Original Article

The effect of plyometric exercises on repeated strength and power performance in elite karate athletes

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Abstract:

Objective: To explore the participation and attitude of institutionalised elderly towards Physical Activity. The purpose of this study was to evaluate the effects of a plyometric protocol on round kick force and lower limbs' jumping performance in elite karate athletes and to examine whether this plyometric protocol could be used over repeated trials in competitive warm up conditions. Ten elite level karate athletes (5 males and 5 females) were randomly assigned to an intervention or a control condition of inactivity. The intervention condition consisted of 3 sets of 5 tuck jumps and was repeated over three trials interspersed by ten min of rest. Round kick force, and counter movement jump (CMJ) height, power, relative power, force and rate of force development (RFD) were measured at the beginning and after each trial. The two-way 2x4 repeated measures ANOVA revealed significant condition x time interaction for CMJ height ($F= 6.510$, $p=0.02$, $\eta^2=0.736$). No main effects for time or between conditions were observed, however, CMJ height after the third trial was increased (+3.5%, $p<0.003$) compared to baseline performance. Significant correlations were found between round kick force and lower limbs' jumping performance. The results of this study may provide useful information for competitive warming-up strategies in contact sports where strength and power are crucial determinants throughout repetitive successive efforts.

Key words: warm-up, Post activation potentiation, contact sports

Introduction

Competitive karate performance is depending on both, technical aspects, and strength and power abilities (Loturco, Artioli, Kobal, Gil, and Franchini, 2014). According to the rules imposed by the World Karate Federation, athlete's main goal is to score by touching the opponent; hence high-intensity actions in punching and kicking techniques are required prior to a response from the opponent (Mori, Ohtani, and Imanaka, 2002).

During a typical kumite-karate competition, karate players perform sequential matches interspersed with variable time spaces of inactivity, on a single day (World Karate Federation, 2009). A karate fight is comprised of two 3-min high intensity bouts where repeated unilateral dynamic defensive and offensive kinetic patterns such as frontal, lateral and circular kicks take place. As the attainment of maximum performance is a demand in every competition, muscle power output is of great value for karate athletes aiming to improve the efficacy of specific kinetic patterns demanded for success (Roschel et al., 2009)

Post activation potentiation (PAP) has been shown to enhance strength and power production in different activities (Feros, Young, Rice, and Talpey, 2014; Kilduff et al., 2010; Miarka, Del Vecchio, and Franchini, 2011; Okuno, Tricoli, Silva, Bertuzzi, Morreira, and Kiss, 2013). PAP constitutes an increase in performance after a high-intensity muscle contraction and has been primarily attributed to increased phosphorylation of the myosin light chains and increased recruitment of motor units (Tillin and Bishop, 2009). However, the conditioning muscle contraction might also induce fatigue and it is the balance between PAP and fatigue that determines the final effect of an explosive activity on performance (Docherty and Hodgson, 2007).

The relation between PAP and fatigue is influenced by a combination of factors, such as volume, intensity and type of the conditioning activity (Bogdanis, Tsoukos, Veligekas, Tsolakis, and Terzis, 2014) as well as the recovery period between the conditioning activity and performance (Tillin and Bishop, 2009). The exact protocol of exercise for inducing potentiation is still under investigation. Previous studies have used half squats with varying loads (Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, and Garas, 2003; Mangus et al., 2006), isometric voluntary contractions (French, Kraemer, and Cooke, 2003; Gullich and Schmidtbleicher, 1996; Hamada, Sale, Mac Dougall, and Tarnopolsky, 2003), electrical muscle stimulation (O' Leary, Hope, and Sale, 1997; Trimble, and Harp, 1998) and plyometrics (Masamoto, Larson, Gates, and Faigenbaum, 2003).

Plyometric exercises are receiving growing attention as potentiating exercises, probably because of their technical structure similarities with sport-specific skills, and their applicability in real life competition

