Journal of Physical Education and Sport ® (JPES), Vol.20 (4), Art 236 pp. 1740 - 1746, 2020
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Effect of a 6-week plyometric training on power, muscle strength, and rate of force development in young competitive karate athletes

CHRISTOS IOANNIDES[1], ANDREAS APOSTOLIDIS[2], MARIOS HADJICHARALAMBOUS[3], NIKOLAOS ZARAS[4]
[1,2,3,4,]Human Performance Laboratory, Department of Life and Health, University of Nicosia, CYPRUS

Published online: June 30, 2020
(Accepted for publication: June 22, 2020)
DOI:10.7752/jpes.2020.04236

Abstract
Problem Statement: The performance in Karate mainly depends on aerobic capacity but particularly on explosive muscular strength production. Plyometric training has been previously shown to increase power, strength, and explosive athletic ability. However, scarce data exist regarding the training-induced changes in power, muscle strength, and rate of force development (RFD) in Karate athletes after plyometric or Kumite training. Purpose: The purpose of this study was to examine the effect of a 6-week plyometric training on maximum power, muscle strength, and RFD in young competitive Karate athletes. Methods: A total of 12 young competitive Karate athletes (N = 10 males and N = 2 females) were divided into plyometric (PG, N = 6) and Kumite (KG, N = 6)groups and followed 2 training sessions for 6 weeks of either plyometric or Kumite training. Measurements were performed before and after training intervention and included countermovement jumps (CMJ), maximum isometric RFD and peak torque (PT), standing long jump, and upper body seated medicine ball throws. Results: No significant differences were observed between groups for CMJ and RFD (p>0.05). Significant difference was determined between PG and KG in isometric PT (PG: 9.52 ± 3.64% vs. KG: 1.75 ± 6.91%, p = 0.03). Standing long jump performance considerably increased for PG compared to that for KG (PG: 4.32 ± 4.97% vs. KG: −1.12 ± 3.51%, p = 0.05). The performance in seated medicine ball throws increased overtime only in PG by 4.8 ± 3.55% (p = 0.017); however, no difference was observed between the groups (p>0.05). Conclusions: The results of this study suggest that 6 weeks of specific plyometric training increases lower body power and strength as well as upper body power performance in young Karate athletes. Therefore, coaches may effectively use plyometric training to increase upper and lower body muscle power in young Karate athletes.
Key words: martial art, Kumite, explosiveness, standing long jump

Introduction

Karate is a fullcontact combat sport which divided into Kata and Kumite. Kata represents the traditional form of Karate where a pre-arranged form of movements is performed in an exhibitioner manner while Kumite includes sparring between two opponents each aiming to achieve points during competition (IPPON, WASSARI and YUKO) (Arazi & Izadi, 2017; Chaabene et al., 2019). Consequently, Kumite athletes spend a large part of their training in sparring and developing technical movements which occasionally leads to a reduction of strength-power component of daily training sessions.Under these circumstances,plyometric training may be a usefultraining tool for increasing strength, power and neuromuscular explosive performance including kicking performance particularly (Suchomel et al., 2019; Douglas et al., 2016). A plyometric protocol consisting of 3 sets of 5 consecutive tuck jumps may acutely enhance round kick force capability and lower limbs' jumping performance in elite Karate athletes (Margaritopoulos et al., 2015). In addition, long-term training intervention studies revealed that a 9-weekof strength-power training program improved physical performance and power in female Karate athletes (Yazdani et al., 2017), whilst 8-week of plyometric-based training significantly increased upper and lower body anaerobic performance in Karate practitioners (Nowakowska et al., 2017).Although there is a strong relationship between power capacity and Karate performance (Roschel et al., 2009; Katić et al., 2010), a previous study reported that power performance measurements, such as the counter movement jump (CMJ), may not be a specific power test for Karate athletes. However,CMJ is frequently used to detect changes in power capacity and/or in neuromuscular explosiveness performance (Roschel et al., 2009). Indeed, empirical data and communication with coaches and athletes revealed that during a Kumite competition, the side, front and rear movements, may provide a better defence and/or offer the opportunity for a reflex-respond kick or punch to the opponent's offence. Consequently, fast horizontalmovement ability may be a crucial factor for Kumite performance (Katić et al., 2010), even though scarce data exists regarding the effects of plyometric and Kumite training on fast horizontal movement ability in Karate athletes.

