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Effects of eight weeks incremental elastic resistance training on roundhouse kick quality and physical performance in Taekwondo athletes in a randomized controlled trial

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This study aimed to evaluate the effects of an 8-week incremental elastic-resistance kick training program on roundhouse kick performance and physical fitness in youth Taekwondo athletes, compared to conventional training methods. A two-group parallel, randomized, quasi-experimental design was employed, dividing participants into an experimental group (*n* = 11, age: 15.5 ± 1.6 years, stature: 171.6 ± 9.6 cm, body mass: 59.2 ± 15.0 kg; training experience: 8.3 ± 1.9 y) and a control group (*n* = 10, age: 14.8 ± 1.1 years, stature: 164.0 ± 7.2 cm, body mass: 51.9 ± 12.8 kg; training experience: 7.5 ± 1.3 y). Both groups tailored training regimens integrated with their regular Taekwondo practice. The study assessed multiple performance metrics, including roundhouse kick average velocity, impact scoring, isometric muscle strength, countermovement jump performance, and simple reaction times. The findings indicate that elastic resistance training significantly enhances Roundhouse Kick average velocity and impact scoring while also improving specific physical fitness attributes. This study contributes to understanding the role of ER training in combat sports and provides insights into optimizing Taekwondo training regimens.

Keywords Youth, Performance, Strength

Performance in Taekwondo is heavily influenced by the unique physical characteristics of the athlete. Consequentely, it is essential that training regimens are meticulously designed to develop and optimize these specific attributes[1,2]. The selection of appropriate fitness training methods is closely linked to the physiological demands of combat scenarios. Notably, Taekwondo athletes display pronounced peak power in their lower limbs, which enables the generation and maintenance of power output through both concentric and "stretch-shortening cycle" muscle actions. This quality has been shown to play a critical role in achieving success at the international level[2]. Explosive power, defined as the rate of force production during a single movement or repetition, is a key physical attribute in Taekwondo[3].

The anaerobic ATP supply rate is crucial for the development of high power output[4]. A decline in force production during short, high-intensity intermittent exercise can result from either an impaired rate of ATP re-synthesis or a reduced rate of ATP utilization by the contractile machinery[5,6]. Under combat scenarios, the anaerobic-alactic energy pathways have been shown to contribute approximately 66 ± 6% of the total energy demand[6,7]. Therefore, the assessment of anaerobic-alactate power level expands the field of interventional effects.

Athletes rely on muscle strength to effectively perfom technical combat maneuvers, including blocking, grappling, and pushing[2,8]. Discussions on muscle strength in Taekwondo often focus on dynamic and maximal strength, typically assessed using field-testing methods. Research indicates that enhancing lower limb muscle can significantly improve both static and dynamic balance[9,10]. It is important to recognize that muscle strength

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is not only the ability to exert maximal force but is also closely linked to movement speed[11]. Given that speeds is inherently sport-specific, researchers have sought to develop assessments that are tailored to the technical actions performed in Taekwondo[12]. Using electronic dual-beam timing technology, studies have consistently shown that males athletes exhibit faster kicking speeds than females, further emphasizing that kicking speed depends on the specific technique used[13]. In a study by Falco et al.[14], a specialized apparatus- comprinsing a force platform and contact sensors embedded in a manikin's body armor - was used to demonstrate that competitive Taekwondo athletes achieve significantly higher turning kick speeds compared to their non-competitive counterparts.

Jakubiak and Sounders[15] assert that the majority (98%) of points in Taekwondo competition are earned through kicking techniques. Among these, numerous studies have highlighted the Roundhouse Kick (RHK) as one of the critical skills in Taekwondo combat[14,16,17]. This technique is frequently utilized for scoring points due to its speed and ability to deliver powerfull attacks. The effectiveness of the RHK is influenced by several factors, including the target's height, execution distance, and the athletes' skill level[16]. Key criteria for evaluating the quality of a RHK include impact force and execution time[14,18]. Previous research has reported a range of impact forces in male Taekwondo athletes, varying from 1000 N to 3000 N[19]. Additionally, studies consistently show that competitors outperform non-competitors in terms of both impact force and execution precision[14,17]. The execution time of head-directed kicks has been observed to range between 0.270 and 0.400 s, depending on the athlete's skill level and the selected kicking distance[19,20]. In real-world scenarios, the execution time of a kick is closely associated with perceptual skills, one of which is reaction time. Reaction time is defined as the interval between the presentation of a stimulus and the onset of the response to that stimulus[21,22]. It can be further divided into pre-motor time, response time, and movement time to provide a more detailed understanding of how a movement is executed[21,23]. Research indicates that reaction time is influenced by various factors, including age, sex, performance level, skill, and the specific demands of the sport[22,24]. Therefore, to accurately evaluate the effects of specific training interventions, it is crucial to isolate changes in movement speed and additionally assess reaction time as a dependent variable. Achieving greater kick force often involves the application of advanced techniques[14] or adjustments in body weight[25]. Notably, research has demonstrated that body weight accounts for 32.6% of the variance in peak impact force among non-competitor group[14].

Elastic resistance (ER) training is as versatile modality that enables the replication of specific mechanical actions through targeted exercises[26,27]. Its advantages include user-friendliness, cost-effectiveness, and versatility across various training environments. Previous studies have shown that ER training programs with diverse characteristics are effective in improving functional capacity, increasing muscle strength, and enhancing muscle activity[15,28,29]. To date, only one study has applied ER training in the context of martial arts[30]. Similarly, only one experimental study has demonstrated improvements in turn-kick speed among Taekwondo athlete. This reseach suggests that a 4-week ER training program, tailored to Taekwondo-specific, individualized, and progressive requirements, can significantly enhance turning kick velocity in male competitors[15]. Available research has confirmed a 3.31% increase in leg power among 14- to 17-year-old Taekwondo athletes following an eight-week training program utilizing resistance bands[31]. Despite these findings, the literature on ER training remains limited, with program durations ranging from 4 to 12 weeks and training frequencies between 2 and 5 sessions per week (Lopes et al., 2019). The incremental approach to resistance training lacks clarity, limiting both its generalizability and interpretability. Furthermore, few studies have combined ER training with routine Taekwondo practice[15,29].

