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Assessing ground reaction force and reaction time in Karate

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ABSTRACT

This study aims to elucidate the biomechanical differences between elite athletes specializing in Kumite and Kata, two distinct disciplines within karate. By examining ground reaction forces during technique execution, we seek to identify variations in movement patterns and performance characteristics that can inform tailored training strategies.

Kumite involves dynamic combat with rapid, forceful movements, while Kata focuses on the precise execution of pre-arranged forms. Understanding the biomechanical distinctions between these disciplines provides insights into their specific performance demands and training requirements.

Elite Kumite and Kata athletes were analyzed using a force platform to measure ground reaction forces under three conditions: attack on target, technique without a target, and maximum power execution. Key metrics included force spectra, reaction times, and balance quality.

Kumite athletes displayed pronounced peaks in their force spectra, corresponding to stages of weight transfer, attack, and return phases. The data revealed significant variability in force spectra across conditions, with more pronounced peaks under target stimulation and at maximum power, and an average reaction time of 0.42 seconds. Conversely, Kata athletes exhibited less pronounced and more consistent force spectra across conditions, with superior balance quality and a slightly lower average reaction time of 0.53 seconds.

The study reveals significant biomechanical differences between Kumite and Kata athletes, emphasizing the need for specialized training approaches tailored to the unique demands of each discipline. These insights contribute to optimizing training strategies, enhancing performance, and reducing injury risk in martial arts. Further research is suggested to explore additional factors influencing performance and their broader applications across various sports.

Keywords: Karate, Biomechanics, Ground reaction force, Reaction time, Training optimization

INTRODUCTION

Karate, a traditional martial art with a rich history, is divided into various styles and disciplines, with Kumite and Kata being two of its central components (Critchley, Mannion, & Meredith, 1999). Kumite, or sparring, is characterized by its focus on dynamic, high-intensity combat. Athletes engage in real-time, reactive movements requiring rapid decision-making, power, and agility to outperform their opponents (Doria et al., 2009 ; Beneke et al., 2004). In contrast, Kata involves the execution of pre-arranged sequences of movements, emphasizing precise technique, balance, and form (Penov, Petrov, & Kolimechikov, 2020). These forms are practiced to improve technique and internalize the principles of karate (Nema et al., 2024).

Understanding the biomechanical underpinnings of Kumite and Kata is crucial for optimizing training approaches and enhancing athletic performance. Ground reaction forces (GRFs)—the forces exerted by the ground on the athlete during movement—are a key measure of biomechanical performance. GRFs influence how effectively an athlete can generate power, maintain balance, and perform techniques (Nikjoo & Sadeghi, 2021).

In Kumite, athletes often exhibit high levels of explosive power and rapid reaction times (Doria et al., 2009 ; Mori et al., 2002). The force spectra associated with Kumite movements typically display pronounced peaks, reflecting the dynamic nature of combat where quick, forceful actions are essential (Zayed & Aly, 2018). Studies have shown that Kumite requires athletes to rapidly adapt to changing situations and execute powerful strikes, which is reflected in their GRF profiles (Cynarski, Wąsik, Szymczyk, & Vences, 2018).

Conversely, Kata demands a different set of biomechanical adaptations. The practice of Kata involves repetitive, controlled movements that require balance, precision, and stability. The GRFs in Kata are often characterized by more consistent and less pronounced peaks compared to Kumite. This consistency reflects the discipline's emphasis on controlled execution and maintaining a stable posture throughout the forms (Lisowska, 2021).

Karate serves as a prime example of a competitive sport characterized by significant temporal and spatial constraints that demand quick reflexes. During sparring (known as "kumite") and matches, two practitioners face off within a 2-meter range, launching attacks against each other. The remarkable

speed and strength of offensive strikes performed by skilled karate practitioners are well-documented (Mori, Ohtani, & Imanaka, 2002).

