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Is isometric mid-thigh pull associated with the competitive performance of striking high-level athletes?
¿El isometric mid-thigh pull está asociado con el desempeño competitivo en atletas striking de alto-rendimiento?

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Abstract. Background: The isometric mid-thigh pull test (IMTP) is commonly used in sports performance assessment, but it remains underutilized among combat sports athletes. Aims: to evaluate whether Pan-American medalists (PM) showed differences when compared with other athletes (NM) when performing the IMTP. Methods: a total of 72 Karate [n=35 (♀12)] and Taekwondo [n=37 (♀15)] athletes were measured (22.4±3.7 yrs.; 67.4±11.5 Kg; 1.7±0.1 m; 22.1±2.8 kg/m^2). From the total, 32 athletes were PM of their specific combat sport (♀11). All participants performed the IMTP 60-90 days before the competition. The following variables were measured: a) Impulse Net at 50; 100; 150 and 200 ms (N*s); b) absolute (N) and relative peak force (PF; N/Kg) and; c) Rating of force development (RFD) at 50; 100; 150 and 200 ms (N/s). Results: PM showed a better performance on absolute (2,398.5±623.1 vs. 2,096.2±559.3 N; p=0.034) and relative PF (34.6±5.0 vs. 31.2±5.1 N/Kg; p=0.006); RFD at 150 (5,273.4±2,670.8 vs. 3,963.4±1,904.2 N/s; p=0.0018) and 200ms (4,870.3±2,184.6 vs. 4,022.1±1,574.8 N/s; p=0.05). Relative PF (Τ=0.249; p=0.011) and RDF at 150 ms (Τ=0.208; p=0.033) showed a positive and significative correlation with the competition result. Conclusion: PM showed a high PF and RFD at 150 and 200 ms. Furthermore, the competition result was correlated with relative PF and RDF at 150 ms. Based on our findings, we recommend that coaches incorporate the IMTP into their evaluation routine for striking athletes.
Keywords: martial arts, athletic performance, elite athlete, task performance and analysis.

Resumen. Antecedentes: La prueba isométrica de tracción a medio muslo (IMTP) se utiliza comúnmente en la evaluación del rendimiento deportivo, pero sigue siendo subutilizada entre los atletas de deportes de combate. Objetivos: evaluar si los medallistas panamericanos (PM) mostraron diferencias con otros atletas (NM) al realizar la prueba isométrica de tracción de la mitad del muslo (IMTP). Métodos: se midieron un total de 72 atletas de Karate [n=35 (♀12)] y Taekwondo [n=37 (♀15)] (22,4±3,7 años; 67,4±11,5 Kg; 1,7±0,1 m; 22,1±2,8 kg/m2). Del total, 32 atletas fueron PM de su deporte de combate específico (♀11). Todos los participantes realizaron el IMTP entre 60 y 90 días antes de la competición. Se midieron las siguientes variables: a) Impulso a 50; 100; 150 y 200 ms (N*s); b) pico de fuerza (PF) absoluta (N) y relativa (PF; N/Kg) y; c) tasa de desarrollo de fuerza (RFD) en 50; 100; 150 y 200 ms (N/s). Resultados: PM presentaron mejor desempeño de PF absoluta (2.398,5±623,1 vs. 2.096,2±559,3 N; p=0,034) y PF relativa (34,6±5,0 vs. 31,2±5,1 N/Kg; p=0,006); RFD a 150 (5.273,4±2.670,8 vs. 3.963,4±1.904,2 N/s; p=0,0018) y 200 ms (4.870,3±2.184,6 vs. 4.022,1±1.574,8 N/s; p=0,05); El PF relativo (Τ=0,249; p=0,011) y el RDF a 150 ms (Τ=0,208; p=0,033) mostraron una correlación positiva y significativa con el resultado de la competición. Conclusión: medallistas mostraron un PF y un RFD elevados a 150 y 200 ms. Además, el resultado de la competición se correlacionó con el PF y el RDF relativos a 150 ms. Con base en nuestros hallazgos, recomendamos que los entrenadores incorporen el IMTP en su rutina de evaluación para los atletas que golpean.
Palabras clave: artes marciales, rendimiento atlético, deportista de élite, análisis y desempeño de tareas.