conditions. Interestingly, plyometric exercises have been found to increase performance in kinetic patterns like shot put throwing performance (Terzis, Spengos, Karampatsos, Manta and Georgiadis, 2009; Terzis, Karampatsos, Kyriazis, Kavouras and Georgiadis, 2012) and golf strikes (Read, Miller and Seelig, 2012). Different forms of plyometric contractions, such as drop jumps (Chen, Yu-Han, Hsien-Te, Ching-Fang, and Min-Hsien, 2013; Hilficker, Hubner, Lorenz and Mart, 2007; Saez Saez de Villareal, Gonzalez-Badillo and Izquierdo, 2007), tuck jumps (Donti, Tsolakis, and Bogdanis, 2014; Masamoto et al., 2003; Till and Cooke, 2009; Tsolakis et al., 2011; Turki et al., 2011), vertical hops and bounds (Esformes, Cameron and Bampouras, 2010) at low (Masamoto et al., 2003; Chen et al., 2013; Till and Cooke, 2009) or high-volume or number of repetitions (Chen et al., 2013; Esformes et al., 2010; Saez Saez de Villareal et al., 2007; Tsolakis and Bogdanis, 2012) have been implemented as potentiating exercises but with conflicting results. The discrepancies observed in the aforementioned studies are attributed to differences in potentiating exercises protocols, subsequent activities following PAP, and study population (Chen et al., 2013; Masamoto et al., 2003).

However, research is limited regarding the use of PAP in combat sports. In one study, Miarka et al., (2010), examined the acute effect of three different PAP protocols, with either plyometric, strength or a combination of strength and plyometric exercises, in “Special Judo Fitness Test” performance in eight male judo athletes. The authors concluded that plyometric exercises and combined strength and plyometric exercises could result in improvements in the Special Judo Fitness Tests index. All contact sports (judo, taekwondo, karate) are characterized by powerful efforts throughout a competition interspersed with variable time spaces of inactivity. However, there is no previous research investigating PAP in karate athletes and over repeated performances.

One key/critical parameter concerning PAP is the applicability of research findings in real time competitive conditions, and over repeated performances, especially when the time between recovery and performance is strictly defined by the rules. This led us to investigate the hypothesis that plyometric exercises may enhance selected variables of lower limb jumping performance as well as the round kick force in elite karate athletes. Therefore, the present study aimed firstly to investigate the acute effect of a plyometric protocol consisting of 3 sets of 5 tuck jumps on round kick force and counter movement jump performance in elite karate athletes and secondly to examine the efficacy of this protocol over 3 repeated trials paused by 10 min of rest, a condition that is modeling kumite-karate competition parameters.

Materials and methods

Participants

In the present study, five male (age 18.4 ± 1.2 yrs, body height 177.0 ± 6.4 cm, body mass 70.8 ± 9.9 kg, BMI 22.3 ± 1.9 kg·m⁻²) and five female (age 19.2 ± 0.4 yrs, body height 161.6 ± 4.4 cm, body mass 52.0 ± 2.0 kg, BMI 20.1 ± 0.8 kg·m⁻²) karate athletes, with 5 ± 0.5 years of karate training experience, all members of the Greek national team, with considerable experience in international competitions, were recruited. All participants trained for 5-6 times per week (~120 minutes per session), with resistance exercises for lower and upper limbs, sports’ specific power drills and technical-tactical exercises at moderate to high intensities (Roschel et al., 2009), while they participated in national competitions approximately every second week. Informed consent was obtained from each participant while written parental consent was also obtained in participants under 18 years of age. This study was approved by the Institutional Review Board and all procedures were in accordance with the Helsinki declaration of 1975, as revised in 1996. The participants were free of injury and the testing was performed during the competitive training period.

Fig. 1. Schematic representation of the study design here
Experimental design and procedures

A crossover, repeated measures design was used, to compare the acute effects of either an intervention or a non-intervention condition of inactivity modeling the kumite-karate competition's parameters. Each subject was required to attend the laboratory on three occasions separated by 72 hours rest over a two-week period. During the first visit, all participants were examined by a physician for limiting health issues, had their body height/mass measured and signed a consent form. They also performed a familiarization session, by performing a series of countermovement jumps and karate round kicks on a force platform. During each experimental day (visits 2 and 3) and prior to the baseline performance measurements (countermovement jump and round kick), subjects underwent a standardized warm-up (5 minutes of standardized warm-up and 5 minutes of dynamic sport-specific stretching preceded every preliminary measurement), similar to their pre-competitive warm-up. After warm-up the subjects executed 4 CMJ's and 4 round kicks, with a randomized assignment, in a randomized order, with 30 sec rest between each effort and 5 min of passive rest between exercises to obtain the baseline values. After 5 min of seated rest, the participants performed either the intervention or the control condition followed by another 5 min of rest and the second performance measurements, according to the order of the first measurements. Subsequently, participants performed 2 more sets of the experimental/intervention conditions and measurements (third and fourth; Fig. 1), with 10min of rest after the second and third measurements (Esformes and Bampouras, 2013). The particular rest interval (10-min) was selected because it is modelling two consecutive matches in the kumite-karate competitions. In the control condition participants remained inactive between measurements. The intervention (plyometric) condition consisted of three sets of five tuck jumps separated/interspersed by 30 sec seated rest. This is a widespread warm-up activity among kumite-karate athletes, included empirically in the warm-up procedure either prior of the first match or at the intervals between repeated matches. Following the second and the third trial, 5 min of rest took place before performance tests. Twenty-four-hours prior to testing, the subjects were instructed not to engage in any intense physical activity. Each karate athlete was instructed and verbally encouraged during each test to perform maximally.