Despite the increasing interest in elastic resistance (ER) training as a tool for performance enhancement, its application in sport-specific skill development for Taekwondo athletes remains underexplored. While previous research has demonstrated the benefits of ER for strength and power development, there is a notable lack of controlled investigations assessing its direct impact on roundhouse kick (RHK) performance and broader athletic adaptations. Given that velocity, impact force, and execution efficiency are key determinants of success in competitive Taekwondo, it is imperative to establish whether incremental ER training can elicit superior improvements in these attributes compared to conventional training methods. ER training is increasingly recognized for its potential in enhancing athletic performance; however, its application in sport-specific skill development for Taekwondo athletes remains insufficiently explored. While previous studies highlight its benefits for strength and power, controlled investigations examining its direct effects on RHK performance and broader athletic adaptations are lacking. Given the critical role of velocity, impact force, and execution efficiency in competitive Taekwondo, it is essential to determine whether an incremental ER training protocol provides advantages over conventional training methods. Furthermore, existing research lacks clear guidelines on the optimal duration, intensity, and progression strategies for ER interventions in Taekwondo. A deeper understanding of its influence on technical execution and key physical performance markers—such as anaerobic power, isometric strength, and reaction time—can inform more effective training regimens. This study seeks to address these gaps by systematically evaluating the effects of an 8-week ER kick training intervention on RHK average velocity, IS, and physical performance variables. Athletic performance is shaped by the complex interplay of physical and technical attributes, requiring precise training stimuli to optimize adaptations[4]. Given the non-linear progression of performance improvements and potential interactions between training components[32], careful monitoring is necessary to prevent interference effects[33]. Thus, the primary objective of this study is to determine whether ER kick training elicits superior improvements in RHK average velocity and IS compared to conventional Taekwondo training. Additionally, we aim to assess its impact on isometric strength, psychomotor reaction time, explosive power, and anaerobic capacity. We hypothesized that (I) incremental elastic resistance RHK training would effectively improve kick V and IS, and (II) this taekwondo-specific intervention would not adversely affect athlete's physical fitness characteristics, including simple eye-hand and eye-foot reaction time, 10 m sprint, anaerobic alactic-power, CMJ power and isometric muscle strength.

Materials & methods

Participants

Power analysis was performed to determine the required sample size. The sample size was cal-culated with G*Power (Version 3.1.9.6. Institut fu¨r Experimentelle Psychologie, Du¨sseldorf, Germany) for an effect size of 0.7, an α of 0.05, and a power of 0.8 (1–β)[36]. The total sample sized computed with this method was a minimum of 21 players. Before data collection, a computer-generated randomization schema was used to randomize participants (1:1) to Experimental (E) and Control (C) groups. (http://www.randomizer.org). To be eligible, participants were required to have a minimum of 4 years of training and competition experience and to attend all 24 ER training sessions and 4 testing sessions. During the study, some athletes were excluded due to injuries, illnesses, or missed sessions, resulting in a final sample of 21 athletes. Maturity offset was calculated for each athlete individually using the equation proposed by Moore et al. (2015) [34]. The E group ($n = 11$, age: 15.5 ± 1.6 years, stature: 171.6 ± 9.6 cm, body mass: 59.2 ± 15.0 kg; training experience: 8.3 ± 1.9 years; maturity offset 1.6 ± 1.3 years) and C group ($n = 10$, age: 14.8 ± 1.1 years, stature: 164.0 ± 7.2 cm, body mass: 51.9 ± 12.8 kg; training experience: 7.5 ± 1.3 years; maturity offset 1.1 ± 1.4 years) were bith part of a unified youth development program. Participants were instructed to avoid additional strength training during the study period. Both groups trained 4 times weekly, with each session lasting 90 min. Prior to the study, all athletes were required to abstain from elastic band training for at least 60 days. Written informed consent was obtained from all participants and their legal guardians for the publication of identifying information and/or images in an online open-access publication. Athletes were informed of their right to withdraw from the study at any time without penalty. The study protocol adhered to the ethical guidelines outlined in the Declaration of Helsinki and was approved by the Institutional Ethics Committee of Vytautas Magnus University - No. #SA-EK-23-29. The study is registered in the clinicaltrials.gov registry (NCT06572969, 26/08/2024).

Experimental procedures

The intervention spanned 8 weeks, with all participants completing four 90-minute Taekwondo training sessions per week. The experimental group incorporated incremental ER training into their regular training regimen, targeting sport-specific technical and physical attributes. The control group followed the same training structure and sequence, excluding the use of elastic resistance equipment. Both groups began each session with a standardized 15-minute warm-up, which included low-intensity Taekwondo drills and dynamic stretching, followed by a 5-minute rest period. Training sessions for both groups were held on alternate days, at the same time (5:00–8:00 PM), and under similar ambient temperature conditions (10–23º C). Coaches and athletes were advised to avoid intense exercise the day before testing and to consume their regular meal at least 3 h prior to the tests. In the E group, participants performed RHK exercises using incrementally resistive elastic tubing. The RHKs targeted shields (Adidas, Curved Kick Shield) held at chest height. Each athlete started with a 2.4 m elastic tubing, with one end attached to the ankle and the other secured to a stable platform, ensuring resistance of 50 N at full kick extension (Fig. 1). After four weeks (12 sessions), the resistance was increased to 100 N by adding an additional tubing. Each training session consisted of three sets of 6 RHKs per leg, performed at maximum speed, with 30-second intervals between kicks and 3-minute rests between sets. This 8-week program included three times per week of progressive ER training. The C group followed a similar RHK training regimen in terms of sequence and duration, performaing the same number of kicks as the E group but without the use of ER equipment. After each training session, a 5-minute rest period was provided before resuming standard Taekwondo training. Following the 8-week intervention, both groups underwent a 2-week retention period wich they followed a uniform training program. Performance metrics, including RHK average velocity, impact scoring, isometric strength, counter-movement jump (CMJ) performance, and simple reaction times, were assessed pre-intervention, mid-intervention (4 weeks), post-intervention (8 weeks), and after a 2-week retention

Fig. 1. Elastic resistance RHK training. The athlete performs kicks resisted by a 2.4-meter length of elastic tubing, with one end attached to the ankle and the otherand secured to a stable platform.

period. These metrics were chosen to comprehensively evaluate the effects of the intervention on Taekwondo-specific skills and physical fitness.