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Introduction

The strength and power of the lower limbs play a crucial role in performance in striking combat sports such as Taekwondo and Karate (Ball et al., 2011; Chaabène et al., 2014; Jia et al., 2024; Przybylski et al., 2021; Quinzi et al., 2022). This combat sports requires a unique combination of physical and technical skills, where the effectiveness of movements depends on the strength and power of the lower limbs (Guan et al., 2021; Jia et al., 2024; Quinzi et al., 2022). Therefore, the ability to generate force in the legs and efficiently coordinate power is crucial to achieving optimal performance (Ball et al., 2011; Guan et al., 2021; Quinzi et al., 2022). To this end, an in-depth understanding of the importance of these physical attributes not only enriches the practice of these sports, but can also contribute to develop more effective training methods, promoting athletic excellence and preventing injuries (Quinzi et al., 2022; Ryu & Lee, 2021). The ability of athletes in Taekwondo to quickly generate muscular force through kicks is fundamental, since 80% of attack actions are performed by the lower limbs (Ball et al., 2011). Differently, in Karate kumite competitions there is a higher predominance of punching compared to kicking actions, whether for attack or counterattack actions (Chaabène et al., 2014). However, high-performance is dependent on the strength and speed exerted by the legs (Przybylski et al., 2021), because the power of the lower limbs is an important predictor of the speed of punches applied during the kumite (r = 0.66–0.80) (Quinzi et al., 2022).

Given the importance mentioned above, it has been recommended to use tests which are capable of measuring and differentiating the strength and power of the lower limbs in Taekwondo and Karate fighters (Jia et al., 2024; Nowakowska et al., 2017; Zhang & Wang, 2023). Recent literature highlights the widespread use of jump tests, particularly the countermovement jump (CMJ), to evaluate performance in striking athletes (Álacks Antonietto et al., 2024; Vagner et al., 2024; Zhang & Wang, 2023). Álacks Antonietto et al. (2024) emphasized that stiffness in the CMJ is a significant variable for predicting the speed of the roundhouse kick (*bandal-chagi*) in Taekwondo international athletes. Alongside these jump tests, the isometric mid-thigh pull test (IMTP) has gained attention in recent years and is now recommended as a valuable component of physical assessment batteries for athletes (Beckham et al., 2013; Grgic et al., 2022). This is an easy and quick application test which enables evaluating the strength characteristics of athletes through an analysis of the force-time curve (Brady et al., 2018). This test was designed to reliably and accurately analyze both peak force production and the rate of force development in different temporal domains (Brady et al., 2018; Dos' Santos et al., 2017). Furthermore, IMTP minimizes the induction of fatigue and stands out for its temporal efficiency when compared to the one maximum repetition test (Dos' Santos et al., 2017). It is also a test which has reliability varying from good to excellent (Grgic et al., 2022).

Although the applicability of the IMTP for performance assessment is recognized, there are few studies which have applied this test to combat sports athletes. A case study with the aim of profiling a professional boxer revealed that the athlete lost 8% of his IMTP performance in the week before the combat (Halperin et al., 2016). In college wrestlers, McGuigan et al. (2006) observed a positive correlation between IMTP and one maximum repetition. Therefore, there is low application of IMTP in combat sports athletes. We believe that this test can be used by coaches and evaluators to differentiate the performance of fighters, as the IMTP has shown an associative capacity with the performance of Netball (Thomas et al., 2017), soccer (Dos' Santos et al., 2018), basketball (Townsend et al., 2019) and rugby athletes (Wang et al., 2016). However, to the best of our knowledge, no study has applied IMTP to measure and differentiate the performance of combat sports athletes. Thus, the present study aimed to compare whether Pan-American Karate and Taekwondo medal-winning athletes differ from others in terms of performance in the IMTP. We hypothesized that medal-winning had a higher impulse, peak force and rate of force development (RFD) when compared to the others.

Methods

Experimental approach

This protocol was designed to verify whether the result obtained in a Pan American championship by a striking fighter is related to the performance in the IMTP. This project was approved by the university where the data were collected (protocol: 275/2024). After approval, the researchers invited athletes who met the inclusion criteria to participate in the study.

IMTP and anthropometric were carried out between 60-90 days of the competitions. The following Pan-American championships occurring in 2022-23 were considered to compute the competitive results: a) Taekwondo – Open (Punta Cana 2022 and Florianopolis 2023); b) Karate – Sub-21 (Mexico City 2022 and Santiago 2023); Open (Santiago 2022 and Bogotá 2023). For inferential analyses, participants were allocated into two comparative groups: a) Medalists (those who reached the podium in competitions; i.e. 1st, 2nd, or 3rd place); and b) non-medalists (other results).