Round Kick

The evaluation of the specific technical performance of kumite-karate athletes during a match (through the experimental modeling of the matches) was performed by measuring the impact force of a round kick technical skill of kumite-karate, ushiro-geri, as it was previously described (Laird and McLeod, 2009) on a force-platform (WP800, Applied Measurements Limited, UK), with a load cell amplifier / signal conditioner (SGA/D, Applied Measurements Limited, UK, 1 kHz sampling). The load cells were connected through an A/D card (PCD-330B-F, Kyowa Electronic Instruments CO., Ltd, Japan) to a computer with a specific software for receiving the signal, analysis and further data processing (DCS 100A, Kyowa Electronic Instruments CO., Ltd, Japan). Each effort begun with participants in battle position (kamae) and after a signal all participants performed the ushiro-geri technique, aiming to touch a specific area of the force-plate, which had previously been marked. The distance between the starting position and the force plate, as well as the height of the specific area of the force-plate were adjusted according to the anthropometric characteristics of each participant, in an effort to assure that all the tread of the kicking leg will be attached to the force-plate (Gulledge and Dapena, 2008; Kim, Kim, Im, 2011), and that at the final contact the knee of the kicking leg would be slightly (5°) flexed (Laird and McLeod, 2009). The athletes were instructed to kick the target as fast and forceful as possible (Estevan, Cameron, Falco, 2013). Four (first measurement) and three attempts (second to fourth measurements) were given in each participant, with 30sec rest interval between trials. Each effort was analyzed with a specific computer software. The raw data from each attempt were smoothed via a smoothing factor, as previously suggested (Gulledge and Dapena, 2008). Round kick force (RKF) was calculated as the highest value of the first 150ms of the impact (Gulledge and Dapena, 2008). The best performance from each measurement, as evaluated by the RKF, was used for statistical analysis. A subgroup of the subjects (n=7) performed the measurements twice, on different days (ICC = 0.924, 95% CI: Lower = 0.86, Upper = 0.96, p = 0.001)

Counter movement jump measurements

For the evaluation of lower limb jumping performance, counter movement jumps were used. All participants, prior to the main evaluations performed 3 CMJs with submaximal intensity. Subsequently, subjects performed 3 maximal effort CMJs with 30 sec rest between jumps, on a force platform (Applied Measurements Ltd Co. UK, WP800- 1000kg weighting platform, s/n:40245, 80x80cm, sampling frequency 1 kHz) with arms akimbo, as previously described (Bosco, Luhtanen, Komi, 1983; Zaras et al., 2014). Data from the force platform were recorded and analyzed (Kyowa sensor interface PCD- 320A, Kyowa Electronic Instruments CO., LTD, Japan) in order to calculate jump height and power according to the following equations: Jump height (cm) = $(0.5 * T_{flight} * 9.81)^2 / 2 * 9.81$, Power (w) = $(body\ weight + F_{max}) * 9.81 * T_{flight}$ (Bosco et al, 1983; Linthome, 2001) and max rate of force development (RFD; N·s⁻¹) = $(Max\ force - Body\ weight) \cdot (Time\ of\ maximum\ force - Time\ at\ which\ force\ reach\ the\ body\ weight)^{-1}$ (Bosco, et al., 1983; Harris, 2009; Sayers et al., 1999). Signals were filtered using a secondary low pass Butterworth filter with a cutoff frequency of 20 Hz. The best performance in jump height was used for further analysis. The ICCs for jump height and power were 0.87, (95%

CI: Lower = 0.83, Upper = 0.95) and 0.91 (95% CI: Lower = 0.90, Upper = 0.99), respectively, n = 13 (Zaras et al., 2014). ICC for max RFD was 0.89 (95% CI: Lower = 0.83, Upper = 0.92; n = 7).

