionally related muscle groups, such as agonist-antagonist or synergistic muscles within a limb segment. This balance is particularly important in lower-limb movements, as asymmetries have been linked to poorer performance in activities like jumping, kicking, and changing direction. Moreover, evidence suggests that unresolved strength or neuromuscular imbalances can increase the risk of injury, especially concerning the hamstring and knee areas.

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This issue is especially critical in karate, where athletes engage in rapid offensive and defensive movements, short accelerations, braking actions, hopping, and directional changes that continuously challenge lower-limb power and joint control. [1, 2, 3, 4, 5, 6].

Tensiomyography (TMG) is an effective tool for assessing muscle function because it non-invasively measures the radial displacement of the muscle belly during an electrically induced twitch. This technique provides key contractile variables such as contraction time, delay time, and maximal displacement. Methodological reviews indicate that TMG is practical and feasible for use in applied sports settings. The outputs, particularly maximal displacement and contraction time, show good to excellent inter-rater reliability, while relaxation-related variables tend to be less stable. Importantly, TMG can also be used to calculate both lateral and functional symmetry indices, which makes it suitable for examining regional balance in the knee, ankle, and lower leg, rather than focusing solely on isolated muscle values. [7, 8, 9].

Despite the increasing use of TMG, several gaps still exist. First, the literature is predominantly focused on football and on single-muscle profiling or injury-screening applications, such as distinguishing biceps femoris after hamstring injury, rather than addressing broader regional functional organization [10]. Second, when examining TMG asymmetry directly, it has most often focused on the knee region in football, where a high prevalence of functional asymmetry has been reported. However, there are inconsistent links to performance or player roles [11]. Third, there is limited evidence in combat sports. The existing study on karate-specific TMG (Task-Movement Group) primarily examined thigh muscle contractile adaptations in male athletes. It did not focus on functional symmetry in the knee, ankle, Achilles complex, patellar mechanism, or the overall leg. Additionally, it did not include female athletes with documented competitive achievements [12]. More broadly, the relationships between asymmetry and performance, as well as asymmetry and injury, remain context-dependent. This emphasizes the importance of profiling athletes individually instead of relying solely on pooled averages [4, 9].

The aim of this study is to analyze the functional symmetry of the lower limbs in five female karate athletes using tensiomyography. The focus is on the symmetry of the knee, ankle, Achilles tendon, patellar ligament, and overall leg function. The study seeks to determine whether the symmetry profiles of these regions differ in magnitude and pattern among the athletes, whether some regions exhibit greater stability than others, and whether a higher competitive level is associated with more organized functional symmetry. We hypothesize that knee and ankle symmetry will show the greatest variability among the athletes, while Achilles tendon and patellar ligament symmetry will be comparatively more stable. Additionally, we suggest that a higher competitive level may not necessarily lead to perfectly uniform symmetry but rather to more localized and well-organized patterns of asymmetry, particularly in the knee and overall leg profiles.

2. METHODS

2.1. SAMPLE CHARACTERISTICS

The sample consisted of five female karate athletes (n = 5) who were actively competing at both national and international levels at the time of testing. Each participant had several years of systematic training experience and was a member of competitive squads that regularly participated in high-level tournaments. The athletes had achieved notable success at the European and World Championship levels, indicating that they performed at a high to elite competitive standard.

Despite some variations in competitive success, all athletes were among the top performers in their respective categories. They had extensive training histories and had been exposed to the high-intensity technical and tactical demands that are typical of elite karate.

The participation of athletes with different levels of success in an otherwise high-performance group enabled the observation of potential differences in neuromuscular organization, particularly regarding the functional symmetries of the lower limbs. All participants were free from acute injuries at the time of testing and were involved in regular training routines.

2.2. PROCEDURES

Tensiomyographic (TMG) assessment was carried out to evaluate the neuromuscular characteristics and functional symmetries of the lower limbs. All measurements were conducted under standardized laboratory conditions, adhering to established TMG protocols. The procedures followed standard guidelines for non-invasive neuromuscular assessment.

Participants were positioned either supine or prone, depending on the muscle group being evaluated. Muscle belly displacement was recorded in response to a single electrical stimulus delivered through surface electrodes placed over the target muscle. The intensity of the stimulation was gradually increased until maximal muscle response was achieved.

Measurements were taken unilaterally on the following muscles: vastus lateralis, vastus medialis, rectus femoris, biceps femoris, tibialis anterior, gastrocnemius medialis, and gastrocnemius lateralis. Each limb was assessed individually, and the corresponding values were later used to calculate symmetry indices.

All measurements were conducted by the same experienced operator to ensure consistency. Before testing, participants were familiarized with the procedure and instructed to remain fully relaxed during the measurements. Adequate rest intervals were provided between stimulations to avoid fatigue effects.