This study aims to provide a comprehensive comparison of the ground reaction forces and the reaction time between elite athletes specializing in Kumite and Kata. By analyzing GRF data under varying conditions—such as performing techniques with and without a target, and at maximum power—we seek to elucidate the biomechanical differences and similarities between these disciplines. The findings will offer valuable insights into how specific training adaptations impact performance and provide a basis for developing more effective and targeted training strategies for both Kumite and Kata practitioners.

1. Methodes and materials

1.1. Participants

The study was performed on two elite athletes in karate, one specialist in kumite and the other in kata. These athletes performed the attacking movements of the Mae-Geri foot and Gyaku tsuki in front of a target placed at trunk level on a mobile stand. The ground reaction force of each athlete was determined for the 4 stages of the movement (armed, attack, return of strike and setting of the foot). The characteristics of our sample are shown in Table 1:

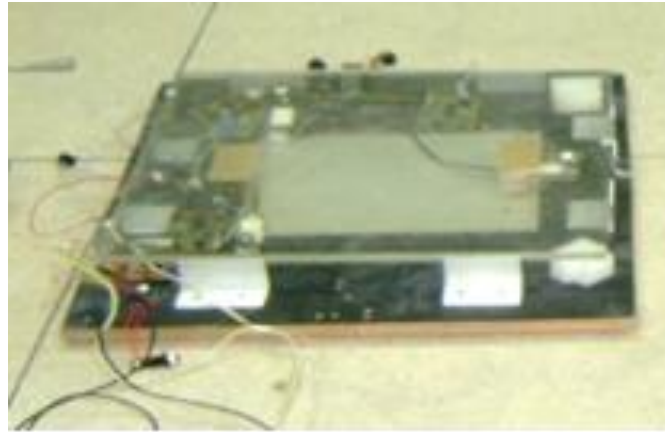
Table 1. Sample characteristics

	Athlete	
	Kumite specialist	Kata specialist
Age (ans)	24	22
Weight (kg)	75	68
Height (cm)	178	172

1.2. Materials

A stabilometry platform designed and developed for experimental purposes is depicted in Figure 1. Notably, the platform features an upper plexiglass plate with a thickness of 20mm, shaped in a square form measuring 52 cm on each side. This upper plate is supported by three load cells, which translate the applied compression force into an electrical signal proportional to the force exerted.

Fig. 1. Stabilometry Platform.



Micro accelerometers were placed on the upper part of the athlete's leading foot, on the hand of an operator (cf. figure 2) as well as on the target holder lever of the experimental bench. The first was designed for measuring reaction time, the second for stimulation and the third for synchronizing video images and data acquired on a PC.

Fig. 2. Accelerometer placed on the operator's hand for stimulation.



The athlete has also been fitted with two flexible FSR-type sensors to track pressure exerted on the heel and forefoot of the attacking foot to identify the contact surface in the step of putting the foot down. The sensor and its installation in an athlete's shoe are shown in Figure 3.

Fig. 3. FSR Sensor and Connection Wiring in an Athlete's Shoe.



1.3. Design and Procedure

Signal processing :