Statistical analysis

According to the study design and the number of the participants, a post-hoc power analysis (G*Power ver 3.1; Frank Faul, Universitat Kiel, Germany) revealed that the results of the present study have an actual power of 0.870 (Cohen, 2013; Faul, Erfelder, Lang, and Buchner, 2007). Data are presented as means and SD. A 2-way repeated measures ANOVA (condition x time) was used to examine differences in round kick and CMJ performance between the two conditions (plyometric and inactivity) and over time. Bonferroni Post-Hoc multiple comparison test, was used to determine differences between means. To prevent inflation of the experiment-wise type I error rate ($p < 0.05$), statistical significance of each test was accepted at the $p < 0.0033$ level. Partial eta squared was also performed, while according to Richardson, (2011), partial eta squared is classified as small (0.01 to 0.059), moderate (0.06 to 0.137) and large (≥ 0.138). Test-retest reliability for all the dependent variables measured in this investigation was determined in separate experiments by calculating the intra-class correlation coefficient (ICC) using a 2-way mixed model (Kottner et al., 2011). Pearson's product moment correlation coefficient was used to examine the relationships between the variables. Statistical significance was accepted at $p < 0.05$. All statistical analysis was performed using the SPSS v18.0.

Results

Descriptive statistics for all the performance measures are presented in table 1. The 2-way repeated measures ANOVA revealed significant condition x time interaction for CMJ height ($F = 6.51$, $p = 0.02$, $\eta^2 = 0.736$). No main effects for time or between conditions were observed, however, the post-hoc comparisons with Bonferroni corrections ($p < 0.0033$) indicated significant differences in CMJ height after the 3rd trial (+ 3.5 %, $p = 0.003$) compared to baseline performance. Due to severe Bonferroni accepted α level ($p < 0.0033$), no other significant post-hoc differences were observed for round kick, CMJ power, relative power, force and RFD respectively.

Table 1. Effect of 3 x 5 tuck jumps compared to inactivity on round kick force and countermovement's parameters in 10 elite karate players.

Parameter	Group	Baseline measures	Trial 1	Trial 2	Trial 3
RKF	Intervention	533.44±82.24	562.41±49.48	533.82±79.07	555.37±68.67
(Nt)	Inactivity	531.49±118.39	542.89±88.01	507.72±112.10	543.14±61.22
CMJH	Intervention	39±7.61	40.4±7.84	39±8.15	40.3±9.82*
(cm)	Inactivity	41.5±7.44	39.9±7.73	39.7±8.02	38.4±8.72
CMJP	Intervention	1066.59±383.45	1106.22±387.45	1053.37±367.77	1081.73±447.49
(W)	Inactivity	1159.52±359.53	1121.32±374.94	1016.12±336.15	1072.43±448.6
CMJRP	Intervention	17.03±3.41	17.84±3.99	16.99±3.99	17.27±5.04
(W·Kg ⁻¹)	Inactivity	18.58±3.72	17.99±4.31	17.36±4.33	17.17±5.5
CMJF	Intervention	737.11±181.3	708.5±172.15	665.6±180.92	693.8±218.16
(N)	Inactivity	749.9±181.83	748.5±139.37	722.3±243.86	790.4±256.42
CMJRF	Intervention	32872.65±8105.52	32213.99±9389	30977.53±10722.04	30064.13±12552.53
(N·s ⁻¹)	Inactivity	34142.16±7195.52	35428.64±5653.98	32584.04±11944.11	35760.43±11863.01

Data are expressed as mean and SD. RKF: Round kick force; CMJH: counter movement jump height; CMJP: counter movement jump power; CMJRP: counter movement jump relative power; CMJRF: counter movement jump force; CMJRFD: counter movement jump rate of force development. With (#) represented the significant effect of condition (†) represent the significant interaction between condition and time and with (*) the significant difference between the time points in each condition. $p < 0.001$.

However, there was a consistent pattern for increased performance values in RKF (533.44 ± 82.24 N·sec⁻¹ to 562.41 ± 49.48 N·sec⁻¹), CMJ height (39 ± 7.61 cm to 40.4 ± 7.84 cm) CMJ power (1066.59 ± 383.45 W to 1106.22 ± 387.45 W) and CMJ relative power (17.03 ± 3.41 W·mass⁻¹ to 17.84 ± 3.99 W·mass⁻¹) immediately after the first plyometric intervention trial. When all participants were considered as one group, irrespective of condition, significant correlations were found between baseline performance evaluations (jumping performance parameters and round kick force), ranging from 0.583 to 0.729 ($p < 0.01 - 0.005$) as well as between baseline and second, third and fourth performance measurements outcomes ($r = 0.432$ to 0.930 ; $p < 0.05 - 0.005$).