Testing overview

RHK average velocity and impact scoring

To assess kick velocity (V), participants executed three maximal RHKs with each leg, with a 20-second rest period between kicks. The best performance time was recorded. Athlete-specific kicking heights and distances were determined based on individual anthropometric measurements[16] and these parameters were consistently applied in all trials and tests. An iPhone 11 Pro digital camera (Apple Inc., USA) with iOS 15.1 and the My Jump app was used to capture and analyzed high-speed videos at 240 frames-per-second[35]. The camera, mounted on a tripod, was positioned to clearly record both the start and the end of the kick. Kick average velocity (meters per second) was calculated by dividing the execution distance by the time taken[36]. The timing was determined by identifying the first frame of the foot leaving the ground and the first frame of impact on the Protector and Scoring System (PSS) on the manikin (Fig. 2). The start and end locations of the kick were marked to ensure accurate measurement of the motion distance. After establishing the RHK's timing, kick average velocity (in meters per second) was calculated by dividing the execution distance (in meters) by the time taken (in seconds). Participants were given a 2-minute rest period following the kick velocity test. The PSS was used to assess the impact scoring of RHKs. Participants performed three maximal-effort RHKs with each leg, with 20-second intervals between kicks, and the highest score was recorded. An arbitrary scale set by World Taekwondo (WT) was employed to assess the Impact Score (IS) during the trials and tests[37]. The PSS score followed WT criteria, using the WT approved Daedo E-Trunk Protector, EPRO 2980 - GEN2 (Daedo Headquarters, Spain), sensor socks (EPRO 29037) and a transmitter (EPRO 29801 - GEN2 Transmitter TK-Strike-Version 1.6; TK-Strike, https://www.tk-strike.com), which relayed signals to a Wi-Fi connected computer analyzed by Daedo TK-Strike software (EPRO 29807 - Software GEN 2, Spain). According to the manufacturer and WT, the PSS does not require prior testing or calibration.

Physical performance measurements

Simple eye-hand and eye-foot reaction time test

The simple eye-hand (E-H) reaction time test was conducted using the Vienna Test System (VTS) SPORT (Schuhfried GmbH, Moedling, Austria), which comprises a portable computer, a response panel, and specialized software[38]. For E-H reaction time measurements, participants sat approximately 50 cm from the computer screen, with the screen positioned 15 cm in front of and at the same height as the response panel. The response

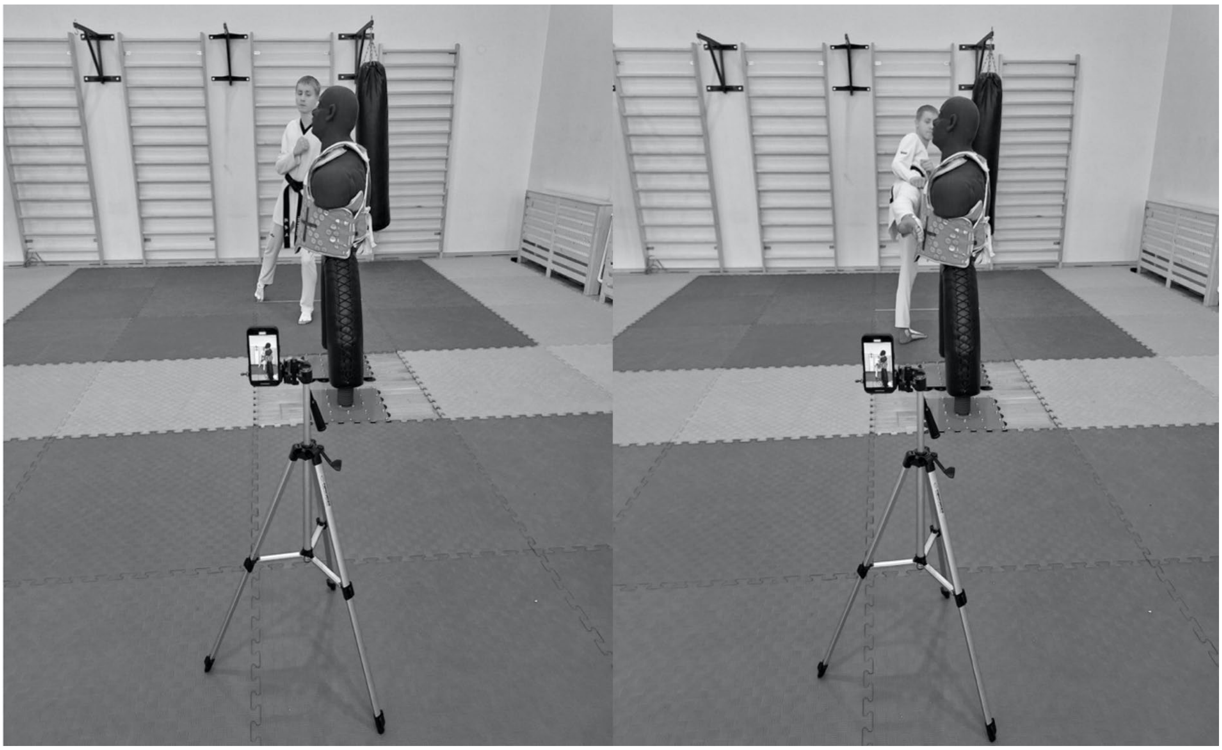

Fig. 2. Measurement of RHK Velocity and Impact Scoring. Kick velocity ($m{\cdot}s^{-1}$) was calculated by dividing the distance covered during execution by the time elapsed, determined by identifying the first frame of the foot leaving the ground and the first frame of impact on the Protector and Scoring System (PSS) on the manikin. An arbitrary-scale set by World Taekwondo (WT) was usedto assess the Impact Score (IS) for each RHK during trials and tests.

involved pressing a button with the index finger of one hand, with the other hand rested beside the panel. Simple Eye-foot (E-F) reactions times were measured using a similar setup, with participants seated at the same distance from the screen. In this test, the response panel was placed on the floor beneath the participant's foot. The response was executed using the toe, while both hands rested on the desk and the other leg remained positioned next to the panel. Before the tests, participants were provided with instructions and allowed to practice until they successfully completed 5 trials. The VTS's simple reaction test used a yellow light as the visual stimulus, which appeared on the screen at random intervals. Participants were required to respond prompty by pressing a square black button on the panel. When no stimulus was present, the participant's finger or toe remained on a sensor button. The primary measured parameter was the reaction time, recorded as the duration (in milliseconds) between the appearance of the stimulus and the pressing of the black button. Errors in the RT were minimal, occurring in less than 1% of cases, and no participant made more than two errors during the test. Reaction times were assessed for both the left and right upper and lower limbs, ensuring comprehensive evaluation of response capabilities.