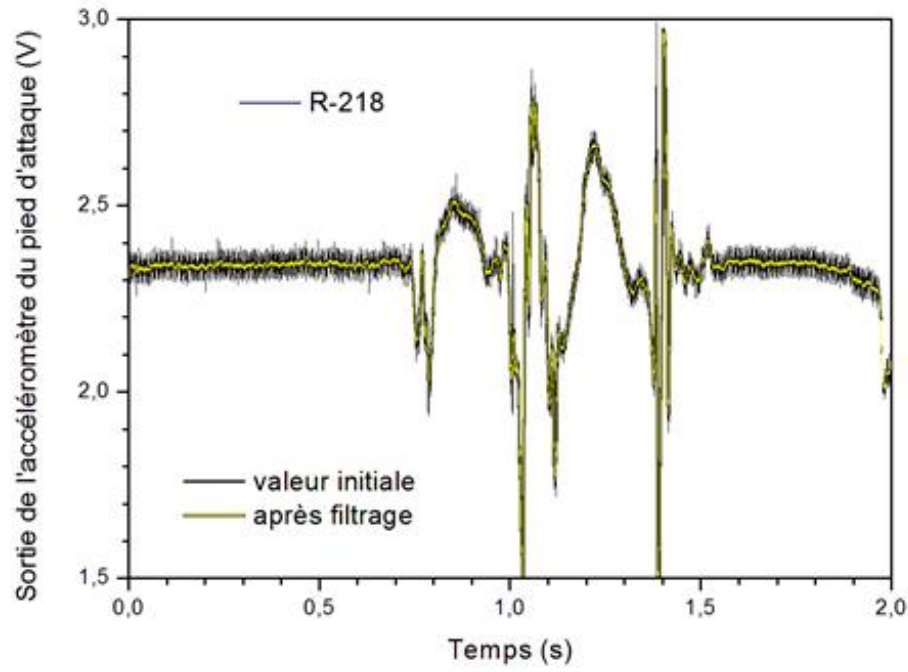
The study of human movement is based on data obtained by various measuring instruments. While the corresponding velocities and accelerations can be calculated from the displacement data, it is not possible to directly derive the raw data, in particular because of noise (interference scrambling the signal). The random variation of the signal is known as white noise. This noise interfering in the signal can have its source in the inaccuracy of the devices (Leroux et coll., 1990). To reduce noise in displacement data, smoothing and filtering techniques are often used. These techniques are essentially mathematical procedures minimizing white noise and random errors due to the digitization of the coordinates of joint landmarks. In the case of smoothing techniques, the fundamental assumption rests on the fact that the general shape of the curve is exact although each discrete data is marred by errors. Thus, to eliminate noise, we look for the curve that passes as close as possible to the raw data. For example, the equation of a line obtained by linear regression is a simplified expression of a smoothing technique. In biomechanics, the most common techniques are polynomial functions and splines (Leroux et coll., 1990).

You can also use a series of sines and cosines with varying amplitudes and frequencies. It is known as the Fourier series. Likewise, there is a variety of digital filters such as Butterworth, Elliptical or Wiener (Leroux et coll., 1990).

Figure 4 depicts the output voltage of the accelerometer positioned on the leading foot. The heavily noisy values were successfully filtered using the

"smooth" function provided by Origin software and the filtered signal after converting the voltages into acceleration values ($1g = 9.81 \text{ m/s}^2$).

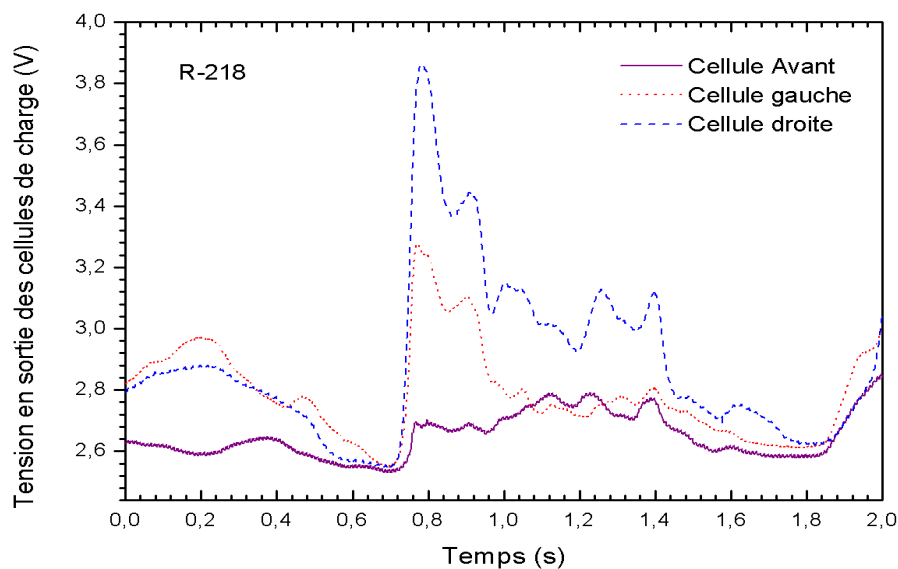
Fig. 4. Visualization of the electrical signal recorded on channel B.