Table 2. Correlation coefficients (Pearson's r) between baseline and first, second and third trial performance measurements for the total of participants, independent of condition ($n=20$).

Parameters	Baseline Measurements				
	RKF	CMJH	CMJP	CMJF	CMJRF
Baseline Meas.	-	0.659 [#]	0.729 [#]	0.656 [#]	0.583 ^{**}
1st trial.	0.930 [#]	0.689 [#]	0.727 [#]	0.570 ^{**}	N.S.
2nd trial.	0.692 [#]	0.619 [#]	0.659 [#]	0.479 [*]	N.S.
3^d trial.	0.913 [#]	0.612 [#]	0.677 [#]	0.583 ^{**}	0.432 [*]

RKF: Round kick force; CMJH: counter movement jump height; CMJP: counter movement jump power; CMJRF: counter movement jump force; CMJRFD: counter movement jump rate of force development; N.S.: Non significant. (*): $p<0.05$, (**): $p<0.01$ and (#): $p<0.005$.

Discussion

The main purpose of this study was to investigate the effect of 3x5 tuck jumps on round kick force and lower limb jumping performance in elite karate athletes. In addition, the efficacy of this plyometric protocol over three repeated trials, paused by 10 min of rest was also examined. The main finding of this study was that 3x5 tuck jumps enhanced CMJ height after the third trial. However, no performance enhancement following this plyometric protocol was observed over three consecutive trials for round kick force and CMJ performance, compared to inactivity. Moreover, significant correlations were found between round kick and lower limb jumping performance measures showing that fitness and technique are interrelated aspects of karate performance.

To our knowledge only one previous study (Esformes, et al., 2010) ~~has~~ examined if whether CMJ performance parameters (maximal displacement, peak power, and peak vertical force, rate of force development and relative force) were enhanced as compared to inactivity, if preceded by heavy-resistance or plyometric exercises in 3 consecutive trials. The results of that study revealed no significant differences for any of the other variables, but greater displacement was found for heavy resistance compared to inactivity or plyometrics, whereas no differences were found for any of the conditions for the repeated trials. In contrast, our findings revealed significant differences in CMJ performance immediately after the third plyometric condition. In the study of Esformes et al., (2010), the testing procedures, the rest period (5 min) between plyometric exercises, the number of repetitions (24 foot contacts) and the duration of the plyometric intervention may have resulted in excess fatigue and decreased power capacity that probably suppressed any potentiating effects (Batista et al., 2007). In our study, 3x5 tuck jumps interspersed by a 10-min rest interval may have resulted in an increased lower limb jumping performance. An increase in RKF, CMJ height, power and relative power was also observed after the first intervention though not significant, showing that this plyometric program may be beneficial as a competitive warm-up strategy in combat sports thus being in line with training and competitive practice.

Warm-up routines prior to competition aiming to attain optimal performance are usually based on the experience of high-level coaches and athletes, lacking scientific evidence supporting their effectiveness (Bishop, Bonetti and Spencer, 2003). Plyometric exercises have been widely used as a training method to improve the efficiency of the stretch-shortening cycle (Chamari et al., 2008; Markovic et al., 2007), however, a need remains to examine their applicability in competitive conditions. It is reported that plyometrics can result in an increase in neural stimulation of the muscle and subsequently improve power production (Hilfiker et al., 2007; Masamoto et al., 2003; Mc Bride, Ninphius, and Erickson, 2005) however, this result is not unanimous (Till and Cooke, 2009; Tsolakis et al. 2011; Tsolakis and Bogdanis, 2012; Turki et al., 2011). Previous studies reported a failure of one set of 3-5 tuck jumps to enhance the excitability of the fast twitch motor units and to cause a PAP effect (Till and Cooke 2009; Masamoto et al., 2003). On the other hand, performing more sets and/or repetitions of a conditioning activity, such as the tuck jumps, may induce fatigue (Tillin and Bishop, 2009). Recently, Turki et al., (2011), demonstrated that 3 sets of 3 tuck jumps were not adequate stimuli to increase the CMJ performance that was measured 0, 4, 8, 12, 16 and 20 min following the jumps. Similarly, Tsolakis et al., (2011), reported that 3 sets of 5 tuck jumps had no effect on CMJ height over a 12 min recovery time in elite fencers.