Back-leg-chest muscle strength dynamometry

Participants, free from lifting restrictions, underwent Isometric Muscle Strength (IMS) testing using a back-leg-chest dynamometer (Saehan, SH5007, Masan 630–728, Korea). This device, which has a strong correlation ($r = .77$, $p < .001$) with manual muscle tests[39], measures the force applied to a spring, moving a pointer to indicate the exerted force. The dynamometer can record forces up to 300 kg with 1 kg resolution and a accurary of t± 0.5 kg at 100 kg. Participants were instructed to stand with their knees and hips flexed at approximately 30ºdegrees while maintaining a proper lordotic curve. They then exerted force using their legs and arms. Two strength measurements were recorded at each testing phase, with the average used to distinguish between learning and training effects. Participants controlled their exertion level to avoid discomfort.

Margaria-Kalamen anaerobic alactic power test

The Margaria-Kalamen stair climb test was used to measure lower body peak power[40]. Participants begans 5 m from the first step and, on the researcher's signal, quickly ascended the stairs, taking three steps at a time. Timers placed on the 3rd and 9th steps record the duration of the climb, starting and stopping as the participant made contact with these steps. The best performance time from three trials, each followed by a 20-second rest, was used. Anaerobic power (watts) is derived by multiplying the participant's weight by the stair height (16 steps) and gravitational acceleration (9.81 m·sec^{-1}), and dividing by the time taken. This formula for computing anaerobic-alactic power follows[41]:

Equation:

$$\text{Anaerobic Alactic Power (watts)} = \left(\text{body mass (kg)} \times \text{distance (0.96 m)} \times 9.81\text{m} \cdot \text{sec}^{-1}\right) / \text{ time } \left(\text{sec}^{-1}\right)$$

10 m sprint test

The 10-meter sprint test (S-10 m) assessed sprint performance using Brower Timing Systems (Wireless Sprint System, Draper, UT, USA). Photocells were placed at the start line (0 m) and at the 10 m mark, positioned 1 m above the ground in accordance with the manufacturer's standard tripod height. Participants performed three maximum-effort sprints, with 3-minute rest intervals between attempts. The fastest sprint time was recorded. The validity and reliability of timing system have been confirmed, with an intraclass correlation coefficient ranging between 0.91 and 0.99 and a coefficient of variation ranging between 0.9% and 2.9% for different distances[42].

Jump performance test

Lower limb power was evaluated using the CMJ test. Participants began each CMJ from a static standing position, performing a countermovement followed by a rapid extension of the lower limbs. Three maximal-effort jumps were performed, with 90-second rest intervals between attempts. The depth of the countermovement phase was self-selected to allow participants to use their preferred jumping technique. Participants were instructed to keep their trunk vertical and their hands on their hips during the jumps. An iPhone 11 Pro, equipped with the MyJump app[35], recorded the jumps at 240 frames per second. The iPhone was mounted on a tripod 0.75 m high and positioned 3 m from the participants to capture the ground contact phase of the jump[43]. Jump height (cm) was estimated using the MyJump app, which calculates this parameter based on flight time. The validity of this approach has been previously established, with an intraclass correlation coefficient ranging from 0.90 to 0.98 and a coefficient of variation of 4.1% [43]. Since the impulse-momentum theorem is applied in force platforms and not in flight-time-based calculations, references to this method have been corrected to avoid methodological inaccuracies. Metrics recorded included jump height (cm) and power (W), with power estimations based on flight-time-derived Eq. [44].

Statistical analysis

Baseline comparisons between the experimental and control groups were conducted using independent samples t-tests for age, body mass, stature, and training experience following confirmation of normality (Shapiro–Wilk test) and homogeneity of variances (Levene's test); effect sizes were calculated using Cohen's d to assess the magnitude of group differences. We employed a repeated measures design to evaluate the effects of different interventions across multiple time points. Prior to analysis, the data were inspected for ensure normal distribution and homogeneity of variance. Analysis of Covariance (ANCOVA) was used to examine the effects of the interventions, with post-intervention test values as the dependent variable and pre-intervention values as the covariate. This approach effectively controls for potential baseline differences among the participants. Pairwise differences were conducted using Bonferroni post-hoc tests to identify specific group differences while controlling the familywise error rate in multiple comparisons. Additionally, intra- and inter-individual variability in performance were assessed, providing insights into the consistency of intervention effects across participants and over time. To quantify the magnitude of the observed effects, Cohen's *d* was calculated as a measure of effect size. The following benchmarks for effect size interpretation were applied: less than 0.2 (trivial), 0.2 to 0.59 (small), 0.6 to 1.19 (moderate), 1.2 to 1.99 (large), and greater than 2.0 (very large)[45]. Statistical significance was set at $p<.05$. All analysis were conducted using the Jamovi software (Version 2.3; The Jamovi Project, https://www.jamovi.org).

Results

Independent samples t-tests revealed no statistically significant differences between the experimental and control groups at baseline for age (t(19) = 1.08, $p=.292$, d = 0.47), body mass (t(19) = 1.20, $p=.246$, d = 0.52), stature (t(19) = 1.46, $p=.159$, d = 0.64), and years of experience (t(19) = 1.10, $p=.283$, d = 0.48). Assumption testing supported the use of parametric analyses: the Shapiro–Wilk test indicated that all variables met the assumption of normality—age (W = 0.928, $p=.123$), body mass (W = 0.980, $p=.920$), stature (W = 0.925, $p=.109$), and years of experience (W = 0.954, $p=.409$). Levene's test confirmed homogeneity of variances across groups for age ($p=.213$), body mass ($p=.688$), stature ($p=.631$), and years of experience ($p=.111$).

The statistical analysis of various performance variables provide important insights (Table 1). For E-F Reaction Right, no significant differences were identified across the assessed time points. However, for E-H Reaction Right, significant differences were observed in the pre vs. 4-week comparison (F = 7.700, $p=.012$) and pre vs. retention (F = 5.130, $p=.036$). Additionally, E-H Reaction Right showed a significant change in the pre vs. post interval (F = 26.40, $p=.036$).