Participants

The following inclusion criteria were adopted for the present study: a) being Taekwondo or Karate athletes of both sexes; b) age ≥18 years; c) be among those selected to compete in the Pan American championship of their combat sport. In turn, the following participants were excluded: a) those where there was an error during data collection; b) those who did not participate in all stages; and c) those who wished to withdraw from the study. Therefore, the final sample was composed of 72 athletes (27♀), of which 37 (15♀) were from Taekwondo and 35 (12♀) from Karate. In addition, 17 (45.9%) from Taekwondo won a medal (7♀), while 15 (4♀) from Karate were medalists (42.9%). Table 1 shows the age and anthropometric characteristics of participants. When performing paired comparisons by sex, there were no differences between medalists and non-medalists ($p>0.05$) for the variables presented in Table 1.

Table 1.
Age and anthropometric characteristics of participants.

	Medalists (n=32)	Non-medalists (n=40)	Total (n=72)
Age (years)	22.3 ± 3.8	22.4 ± 3.6	22.4 ± 3.7
Body mass (kg)	66.6 ± 12.7	68.3 ± 10.0	67.3 ± 11.5
Height (m)	1.7 ± 0.1	1.8 ± 0.1	1.7 ± 0.1
Body mass index (Kg/m^2)	22.1 ± 3.1	22.0 ± 2.3	22.0 ± 2.8

IMTP performance

The athletes initially received guidance from the researchers on how to perform the IMTP, followed by a warm-up consisting of stretching exercises, joint movements of the shoulders, knees and hips according to the recommendations by Comfort et al. (2019). IMTP was performed on two force platforms (Model PS-2142; sampling: 50-1000Hz; Range: -1000 to 4400N over 6600N; Resolution: 0.34N; dimensions 350mm x 350mm, PASCO® Instrument Inc., USA), which were supported on a specific apparatus for this test as exemplified in Figure 1. The Hack was individually adjusted to meet the required hip and knee angulation (Peterson Silveira et al., 2017). The sampling was set at 1000Hz, since it has shown good reliability in force-time variables (Dos' Santos et al., 2017). The initial position was individualized to each athlete, with all partici-

2024, Retos, 60, 527-533

pants holding the bar straight and keeping their arms relaxed with a hip flexion angle approximate 130-140° and a knee flexion angle of approximately 145º (measured with a goniometer), keeping the trunk erect. These angles were selected because they increase the reliability of the test (Brady et al., 2018).

Before performing the first attempt, participants were encouraged to perform a small tension (≤50 newtons over their body weight) to check whether there was a need for adjustments to the equipment or body position. Once the starting position was verified, the evaluator performed a negative count starting at 5 and encouraged the performer to maintain a maximum effort during 5 seconds. The rest time between each effort was 120 seconds; if necessary, the test was repeated until 3 valid attempts were achieved. The best result between the attempts was analyzed. The cut-off point of intraclass correlation coefficient (ICC) ≥0.7 and 15% of coefficient variation (CV) between attempts was used for internal validation, as suggested by Drake et al. (2017). Those with ICC <0.7 repeated the tests on another day. The Capstone 2.0 software (Pasco company, California, United States) was used to capture the signal emitted by the platforms and the data was processed by MATLAB 2022 (MathWorks®, Inc., Natick, Massachusetts, United States).

The test for data collection was started after ground-reaction force increased 40 N from the average of body weight, with this onset calculated according to the recommendations by Dos' Santos et al. (2017) to achieve better reliability of the attempt. The impulse (average Force × Δ Time; N*s) and RFD (ΔForce/ΔTime; N/s) were measured at 50, 100, 150 and 200 milliseconds after starting the attempt in each trial. Maximum force developed by each repetition was measured as the absolute peak force (N), and this data was applied to calculate the relative peak force by body mass (N/Kg). All data collected was performed following the recommendations by Brady et al. (2018).