1.4. Stabilometric signals:

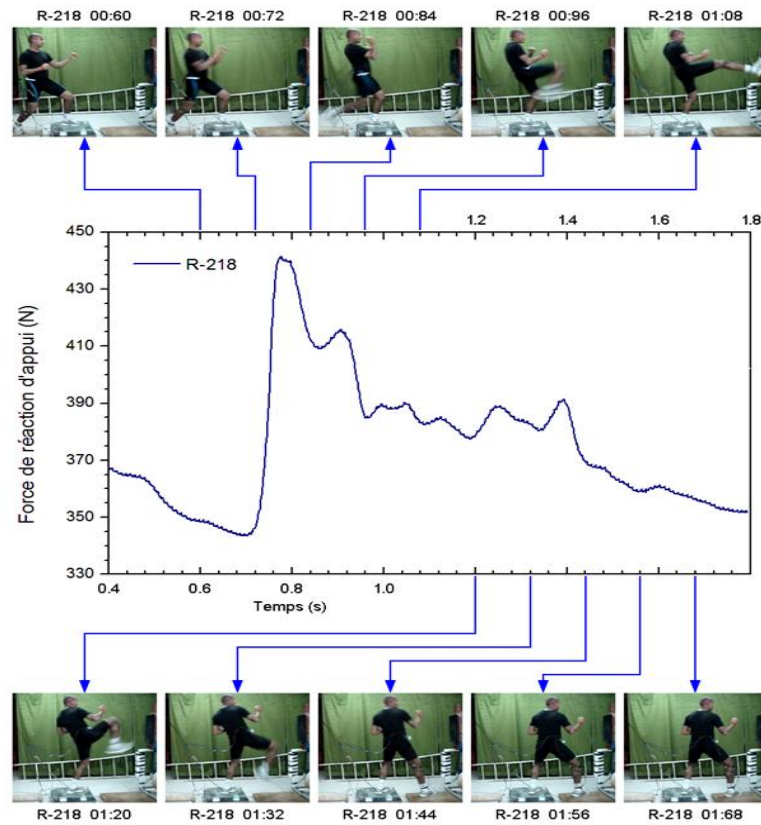
Figure 5 depicts the voltage output from the load cells placed beneath the platform of the stabilometry apparatus. The front cell corresponds to channel F, the left one to channel G, and the right one to channel H.

Fig. 5. Signals from channels F, G, and H corresponding to the load cells.



The ground reaction force determined from the signals of channels F, G, and H has been correlated with video images for interpretation (Figure 6).

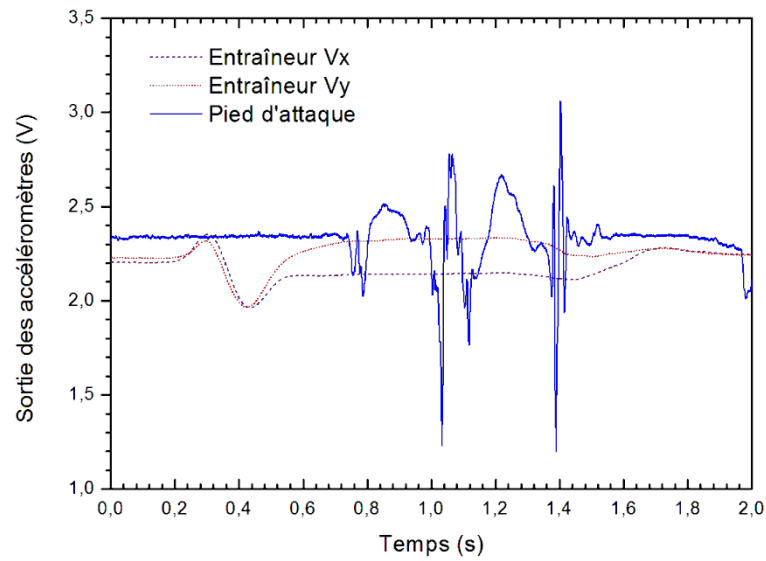
Fig.6. Correlation "ground reaction force spectrum" - "video images"