Kick V, for both right and left kicks, demonstrated significant changes in most comparisons, particularly pre vs. post and pre vs. retention intervals, indicating substantial improvements over time. Similarly, for kick IS right and kick IS left, notable differences were observed in specific intervals, especially in the pre vs. post and 4-weeks vs. retention phases (Table 2).

CMJ height and CMJ power showed moderate variations, with significant differences in certain intervals, such as pre vs. retention for the first. In contrast, Margaria-Kalamen test power (W) and Margaria-Kalamen test relative power (w/kg) showed minimal significant differences across all intervals.

Variables such as S-10 m test, IMS, and Kick Left Velocity presented significant changes across several time intervals, reflecting considerable changes in these metrics. Notably, Kick Right Velocity and Kick Left Velocity exhibited highly significant changes across nearly all intervals, emphasizing their consistent variability and progression throughout the study (Table 3).

Overall, the results suggest differential responses of various performance variables to the conditions over time, highlighting the complexity of assessing athletic performance in dynamic sports environments (Fig. 3).

Discussion

This study aimed to evaluate the impact of an 8-week incremental elastic resistance RHK training program on physical performance and kick quality, compared to conventional training methods. The findings were as follows: (a) RHK average velocity and IS for both legs improved consistently over 4 and 8 weeks, as well as during

Variable	Control				Experimental			
	Pre	4 weeks	Post	Retention	Pre	4 weeks	Post	Retention
Kick R V (m/s)	7.08 ± 1.08	7.10 ± 0.99	7.12 ± 1.22	6.89 ± 1.07	8.11 ± 1.31	8.28 ± 0.95	9.06 ± 1.22	9.82 ± 1.58
Kick L V (m/s)	6.80 ± 0.98	6.66 ± 0.86	6.95 ± 0.97	6.78 ± 0.90	7.92 ± 1.21	8.39 ± 1.04	9.04 ± 1.36	9.59 ± 1.57
E-Freact. R (mls)	254.40 ± 28.33	239.10 ± 25.38	234.90 ± 31.25	241.10 ± 27.38	234.55 ± 28.49	228.36 ± 18.55	218.82 ± 31.61	221.45 ± 23.75
E-Freact. L (mls)	265.30 ± 44.99	260.80 ± 40.23	257.40 ± 50.92	268.20 ± 36.48	243.73 ± 27.69	249.18 ± 48.88	235.91 ± 26.55	237.82 ± 54.60
E-Hreact. R (mls)	187.10 ± 23.50	206.90 ± 26.79	190.80 ± 32.96	197.20 ± 27.82	182.00 ± 17.77	179.36 ± 16.17	179.64 ± 18.34	173.73 ± 16.46
E-Hreact L (mls)	189.70 ± 24.57	192.20 ± 21.51	197.60 ± 27.02	193.20 ± 21.40	170.09 ± 15.23	180.82 ± 30.01	183.00 ± 31.72	176.82 ± 29.35
IS R (a.u)	36.50 ± 11.36	39.80 ± 10.12	38.40 ± 9.73	38.20 ± 10.03	46.64 ± 4.91	46.82 ± 5.44	47.91 ± 6.24	49.18 ± 5.06
IS L (a.u.)	35.30 ± 11.08	36.10 ± 9.89	34.10 ± 9.57	35.80 ± 8.63	41.64 ± 7.26	45.18 ± 7.91	48.73 ± 8.04	46.09 ± 9.12
CMJ-H (cm)	29.22 ± 5.70	28.72 ± 4.90	29.31 ± 5.44	29.74 ± 5.02	40.61 ± 10.28	39.70 ± 9.08	41.45 ± 9.52	43.07 ± 10.26
CMJ-P (w)	1427.62 ± 361.91	1405.05 ± 332.77	1438.30 ± 371.40	1462.55 ± 359.44	2384.31 ± 941.30	2300.11 ± 856.37	2430.47 ± 930.10	2549.79 ± 995.68
AAP (W)	672.59 ± 266.81	720.12 ± 313.05	681.25 ± 269.613	773.37 ± 310.48	768.30 ± 267.60	817.78 ± 321.15	787.62 ± 231.74	830.52 ± 353.00
AAP (W/kg)	12.71 ± 2.95	13.74 ± 4.47	14.66 ± 4.47	12.72 ± 2.29	12.72 ± 2.29	13.55 ± 4.08	12.88 ± 1.55	13.74 ± 4.70
S-10 m (s)	2.09 ± 0.20	2.15 ± 0.16	2.13 ± 0.20	2.19 ± 0.16	1.92 ± 0.20	1.97 ± 0.22	1.88 ± 0.23	1.88 ± 0.33
IMS (kg)	82.80 ± 21.41	79.20 ± 22.74	95.20 ± 215.35	85.40 ± 19.06	119.64 ± 41.19	122.36 ± 37.59	119.45 ± 39.54	123.09 ± 41.15

Table 1. Effect of control and experimental training program on variables performance of the participants. *E-Freact.R* eye-foot reaction right, *E-Freact.L* eye-foot reaction left, *E-Hreact. R* eye-hand reaction right, *E-Hreact. L* eye-hand reaction left, *IS R* impact score right, *IS L* impact score left, *CMJJ-H* vertical jump height, *CMJ-P* vertical jump- power, *AAP-W* anaerobic alactic power watts, *AAP-W/kg* anaerobic alactic power watts/kilograme, *S-10 m* Sprint 10 m, *IMS* isometric muscle strength, *Kick R V* kick right velocity, *Kick L V* kick left velocity. Units: (a.u.) auxiliary units.