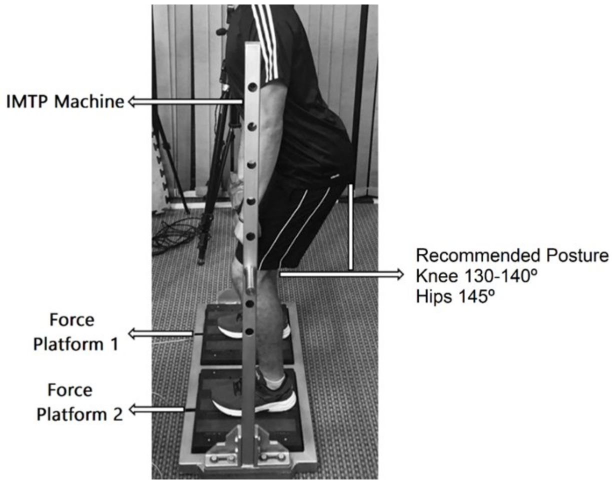

Figure 1. Starting position to perform the Isometric Mid-Thigh Pull test (IMTP).

Statistical analysis

The data were initially tabulated in SPSS software spreadsheets (version 22.0). The Kolmogorov-Smirnov test was performed to verify the distribution of all variables. Data that presented a normal curve were analyzed using the T-test for independent samples (i.e., Impulse at 200ms, relative peak force and RFD at 150 and 200ms), while the others were analyzed using the Mann-Whitney test. Since no variable violated the normality assumptions, the T-test for independent samples was performed to compare medalists vs. other athletes. The effect size (ES) in all comparisons was calculated by Cohen's d' and r' for parametric and nonparametric data respectively, in accordance with the recommendations of Fritz et al. (2012). Kendall (Tau) non-parametric correlation was performed to measure the association of the competition result (i.e., PM or NM vs. IMTP variables). Finally, p≤0.05 was adopted as the significance value in all tests.

Results

Table 2 shows the results for IMTP comparing the medalists versus non-medalists. The comparison between the groups showed a difference for absolute (p=0.034; r'=0.3) and relative peak of force (p=0.006; d'=0.93) and RDF at 150 (p=0.018; d'=0.56) and 200ms (p=0.05; d'=0.44). Only absolute peak force showed a small ES, the other significant variables showed medium and large ES.

Table 2.
Descriptive and inferential statistics for the IMTP test for the medalists and non-medalist striking athletes.

IMTP	Medal	Result	ICC (90% CI)	%CV (90% CI)
Impulse Net, 50 ms (N.s)	NM	21.1 ± 21.0	0.8 (0.65; 0.91)	10.0 (9.2; 12.9)
	PM	11.5 ± 12.1	0.82 (0.7; 0.9)	9.1 (8.2; 11.6)
Impulse Net, 100 ms (N.s)	NM	53.1 ± 44.8	0.83 (0.68; 0.92)	9.8 (8.3; 11.8)
	PM	37.5 ± 24.4	0.81 (0.74; 0,88)	9.9 (8.6; 12.5)
Impulse Net, 150 ms (N.s)	NM	96.3 ± 68.9	0.82 (0.72; 0.94)	9.7 (8.6; 12.0)
	PM	79.5 ± 39.3	0.87 (0.79; 0.96)	9.6 (9.0; 12.2)
Impulse Net, 200 ms (N.s)*	NM	149.4 ± 91.6	0.86 (0.73; 0.93)	10.1 (8.9; 12.1)
	PM	134.2 ± 53.8	0.81 (0.72; 0.89)	9.9 (9.0; 12.3)
Peak force (N)	NM	2,096.2 ± 559.3	0.92 (0.89; 0.96)	4.9 (4.0; 5.8)
	PM	2,398.5 ± 623.1 [a]	0.9 (0.85; 0.95)	4.7 (3.9; 5.8)
Peak force /BM (N/kg)*	NM	31.2 ± 5.1	0.89 (0.73; 0.96)	5.1 (4.2; 6.0)

	PM	34.6 ± 5.0 [a]	0.86 (0.77; 0.91)	5.5 (4.8; 6.3)
RFD 50 ms (N/s)	NM	2,366.2 ± 1,535.4	0.82 (0.65; 0.91)	9.5 (8.4; 17.1)
	PM	2,788.8 ± 1,669.2	0.8 (0.7; 0.93)	9.3 (8.2; 16.1)
RFD 100 ms (N/s)	NM	4,009.3 ± 2,390.1	0.92 (0.88; 0.95)	5.5 (3.8; 6.5)
	PM	5,039.8 ± 2,902.4	0.91 (0.89; 0.96)	5.8 (3.9; 6.9)
RFD 150 ms (N/s)*	NM	3,963.4 ± 1,904.2	0.86 (0.77; 0.97)	9.9 (8.2; 14.9)
	PM	5,273.4 ± 2,670.8 [a]	0.88 (0.79; 0.95)	9.6 (7.9; 15.5)
RFD 200 ms (N/s)*	NM	4,022.1 ± 1,574.8	0.92 (0.82; 0.96)	7.6 (4.9; 10.8)
	PM	4,870.3 ± 2,184.6 [a]	0.9 (0.89; 0.97)	8.5 (5.4; 11.1)