Based on muscle responses obtained from both limbs, functional symmetry indices were calculated for key anatomical and functional units of the lower limbs. These included the knee joint (quadriceps–hamstrings relationship), the ankle joint (dorsiflexors–plantarflexors), the Achilles tendon (medial–lateral gastrocnemius relationship), the patellar ligament (vastus medialis–vastus lateralis relationship), and overall leg function (anterior–posterior muscle groups).

2.3. VARIABLES

The main variables in this study were functional symmetry indices derived from tensiomyographic responses of selected lower limb muscles. These indices represented the relationships between functionally related muscle groups within and across limbs.

Functional symmetry was assessed for the following anatomical and functional units:

- Knee joint symmetry is defined as the relationship between knee extensors, specifically the vastus lateralis, vastus medialis, and rectus femoris, and the knee flexor, biceps femoris. This reflects the balance between the quadriceps and hamstring muscle groups;
- Ankle joint symmetry is defined as the relationship between the dorsiflexor (tibialis anterior) and the plantar flexors (gastrocnemius medialis and gastrocnemius lateralis), which represents the functional balance of the ankle joint;
- Achilles tendon symmetry refers to the balance between the medial and lateral heads of the gastrocnemius muscle, indicating how load is distributed within the triceps surae complex;
- Patellar ligament symmetry refers to the relationship between the vastus medialis and vastus lateralis, reflecting the balance of forces acting on the patella;
- Overall leg symmetry is defined as the relationship between the anterior thigh muscles (vastus lateralis and vastus medialis) and the posterior lower leg muscles (gastrocnemius medialis and gastrocnemius lateralis), which represents a broader indicator of lower limb functional organization.

All symmetry indices were expressed as percentages, where higher values indicate a more balanced relationship between the analyzed muscle groups, while lower values reflect greater functional asymmetry.

2.4. STATISTICAL ANALYSIS

Descriptive statistics were calculated for all functional symmetry variables, presented as mean ± standard deviation, along with individual values due to the small sample size. Given the limited number of participants ($n = 5$), no inferential statistical tests were conducted. Because of the exploratory nature of the study, the focus was on individual neuromuscular profiles rather than on group-level inferences. The analysis concentrated on the magnitude and distribution of functional symmetry values among participants.

Comparative interpretation was achieved by qualitatively examining differences between athletes of varying competitive levels, with particular attention given to patterns of functional symmetry in the knee and ankle joints.

3. RESULTS

Functional symmetry analysis revealed significant variability between individuals in all examined segments of the lower limbs. The data distribution suggested that different anatomical units display unique patterns of neuromuscular organization. (Table 1).

Knee joint symmetry showed the greatest variability among the participants, with values ranging from very low to relatively high levels. This finding suggests significant differences in the functional relationship between the quadriceps and hamstring muscle groups.

In contrast, ankle joint symmetry values were more consistently distributed, generally remaining within a moderate range. This indicates a relatively uniform balance between the dorsiflexor and plantarflexor muscles, although it may not be optimal.

The patellar ligament exhibited the highest mean symmetry values, indicating a well-maintained balance between the vastus medialis and vastus lateralis muscles across participants. In comparison, the Achilles tendon displayed moderate symmetry values with considerable variability among individuals, suggesting differences in the functional relationship between the medial and lateral gastrocnemius muscles.

When examining overall leg symmetry, the results revealed a wide range of values, highlighting differences in the global organization of the anterior and posterior muscle groups in the lower limb.

At the group level (Table 2), the highest symmetry values were observed in the patellar ligament, while the lowest values were found at the ankle joint. The greatest variability was observed in the knee and Achilles tendon segments.

The radar chart displays the differences between the left and right lower limbs in various functional segments. Some slight asymmetries can be seen, especially at the knee and Achilles tendon, while the ankle and patellar areas show more balanced values. Overall, this profile suggests that functional symmetry is not evenly distributed between the limbs.

Table 1. Functional symmetry values (%) for each participant

Athlete	Knee (L/R)	Ankle (L/R)	Achilles (L/R)	Patellar (L/R)	Leg (L/R)
Athlete 1	67 / 72	57 / 42	56 / 54	74 / 98	55 / 62
Athlete 2	90 / 50	48 / 47	46 / 41	87 / 69	60 / 62
Athlete 3	38 / 73	52 / 43	77 / 63	44 / 62	64 / 58
Athlete 4	53 / 39	45 / 65	95 / 89	82 / 73	82 / 77
Athlete 5	73 / 44	46 / 56	91 / 56	83 / 72	83 / 67

Table 2. Mean functional symmetry values

Symmetry	Mean (%)	SD
Knee	59.9	16.5
Ankle	50.1	7.4
Achilles	66.8	18.0
Patellar	74.4	14.3
Leg	67.0	10.3