Variable	Pre vs. 4weeks			Pre vs. Post			Pre vs. Retention		
	F	*p*	ηp²	F	*p*	ηp²	F	*p*	ηp²
Kick R V (m/s)	31.70	< 0.001*	0.638	45.60	< 0.001*	0.717	63.20	< 0.001*	0.778
Kick L V (m/s)	20.10	< 0.001*	0.528	15.60	< 0.001*	0.464	30.60	< 0.001*	0.630
IS R (a.u)	1.070	0.316	0.058	3.687	0.071	0.170	4.270	0.05*	0.192
IS L (a.u.)	2.730	0.116	0.132	10.80	0.004*	0.375	3.930	0.063	0.179
E-Freact. R (mls)	0.405	0.532	0.022	0.044	0.835	0.002	1.780	0.199	0.090
E-Freact. L (mls)	-0.02	0.980	0.000	0.464	0.504	0.025	0.944	0.344	0.050
E-Hreact. R (mls)	7.700	0.012*	0.300	0.597	0.450	0.032	5.130	0.036*	0.222
E-Hreact L (mls)	0.252	0.622	0.14	26.40	0.036*	0.002	1.540	0.230	0.079
CMJ-H (cm)	1.320	0.265	0.068	2.160	0.159	0.107	5.100	0.037*	0.221
CMJ-P (w)	0.322	0.578	0.018	0.536	0.474	0.029	1.690	0.210	0.086
AAP (W)	0.047	0.983	0.000	0.253	0.621	0.014	0.116	0.738	0.006
AAP (W/kg)	0.028	0.868	0.002	-0.02	0.990	0.000	0.296	0.593	0.016
S-10 m (s)	0.765	0.393	0.041	3.230	0.089	0.152	2.650	0.121	0.129
IMS (kg)	58.89	< 0.001*	0.766	64.58	< 0.001*	0.782	111.79	< 0.001*	0.861

Table 2. Effect of SSG and SMHT training methods on game motion characteristics of the participants. *E-Freact.R* eye-foot reaction right, *E-Freact.L* eye-foot reaction left, *E-Hreact. R* eye-hand reaction right, *E-Hreact. L* eye-hand reaction left, *IS R* impact score right, *IS L* impact score left, *CMJJ-H* vertical jump height, *CMJ-P* vertical jump- power, *AAP-W* anaerobic alactic power watts, *AAP-W/kg* anaerobic alactic power watts/kilograme, *S-10 m* Sprint 10 m, *IMS* isometric muscle strength, *Kick R V* kick right velocity, *Kick L V* kick left velocity. Units: (a.u.) auxiliary units.

Variable	4weeks vs. Post			4weeks vs. Retention			Post vs. Retention		
	F	*p*	ηp²	F	*p*	ηp²	F	*p*	ηp²
Kick R V (m/s)	4.200	0.055	0.189	16.20	< 0.001*	0.473	11.20	0.004*	0.384
Kick L V (m/s)	0.262	0.615	0.014	3.740	0.069	0.172	5.210	0.035*	0.224
IS R (a.u)	2.740	0.115	0.132	5.490	0.031*	0.234	2.420	0.137	0.119
IS L (a.u.)	6.850	0.017*	0.276	1.350	0.260	0.070	0.284	0.601	0.16
E-Freact. R (mls)	0.448	0.512	0.024	1.790	0.198	0.090	1.540	0.230	0.79
E-Freact. L (mls)	1.100	0.309	0.057	0.432	0.05*	0.194	0.872	0.363	0.046
E-Hreact. R (mls)	0.129	0.724	0.007	0.103	0.752	0.006	4.290	0.05*	0.193
E-Hreact L (mls)	0.606	0.447	0.034	1.010	0.328	0.053	0.355	0.559	0.020
CMJ-H (cm)	0.580	0.456	0.031	1.470	0.241	0.075	0.796	0.384	0.042
CMJ-P (w)	0.211	0.652	0.012	0.781	0.389	0.042	0.547	0.469	0.030
AAP (W)	0.419	0.525	0.023	0.021	0.885	0.001	0.261	0.616	0.014
AAP (W/kg)	0.002	0.965	0.000	0.218	0.646	0.012	0.322	0.578	0.018
S-10 m (s)	1.950	0.180	0.098	2.050	0.170	0.102	0.579	0.456	0.031
IMS (kg)	4.010	0.06	0.182	0.088	0.770	0.005	4.400	0.05*	0.196

Table 3. Effect of SSG and SMHT training methods on game motion characteristics of the participants. *E-Freact.R* eye-foot reaction right, *E-Freact.L* eye-foot reaction left, *E-Hreact. R* eye-hand reaction right, *E-Hreact. L* eye-hand reaction left, *IS R* impact score right, *IS L* impact score left, *CMJJ-H* vertical jump height, *CMJ-P* vertical jump- power, *AAP-W* anaerobic alactic power watts, *AAP-W/kg* anaerobic alactic power watts/kilograme, *S-10 m* Sprint 10 m, *IMS* isometric muscle strength, *Kick R V* kick right velocity, *Kick L V* kick left velocity. Units: (a.u.) auxiliary units.

the retention phase; (b) back-leg-chest IMS also improved during these periods, with simple reaction time of the right arm showing significant improvement within 4 weeks, and the left arm reaction time and CMJ height improving within 8 weeks; (c) however, incremental ER kick training did not significantly influence CMJ power, anaerobic-alactic power, or S-10 m performance.