IMTP: Isometric mid-thigh pull test; NM: Non-medalist; PM: Pan-American Medalist; ICC: intraclass correlation coefficients; %CV coefficient of variation. 90%CI: 90% confidence interval. * Data compared by T-test p≤0.05. [a] p≤0.04 vs. non-medalist.

Table 3 shows the results by correlations between the competition result and IMTP variables.

There was a significant correlation for the relative PF and RFD at 150 ms (p≤0.033).

Table 3.
Correlations between competition result and isometric mid-thigh pull test variables.

IMTP Variables									
Impulse (N*s)				Peak force		Rating of force development (N/s)			
50 ms	100 ms	150 ms	200 ms	Absolute (N)	Relative (N/Kg)	50 ms	100 ms	150 ms	200 ms
T=-0.142; p=0.147	T=-0.081; p=0.408	T=-0.044; p=0.65	T=-0.029; p=0.768	T=0.185; p=0.058	T=0.249; p=0.011	T=0.115; p=0.239	T=0.163; p=0.096	T=0.208; p=0.033	T=0.147; p=0.132

Discussion

Previous studies have shown the predictive power of IMTP in relation to the performance of rugby (Wang et al., 2016) and basketball (Townsend et al., 2019) athletes. In addition to the previously researched sports, the lower limb strength proved to be an important variable to determine the performance of Karate (Quinzi et al., 2022) and Taekwondo (Álacks Antonietto et al., 2024; Ball et al., 2011) athletes. To the best of our knowledge, this is the first study to verify whether the IMTP performance is associated with the competitive result of high-performance athletes in two striking Olympic combat sports. Our main results indicated that athletes who reached the podium in Pan-American Karate and Taekwondo championships showed a better result for the absolute and relative peak of force and RFD at 150 and 200ms when performing the IMTP. Moreover, there was a significant correlation between the RFD at 150ms and relative PF with medal result. In recent studies, some authors have endeavored to correlate test results, whether generic (Barley et al., 2019) or specific (Chaabene et al., 2018), with the outcomes in combat sports. This effort represents a significant challenge due the intricate technical demands inherent in striking combat sports performance (Barley et al., 2019; Chaabene et al., 2018). In this line, the systematic review performed by Chaabene et al. (2018) showed that are biases in studies which carried out physical tests in combat sports athletes, as 74% had less than 30 participants, while approximately 30% did not present a description of the participants. In addition, the vast majority only quantified the participants' performance in the test and did not measure or correlate them to competitive performance. These gaps show the importance of carrying out new testing protocols on fighters, especially those that can help coaches select the most apt athletes, and can be used to guide the physical aim to achieve high performance.

Maximal isometric tests are currently preferred for measuring athletic performance to the detriment of dynamic tests such as the 1RM test (Dos' Santos et al., 2017). Among the advantages are simpler administration, reliability and reproducibility of results and lower risk of injury during the test (Dos' Santos et al., 2017; Drake et al., 2017; Grgic et al., 2022). In this context, IMTP has become increasingly popular in recent years as part of the assessment routine in different sports (Brady et al., 2018; Chaabene et al., 2018; Grgic et al., 2022). Another interesting advantage of IMTP is being able to analyze the force-velocity curve and obtain important information that determines performance, such as peak force and RFD (Brady et al., 2018; Chaabene et al., 2018). The peak force results from the ground force reaction applied by the feet of the subject during the IMTP performance (Beckham et al., 2013). When analyzing the specific literature, it is observed that peak force has been the main variable analyzed in the test, as it is the most reliable measure to be reported due to the consistency of the results (Brady et al., 2018).