2. Results

Figure 7 shows the voltage output of accelerometer B mounted on the lead foot and the voltages at outputs D and E of the dual-axis accelerometer placed on the operator's hand. These signals were recorded during the execution of the maegeri movement on a target after stimulation. The movement performed by the operator is reflected in the variation of the Vx and Vy signals related to channels D and E. The time interval between the appearance of these variations and those observed on accelerometer B mounted on the lead foot indicates the athlete's reaction time to the visual stimulus. This type of excitation was chosen due to its consistency with the reality of karate.

Fig. 7. Signals from the accelerometers on the lead foot and the operator



Ground reaction force:

•Elite athlete specializing in Kumite

Fig.8. Ground reaction force on the force platform for the elite athlete specializing in Kumite

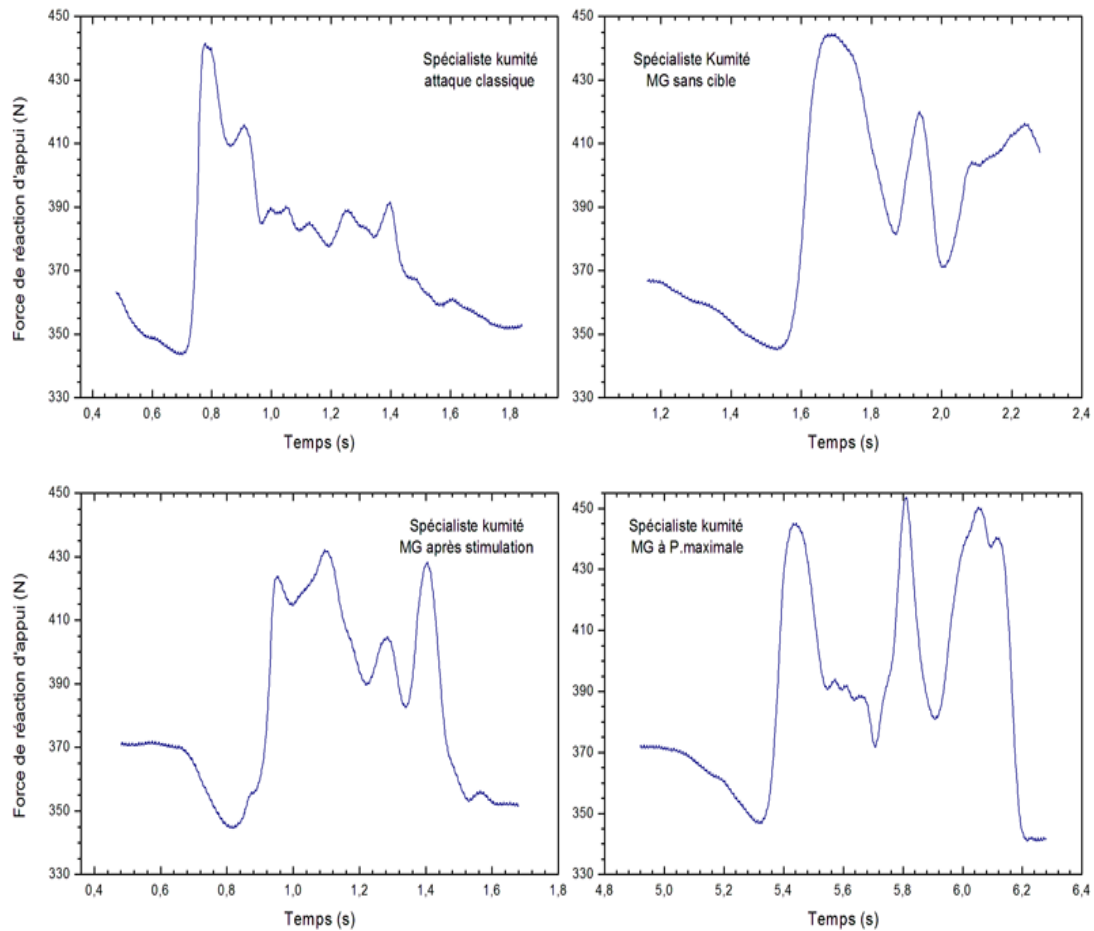


Figure 8 shows the spectrum of ground reaction force for the elite athletes specializing in Kumite under different execution conditions of the technique.

In the graph representing the classic attack or reference situation (attack on target), we notice that at the beginning of the movement, representing the weight transfer stage to the support leg, there is first a weight transfer to the rear leg. This stage represents the tensioning of the muscles involved in the movement to generate a propulsion force. Following this is the weight transfer stage to the front leg, represented by the peak seen on the graph. During the two stages of preparation and attack, we observe that the weight is progressively distributed between the two legs, even though the athlete is on a single-leg support. At the end of the movement, most of the weight is transferred to the front leg, and the athlete is on a double-leg support.

Changes in the execution conditions of the technique lead to modifications in the graph. Thus, in the condition of executing the technique

without a target and in the condition of executing the technique on a target after stimulation, we observe an accentuation of the peak representing the weight transfer to the front and the transition to single-leg support, followed by a second peak representing the return phase of the strike. The spectrum of the condition of executing the technique at maximum power shows three significant peaks, representing respectively the transition to single-leg support, the attack phase, and the return phase of the strike.

- **Elite athlete specializing in kata**

Fig. 9. Ground reaction force on the force platform for the elite athlete specializing in Kata