There is lack of information on the effects of plyometric exercises on leg force and power as well as on the force application through technical skill execution in contact sports. To our knowledge, only one study has recently used plyometric protocols as potentiating exercises in well-trained judo athletes. Miarka et al., (2010), compared different potentiating protocols consisting of maximum strength, plyometric and contrast methods on a specific judo test performance. The authors reported that 10 series of 3 consecutive modified drop jumps from increasing heights (20 – 40 – 60 cm) resulted in significant specific functional kinetic patterns (ukes) improvement during the first 15 sec of the test compared to the-control condition (Miarka et al., 2010).

The results of the present study indicated that CMJ height significantly increased after the third intervention as compared to baseline measures. It should be noted that CMJ power also increased, though non significantly, after the first intervention. It can be speculated that plyometric exercises can recruit higher

threshold motor units, which in turns enhance neural stimulation only when high power outputs are demanded (Masamoto et al., 2003; Chen et al., 2013; Hilficker et al., 2007; Mahfield et al., 2004). Unfortunately, electromyography (EMG) was unavailable, making it impossible to explore the underlying mechanisms of the results.

In addition, Sale (2002), stated that the longer the rest length between the end of the conditioning activity and the beginning of the performance, the greater the recovery from the fatigue accompanied however by a greater decay of the PAP mechanism. In the present study, the 5 min interval was an adequate rest length to induce performance enhancement in well-trained elite karate athletes. It is previously reported that in well-trained athletes, the recovery from fatigue may be rapid enough to exhibit a portion of the initial heightened contractile ability (Harisson, 2010).

As expected, round kick force was significantly and positively correlated with lower limb performance parameters (CMJ height, power, relative power and force) underlying the importance of physical fitness abilities in optimizing technical performance (Loturno et al 2014). This result is of practical relevance because in karate combats, performance strategies aiming to maximize muscle power and force may be of great value for karate athletes. As Loturno et al., (2014), pointed out, athletes may intentionally execute a punch or a kick aiming for either maximum speed or maximum impact, depending on whether the competition is “full contact” or not. Karate players perform on a single day, sequential matches interspersed with variable time spaces of inactivity (World Karate Federation, 2009), a condition that can seriously jeopardize their performance. One interesting finding of the present study was that performance enhancement in CMJ height was observed after the third intervention. Additionally RKF, CMJ height, power and relative power performance tended to be increased after the first intervention. It is possible that the three sets of tuck jumps may provide an alternative to traditional warm-up practices in these athletes. It may also be possible that the inclusion of tuck jumps in an athlete preparation for his/hers next performance will ensure consistent force generation across repeated trials. However, it is still a debate, which is the best preparation strategy, for elite-level athletes (Fletcher 2013).

The training status of the participants should also be taken into consideration when interpreting the results. All athletes were active members of the Greek national team competing at international level with a considerable training and competing experience, thus a population that even small improvements may be relevant. Athletes of this level may have reached a “ceiling effect” in their performance where a significant change is unlikely to be observed (Cormie, McGuigan and Newton, 2011a,b). It should be recognized that the number of participants (5 male and 5 female international level karate athletes) is limited however, it was thought that lower level athletes might have a different response to potentiating exercises, especially to a protocol modeling competition parameters.

One issue that is not addressed is the fact that the conditioning activity may have a warm-up rather than a potentiating effect on performance specifically when the performance evaluated in repeated trials. For practitioners and athletes, the line of discrimination between PAP and warm-up is thin and in most competitive situations as defined by sport specific rules, it would seem a more practical approach to use a sport-specific warm-up, given its relative effectiveness and ease of implementation.

Since PAP is an inter-individual phenomenon, implementation of this training strategy should be adapted by coaches taking into consideration intensity, volume and rest periods of potentiating exercises, (Till and Bishop, 2009), therefore further research is required on the implementation of plyometric exercises as part of a sport specific warm-up during competition.

Conclusions

In conclusion, the results of this study showed that plyometric exercises can be incorporated in competitive warm-up conditions to enhance and maintain selected jumping performance parameters in elite karate athletes. However, the potentiating effect of plyometrics included in the warm-up was not apparent in technical skills force application over repeated trials. Taking into consideration that PAP is an inter-individual phenomenon, and especially in elite athletes coaches should consider the individual responses of their athletes and reshape the characteristics of the plyometric intervention in order to find the adequate training stimuli to enhance competitive karate performance.

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