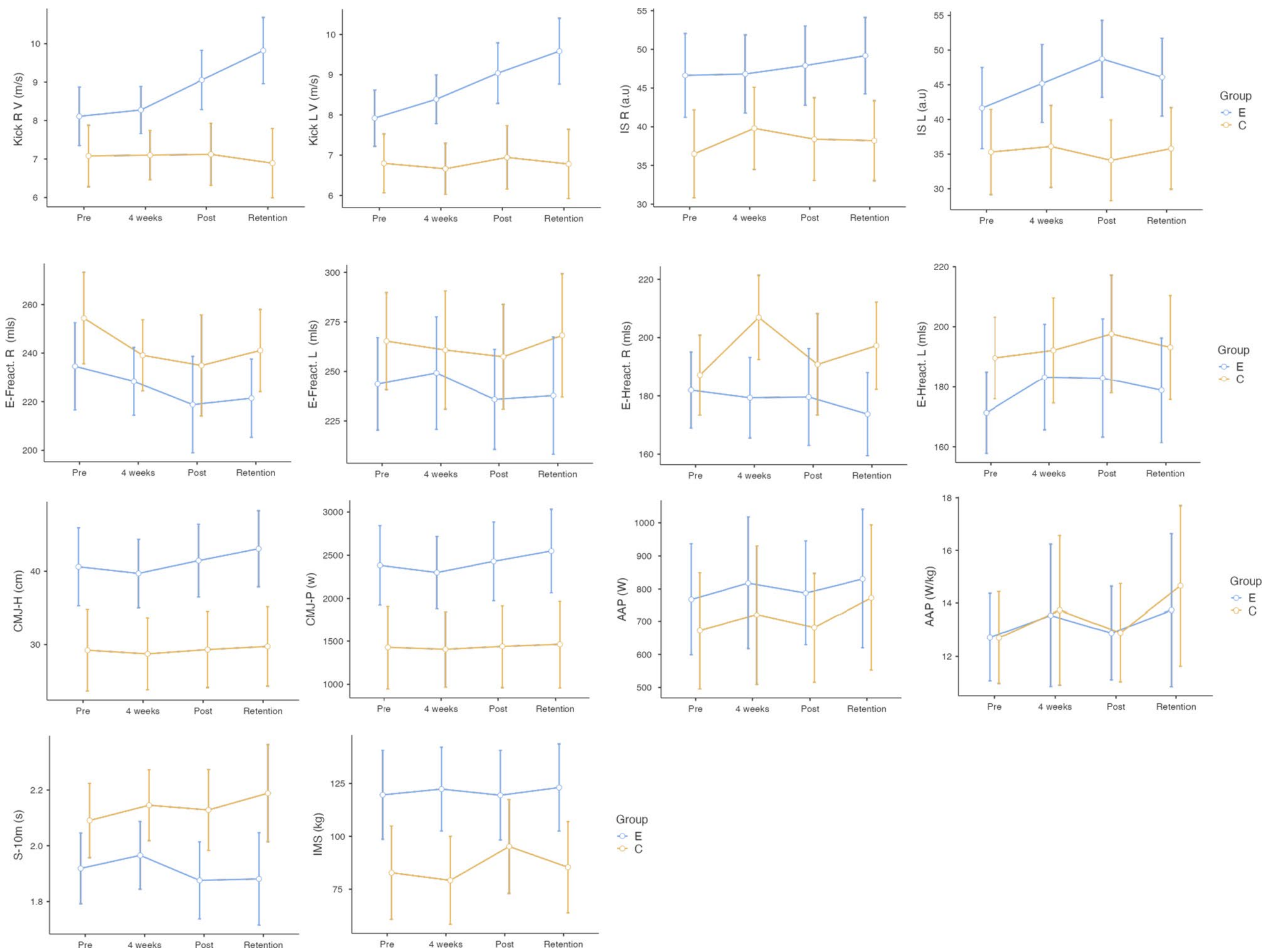

Fig. 3. Mean changes from pre to 4 weeks, to post and retention phase in all studied variables. *E-Freact. R* eye-foot reaction right, *E-Freact. L* eye-foot reaction left, *E-Hreact. R* eye-hand reaction right, *E-Hreact. L* eye-hand reaction left, *IS R* impact score right, *IS L* impact score left, *CMJJ-H* vertical jump height, *CMJ-P* vertical jump- power, *AAP-W* anaerobic alctic power watts, *AAP-W/kg* anaerobic alactic power watts/kilograme, *S-10 m* Sprint 10 m, *IMS* isometric muscle strength, *Kick R V* kick right velocity, *Kick L V* Kick left velocity. Units: (a.u.) arbitrary units.

The efficacy of ER training, compared to conventional training has been extensively studied various sports and across different athletic levels[26,28–30]. Its effectiveness in improving Taekwondo turning kick velocity has also been established[15]. The novelty of this study lies in its focus on incremental resistance training for the RHK among Taekwondo athletes. The observed improvements in kick velocity suggest that this training approach benefits both short-term (4 weeks) and longer-term (8 weeks) adaptations, supporting 50 N and 100 N resistance as optimal levels for technical improvement. However, this relatively simple study does not elucidate the underlying mechanisms responsible for the increase in RHK average velocity, highlighting the need for further research to explore the neuromuscular and biomechanical adaptations induced by ER training. The observed improvements may be attributed to the neurophysiological mechanisms of the RHK, which involve coordinated neural activation, muscle sequencing, and proprioceptive feedback to optimize speed, power, and accuracy[46,47]. Neural efficiency in elite athletes minimizes unnecessary muscle activation, conserving energy while maximizing output[17]. Additionally, differences between "hit" and "miss" techniques suggest context-dependent motor programming, where combat experience sharpens the central nervous system's ability to prioritize speed or precision[46]. Previous studies, consistent with our findings, demonstrated that a 4-week ER training intervention in Taekwondo athletes increased turning kick velocity by 7% [15]. Furthermore, competitive martial arts athletes initiated post-activation potentiation, which positively enhanced kinematics and performance in roundhouse kicking after incorporating elastic resistance into their warm-up routines[30].

The improvements in RHK velocity and impact scoring observed in this study can be attributed to a combination of neuromuscular and biomechanical adaptations. The progressive nature of ER training introduces increasing resistance throughout the kicking motion, forcing athletes to generate greater force during the final phase of the movement. This differs from traditional resistance training, where maximal force is often exerted at the beginning or mid-range of motion[48]. A critical biomechanical factor influencing RHK effectiveness is the coordination of hip flexion, knee extension, and ankle dorsiflexion, which dictate the trajectory, speed, and impact force of the kick[49]. Given that elastic bands create variable resistance—with lower force at the initiation of movement and peak resistance at full extension—this training modality likely enhances motor unit recruitment patterns specific to Taekwondo kicking mechanics. Future research should consider kinematic and kinetic analyses to determine whether ER training influences hip and knee angular velocity, force application angles, and ground reaction forces, providing deeper biomechanical insights.

RHK average velocity and IS are critical for successful Taekwondo performance and are often employed in combination during combats. However, in this study, these variables were analyzed independentely using two different devices. In Taekwondo competition, scoring is based on kicks meeting force thresholds set by WT standards[37]. Unlike assessments that classify athletes by weight classes, our study sought to empirically evaluate overall improvements in IS across all participants. The PSS was employed due to its well-documented objectivity and reliability, making it an essential tool in both research and competitive contexts[50,51].