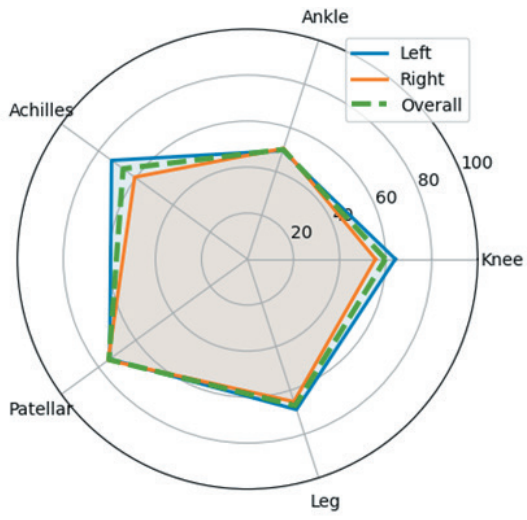

Figure 1. Functional symmetry profiles of the left and right lower limbs with overall mean values

4. DISCUSSION

The main finding of this study is that the functional symmetry of the lower limbs in female karate athletes varies by segment rather than being uniform across the entire limb. The results indicate that different anatomical regions display unique patterns of neuromuscular organization. This suggests that symmetry should be understood as a localized functional property rather than a global one.

In this sample, the patellar ligament exhibited the highest mean symmetry values (approximately 74%), indicating a relatively well-preserved balance between the vastus medialis and vastus lateralis among participants. In contrast, the symmetry of the ankle joint demonstrated consistently moderate to low values (around 50%) with little variability. This suggests a uniformly reduced balance between the dorsiflexor and plantarflexor muscle groups. Such a pattern may reflect either a systematic underdevelopment of dorsiflexor function or a sport-specific adaptation that favors plantarflexor dominance [7, 8].

The Achilles tendon showed moderate mean symmetry values of approximately 67% with significant variability among individuals (standard deviation of about 18%). This indicates that there are considerable differences in the functional relationship between the medial and lateral gastrocnemius muscles. Unlike the patellar mechanism, this suggests that the coordination of the gastrocnemius may be more influenced by individual neuromuscular strategies and training history.

The knee joint exhibited one of the highest levels of variability among the sample, with symmetry values fluctuating significantly across and within athletes (ranging from approximately 38% to 73%). This observation underscores notable differences in the functional relationship between the quadriceps and hamstring muscle groups. Since this interaction is crucial for knee stabilization, such variability may have implications for both athletic performance and injury risk. Previous studies have indicated that imbalances between the quadriceps and hamstrings are linked to an increased risk of anterior cruciate ligament injuries and hamstring strains [3, 5, 10].

The observed asymmetries can be partly explained by the specific biomechanical demands of karate. Many techniques require asymmetric use of the lower limbs, where one leg primarily serves as a stabilizing support limb while the other generates force during kicking actions. This repeated functional specialization may result in consistent differences between the limbs. In the current data, slight asymmetries were evident, particularly around the knee and Achilles tendon areas, which may reflect a dominant strategy of using one leg for support. These asymmetries have previously been described as functional adaptations rather than pathological deviations [1, 13].

The results indicate that a higher competitive level does not always correlate with consistently higher symmetry values. Instead, athletes who achieve better competitive outcomes tend to exhibit more organized and specific symmetry patterns in different segments, rather than uniformly high symmetry across all areas. This suggests that optimal performance may rely on the efficient organization of asymmetry, rather than the complete removal of it [2, 12].

From a practical perspective, the findings emphasize the need for segment-specific monitoring of neuromuscular function. While the patellar region appears to be relatively stable, the knee and Achilles tendon show significant variability, indicating that these areas may require more attentive monitoring. Additionally, the consistently low ankle symmetry highlights a potential target for intervention, particularly through dorsiflexor strengthening and proprioceptive training. Similar patterns of asymmetry have been observed in elite athletes across various sports, reinforcing the importance of individualized analysis [4, 11].

Several limitations of this study should be acknowledged. Firstly, the sample size was small (n = 5), which restricts the generalizability of the findings and prevents the use of inferential statistics. Consequently, the analysis relied on descriptive and qualitative interpretations of individual profiles. Additionally, TMG provides information on contractile properties under static conditions, which does not directly reflect dynamic performance. Factors such as electrode placement and the state of muscle activation may also influence the measurements [9].

In conclusion, the findings indicate that functional symmetry in female karate athletes is defined by segment-specific organization rather than a uniform balance. The patellar ligament exhibited the highest symmetry values, while the ankle joint consistently showed low values. In contrast, the knee and Achilles tendon displayed significant variability. These results support the idea that asymmetry in elite athletes may be a reflection of functional adaptation rather than dysfunction. This emphasizes the importance of individualized assessments and targeted training strategies.

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