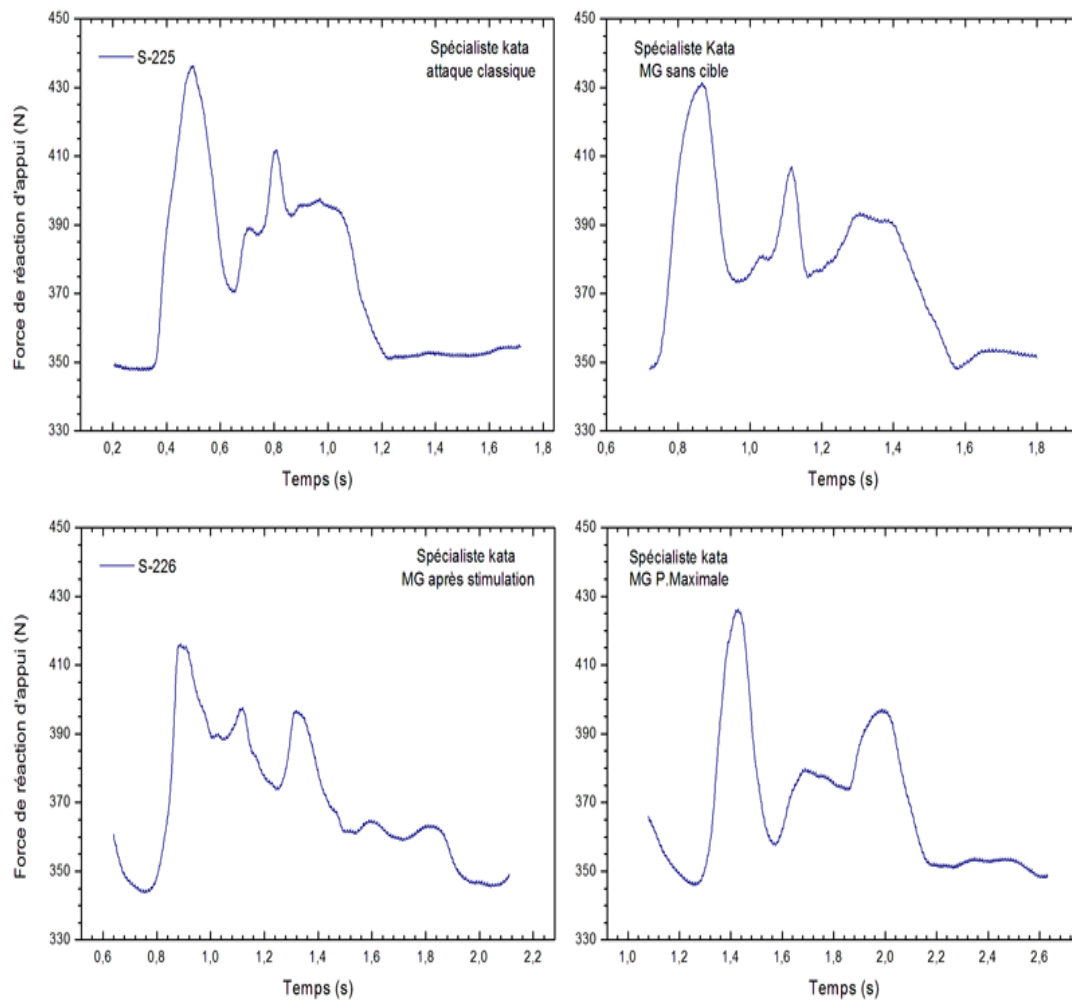


Figure 9 shows the spectrum of ground reaction force for the elite athletes specializing in Kata under different execution conditions of the technique.

We notice that these spectra show characteristics almost identical to those of the elite athletes specializing in Kumite, with less pronounced peaks. A significant difference is observed in the conditions of executing the technique on a target after stimulation and at maximum power. We do not record major differences in the spectra of the different execution conditions for this athlete.

It should be noted that despite the differences recorded, both athletes exhibit a high quality of balance given the restricted area within which their center of pressure moves. However, it is slightly better in the elite athletes specializing in Kata.

The reaction time was estimated at 0.42 seconds for the elite athletes specializing in Kumite and 0.53 seconds for the

elite athletes specializing in Kata. This may be due to adaptations related to the specific demands of the sport discipline and the specialization within the discipline or to the athlete's adaptation to the execution conditions of the technique.

3. Discussion

The analysis of ground reaction forces in elite athletes specializing in Kumite and Kata under various conditions reveals several key insights into their performance dynamics and physiological adaptations.

- **Similarities in Ground Reaction Force Spectra**