Our findings indicate that ER training significantly enhances IS during RHK, as measured by the PSS. Specifically, the IS for the right leg increased by 5.2% from the pre-test to the retention-test, while the left leg demonstrate a 14.5% increase from the pre-test to the post-test. Lenetsky et al.[52] identified leg strength, particularly in the transverse plane, as a critical factor for developing impact force in combat sports. Supporting this, a meta-analysis revealed that elastic resistance training can produce strength gains comparable to conventional training methods across a variety of populations and protocols[26]. A unique advantage of ER training is that it does not hinder the technical execution of movements. Estevan & Falco[16] emphasized that adapting technique based on distance is crucial for optimizing impact force. The increased number of repetitions due to the additional training load may have also contributed to the observed improvements, particularly given the positive trends seen in the control group. Unlike other studies, our approach allowed for the objective quantification of changes in athletes' techniques within this specific training context. The study demonstrated the interaction between Taekwondo-specific training interventions and physical performance indicators[12]. Eight weeks of incremental ER training did not affect anaerobic-alactic power, CMJ power, or S-10 m performance, suggesting that the training was highly specific to the sport's energy systems, muscle groups, and technical skills[4]. This specificity ensured optimal adaptation without necessarily enhancing or diminishing certain general performance indicators. Recent studies on the specificity of combat sports have utilized the 10-second frequency speed of kick test[53]. Ulupinar et al.[54] reported that this test can more effectively distinguish successful kickboxers from less successful ones compared to the CMJ test (91.7% versus 70.8%). This measurement enabled a specific assessment while also providing a comprehensive evaluation by combining exercise duration, intensity, and kick quality. Although the CMJ test remains a widely utilized tool for monitoring leg muscle power in Taekwondo athletes[31,55], our study highlights that certain assessment methods may not fully capture the specificity of adaptive training effects. Incremental ER training led to significant increases in isometric back-leg-chest muscle strength, consistent with findings from previous studies on ER programs of similar duration (4–8 weeks)[26]. Taekwondo athletes rely heavily on isometric strength for executing technical and tactical actions such as kicking, punching, blocking, and holding[8,56]. During the fighting stance, athletes often perform preparatory isometric presses to generate and channel force into their techniques[56]. Wallace et al.[57] reported that ER training improves peak force, which enhances eccentric muscle contraction velocity due to the downward pull of elastic bands during the eccentric loading phase. Similarly, Cronin et al.,[58] highlithted the efficacy of eccentric loading in strength and power training, attributing its benefits to the elastic properties of skeletal muscle tendons, which store and release elastic energy. In this study, training the RHK with elastic resistance was found to influence isometric strength across multiple muscle groups. Significant improvements were observed after 4 weeks of training with lower resistance and continued after 8 weeks with increased resistance. CMJ height also improved, aligning with results from prior ER training studies[29,59]. While previous research linked increases in jump height to various biomechanical variables[60], our findings suggest that the observed improvements are more attributable to lower limb strength than to movement velocity. Additionally, significant training effects became most apparent during the retention period, suggesting a delayed training effect.

Taekwondo is a highly dynamic and reactive sport[12,21], where reaction speed and the ability to respond to visual stimuli are crucial for sucess[21]. Literature emphasizes that even a minuscule difference in reaction time, such as 0.01-seconds, can be decisive in determining success or failure in combat or game situations. This underscores the vital importance of reaction time in the fast-paced context of Taekwondo and similar sports[22] Both E-H and E-F reaction times are essential in Taekwondo combat[24]. While this study did not directly manipulated visual stimuli, it assessed changes in these reaction times during the training program. Notably, the simple reaction time of the right hand improved significantly within the first four weeks and continued to improve through the retention period, whereas the reaction time of the left hand remained unchanged. Additionally, the study observed a reduction in the simple reaction time of the eyes and left leg after 4 weeks, prior to the retention period, while the right leg's reaction time remained stable. This finding is novel and lacks direct support from available research. Simple reaction time is understood as a composite of three components (the time required for a visual pathway cell to detect a stimulus), cellular transmission time (the time needed for this signal to reach the visual cortex), and motor reaction (the time required to initiate a neuromuscular response)[22,61]. During the ER training program, neither integration time nor cellular transmission time showed measurable improvement. Consequently, while the observed improvements in simple reaction time are promising, its underlying mechanisms remain unclear and warrant further investigation. Previous evidence suggests that training interventions in youths with varying maturity status may differentially impact neuromuscular function, motor control, and physical performance[62]. Based on the maturity offset levels calculated for both groups (all exceeding 0.99 years), it is clear that both groups had already reached and surpassed their peak height velocity[63]. As a result, the maturity status did not affect the intervention's outcomes.

ER training is a valuable tool for Taekwondo, offering enhancements in kick velocity and strength while being portable and cost-effective. Its versatility enables adaptation across various martial arts disciplines, making it an excellent addition to any training regimen. Resistance bands are highly adaptable to different kicking drills and can be used effectively for warm-ups, technical practice, or strength-building routines.

Conclusion

The findings of this study suggest that an 8-week incremental ER kick training program significantly enhances RHK average velocity and impact scoring in Taekwondo athletes, partially confirming our hypothesis. The effects of Taekwondo-specific ER kick training on physical performance were somewhat unexpected, as the intervention also improved back-leg-chest isometric strength, vertical jump performance, and simple E-H and E-F reaction times at different stages of the intervention. These improvements may contribute to enhancing RHK quality. However, the lack of changes in sprint performance, jump power, and anaerobic-alactate muscle power aligns with our hypothesis, emphasizing the intervention's specificity to the energy system, muscle groups, and technical skills required for Taekwondo. This specificity highlights the potential of ER kick training to target key performance attributes in a sport-specific manner, suggesting it can be effectively integrated into broader physical training programs to complement other aspects of athletic development. Although this study did not include psychological assessments, it is plausible that increased exposure to high-resistance RHK execution may also influence athletes' confidence, perceived control, and focus—factors that may interact with physical gains to shape performance. Future research should integrate psychological measures to explore how neuromuscular adaptations relate to perceived readiness and competitive effectiveness. Additionally, long-term follow-up studies are warranted to determine whether the observed performance benefits persist across extended training periods or competitive cycles.

Limitations

This study has limitations that should be acknowledged. The participants were recruited exclusively from a unified youth development program, which ensured a controlled and standardized training environment. While this approach minimized variability in training load, session structure, and intervention fidelity, it may limit the generalizability of the findings to athletes from different training backgrounds or less structured environments. Athletes in diverse programs might exhibit varying responses to the intervention due to differences in baseline fitness, coaching styles, or training regimens.

Data availability

Data are available upon reasonable request. Interested researchers may contact the corresponding author to request access to the data (VMU, info@vdu.lt).

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Author contributions
RP, VP and BF collaborated in the literature review and producing the figures and tables. RP, VP and BF collaborated in writing the manuscript. All the authors contributed to the article and approved the submitted version.

Declarations

Competing interests
The authors declare no competing interests.

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