Medalists showed a peak force ≈15% higher when compared to non-medalists. Our results are in agreement with other studies which IMTP showed to be able to differentiate athletes in terms of sporting level (Beckham et al., 2013; Darrall-Jones et al., 2015; Stone et al., 2004). In this sense, Stone et al. (2004) observed that cyclists with higher peak force had a higher sprint speed . Specifically , we believe that the difference in peak force for striking is transferred to faster and more powerful attacks . In this context , Álacks Antonietto et al. (2024) found that, when evaluating elite Taekwondo athletes using the squat jump, peak force at takeoff was a predictor of *bandal-chagi* kick speed. Furthermore , in a study with kinematic analysis with Taekwondo athletes (elite x sub-elite comparison), Moreira et al. (2016) observed that elite competitors pre- sent a higher ground force reaction when performing the roundhouse kick (*bandal -chagi*). Furthermore, Quinzi et al. (2022) observed that karatekas with greater lower limb power performed high powerful punches (*kizami tsuki* and *gyaku tsuki*).

In addition to peak force, RFD provides insight into the ability to rapidly generate force during the initial phase of muscle contraction (McGuigan et al., 2006; Stone et al., 2004). Kavvoura et al. (2018) suggest that this variable is crucial for Taekwondo performance. Thus, the isolated analysis of peak force makes the interpretation of the test result incomplete, as RFD can show how much this maximum force can be used by the athlete during a movement (Giles et al., 2022). In this context, the combined analysis of peak force and RFD can show coaches which athletes have strength and are slow (high peak force low RFD), or athletes who are fast but have low strength (low peak force and high RFD) (Brownlee et al., 2018). Our results indicated that medalists showed higher RFD at 150 ms (≈ ↑33%) and 200 ms (≈ ↑20%). Such findings suggest that medalists differ in terms of their ability to sustain applied force. Considering that striking combat athletes such as Taekwondo (Antonietto et al., 2023) and karate (Chaabène et al., 2014) spend most of the time in preparation and then carry out powerful attacks, the efficiency of these attacks is crucial to win a match. We believe that fighters with higher RFD are able to express and sustain the force during a movement, whether attacking, counterattacking or in defense. In fact, the ability to move faster and anticipate the opponent is one of the factors that differentiate winners in Karate (Vidranski et al., 2015) and Taekwondo (Antonietto et al., 2023). In Taekwondo, Álacks Antonietto et al. (2024) found that the RFD in the non-dominant lower limb is crucial for the velocity of kicks delivered with the dominant rear leg.

It is therefore suggested that winning fighters are able to transfer the RFD to movements where they need to be more agile against the opponent. Results similar to ours were observed in football players, where RFD at 150 and 200 ms showed a high correlation with maximum sprint speed (Mason et al., 2021). Leary et al. (2012) observed that applying force to the lower limbs in golfers between 150 and 200 ms is an important skill for producing powerful shots.

Impulse is another of the variables obtained in IMTP which enables analyzing the force-time curve (Comfort et al., 2019). This variable is calculated by the force applied in Δ time (Brady et al., 2018). Our results showed no significant differences between the two groups. Previous studies have shown that isometric impulse is a good predictor of performance in sprints (Thomas et al., 2015), squat jumps and countermovement jumps (Tran et al., 2015). Comfort et al. (2019) considers that the information obtained through isometric impulse is useful, however, few studies have adequately explored its use, so more investigations are needed to understand the applicability of this measure for athletes.

As this is the first study to show such results and considering that performance in combat sports is multifactorial (Wąsacz et al., 2023), it is important to observe whether our data will be consistent in future protocols. Furthermore, although we observed correlations between IMTP variables and the competitive result, the correlations are considered weak based on the criteria recommended by Gignac and Szodorai (2016). Our protocol sought to bring IMTP closer to real competitive performance. In general, studies have compared IMTP to other isolated tests such as jumps (Tran et al., 2015), sprints (Thomas et al., 2017) and change of direction tests (Brownlee et al., 2018; Thomas et al., 2015). It is also worth noting that this protocol analyzed a mixed sample; future studies may also verify that there are differences in terms of gender or age categories. It is also important to highlight that the comparison of our results must be done with caution, as there is no unanimity regarding the method for calculating the RFD, as well as the time subunits (Brady et al., 2018; Chaabene et al., 2018). On the other hand, we presented the ICC and CV in all measurements, which is a limitation observed in previously published papers (Grgic et al., 2022). Although there is no predetermined standard for acceptance of these measures, Hopkins (2000) recommends ICC ≥ 0.80 and a CV ≤ 10% as a minimum threshold, which was observed in all measurements in the present study. Based on our aims, applied methods, results and limitations, we conclude that Pan-American medalists in Karate and Taekwondo showed a better performance for peak-force and RFD during an IMTP test.

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