Both athletes, despite their specialization in different forms of Karate, exhibit remarkably similar ground reaction force spectra. This similarity suggests that the fundamental biomechanics involved in generating propulsion and maintaining balance during rapid movements are consistent across both disciplines. The peaks observed in the force spectra indicate stages of weight transfer, muscle tensioning, and propulsion that are critical for executing powerful and precise movements. This finding underscores the shared foundational techniques and training principles between Kumite and Kata.

- **Differences in Peak Force Magnitudes**

The primary difference noted between the two athletes lies in the magnitude of the peaks. The elite Kumite athlete displays more pronounced peaks, particularly under conditions involving maximum power and target stimulation. This can be attributed to the dynamic and combative nature of Kumite, where rapid, forceful movements are essential for both offense and defense. In contrast, the peaks for the Kata specialist are less pronounced, reflecting the emphasis on controlled, precise movements characteristic of Kata performance. This variation highlights the impact of discipline-specific demands on the athlete's biomechanical output.

- **Execution Conditions and Force Spectra Variability**

The Kumite athlete's force spectra show distinct peaks corresponding to different execution conditions, such as target stimulation and maximal power execution. These peaks represent the transition to single-leg support, the attack phase, and the return phase of the strike. This variability indicates a

higher degree of responsiveness to different stimuli and the need for explosive power in Kumite.

Conversely, the Kata athlete's spectra exhibit less variability across different conditions, suggesting a more consistent execution pattern. This consistency is likely due to the emphasis on form, precision, and fluidity in Kata, where movements are performed with a high degree of control and repeatability.

- **Balance and Reaction Time**

Both athletes demonstrate exceptional balance, as evidenced by the restricted area within which their center of pressure moves. However, the Kata specialist shows slightly better balance, likely due to the disciplined and deliberate nature of Kata training, which emphasizes stability and control.

The reaction time difference, with the Kumite athlete at 0.42 seconds and the Kata athlete at 0.53 seconds, may reflect the specific demands of their respective disciplines. The faster reaction time in Kumite is crucial for effective combat performance, where quick responses to an opponent's actions are vital. The slightly slower reaction time in Kata could be due to the focus on the precision and intentional execution of each movement rather than speed.

- **Implications for Training and Performance**

The observed differences in ground reaction forces and reaction times highlight the importance of tailored training programs for each discipline. For Kumite athletes, training should focus on enhancing explosive power, speed, and rapid responsiveness. In contrast, Kata athletes should emphasize balance, precision, and the controlled execution of techniques. Understanding these nuances allows coaches and athletes to optimize their training regimens, improving performance and reducing the risk of injury.

4. Conclusion

The comparative analysis of elite athletes specializing in Kumite and Kata provides a profound understanding of the intricate interplay between shared biomechanical foundations and discipline-specific adaptations in Karate. This study reveals both the commonalities and distinct differences in how these athletes generate and manage ground reaction forces during their respective movements, offering key insights into their training, performance, and physiological responses.

Despite the different focuses of Kumite and Kata, the fundamental biomechanics involved in executing powerful and precise movements are remarkably similar. Both disciplines require a robust foundation of muscle tensioning, weight transfer, and propulsion to perform effectively. This common ground suggests that core Karate principles and techniques are universally applicable, providing a solid base for training across different forms of the martial art.

However, the distinct nature of Kumite and Kata leads to unique adaptations in the athletes' performance dynamics.

The pronounced peaks in the ground reaction force spectra of Kumite athletes reflect the high demands for explosive power and rapid movements necessary for combat scenarios. The variability in force spectra under different conditions, such as target stimulation and maximum power execution, indicates a higher degree of responsiveness and adaptability. Faster reaction times in Kumite are essential for effective defense and counter-attacks, highlighting the importance of speed and agility in this discipline.

In contrast, Kata athletes exhibit more consistent force spectra with less pronounced peaks, emphasizing controlled, precise movements. The slightly better balance and controlled execution patterns observed in Kata athletes underscore the discipline's focus on form, stability, and fluidity. The slightly slower reaction times, while indicative of a deliberate execution style, do not detract from the overall performance, as precision and intentionality are paramount in Kata.

These findings have significant implications for training programs tailored to each discipline. For Kumite athletes, training should prioritize enhancing explosive power, speed, and rapid responsiveness to improve performance in dynamic combat situations. Drills that simulate real combat scenarios and enhance quick reaction times are crucial. Strength and conditioning programs focusing on plyometric exercises, agility drills, and reaction training can be beneficial.

For Kata athletes, the emphasis should be on perfecting balance, precision, and the controlled execution of techniques. Training should include exercises that enhance stability, such as core strengthening and proprioceptive training. Practicing Kata forms repeatedly to refine technique and improve muscle memory is essential. Flexibility and coordination exercises can further enhance the fluidity and grace of movements.

Beyond the specific context of Karate, this study contributes to the broader field of sports science by demonstrating how detailed biomechanical analysis can inform training and performance optimization. Understanding the specific demands of different athletic disciplines allows for the development of targeted training strategies that cater to the unique needs of athletes. This approach not only improves performance but also reduces the risk of injury by addressing discipline-specific stressors and movement patterns.

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