Corresponding Author: . NIKOLAOS ZARAS, E-mail: zaras.n@unic.ac.cy

Explosive strength is described as the rate of force development (RFD). RFD evaluates the force that can be applied in short time-periods, usually in time frames of 0-250miliseconds and it can be calculated from the force/torque-time curve during an explosive muscle contraction (Maffiuletti et al., 2016).Leg press isometric RFD has been correlated with neuromuscular explosiveness performance in throwers and elite weightlifters (Zaras et al., 2016a; 2020), while elite Taekwondo athletes produced comparable lower body RFD relative to heavier power athletes (Kavvoura et al., 2018). Similar to Taekwondo, Kumite considers as a high intensity activity sport wherealmost all the offensive and defensive actions are performed with maximum velocity and power effort (Zehr et al., 1997; Arazi and Izadi, 2017).Considering the significant contribution of the RFD in explosive strength production, then the RFD might be of a great importance for the outcome of a Kumite fighting game. However, RFD in Karate athletes has not been previously described, whilst whether plyometric or Kumite training may enhance RFD in Karate athletes, remains largely unknown.
The purpose therefore of the present study was to investigate the effect of 6 weeks plyometric vs. Kumite training on power, muscle strengthand RFD performance in young competitive Karate athletes. The hypothesis was that plyometric training may induce greater increases in muscle power and strength and in RFD than the traditional Kumite training.

Materials and Methods

Athletes

Twelve Karate athletes (N=12) 10 males and 2 females with 5.2 ±2.1years training experience, participated in the study. Athletes were divided in two groups according to their initial power performance in (CMJ) and standing long jump (CMJ: P = 0.933 and standing long jump: P = 0.790): the plyometric group (PG: N=6, 5 males, 1 female, age17.6 ± 1.5 years, body mass 65.1 ± 10.2 kg, body height 1.72 ± 0.01 m) and the Kumite group (KG: N=6, 5 males, 1 female, age 17.0 ± 0.9 years, body mass 67.1 ± 9.6 kg, body height 1.77 ± 0.09 m). Athletes participated in National and International Kumite competitionswhile8 of them were among the winnersof the last National championship. Athletes were fully informed of the risks and benefits of the study prior to entry and then they signed an institutionally approved informed consent. In addition, signed parental consent was obtained for athletes who were under 18 years of age. All procedures were in accordance with the 1975 Declaration of Helsinki as revised in 2000 and were approved by the institutional ethics committee (project number EEBK/ΕΠ/2019/107).

Experimental design

Athletes visited the laboratory on two different occasions before and one after training intervention. During the first visit athletes sign the informed concern and performed familiarization testing's with the CMJand the isometric leg extension measurements. During the second visit athletes evaluated in the CMJ and the isometric leg extension measurement. On a different daythe standing long jump and the seated medicine ball throws measurements were performed in the sports facilities of the athletes. After the end of the 6 weeks training athletes visited one time the laboratory (CMJ and isometric leg extension)and the sports facilities (standing long jump and medicine ball throws) for follow up measurements.

Training

Athletes normally performed 4-5Karate training sessions per week. Both PG and KG added 2 training sessions within the existing training schedule suppurated by 48h of either plyometric or Kumite training. Athletes in PG were instructed to perform the jumping bounds as fast as possible, while athletes in KG were instructed to performed as many offensive actions as possible during the Kumite sparring. Training variables for PG and KG are described in Table 1. Plyometric and Kumite training programs were design according to the theory of periodization and progressively increased during the 6 weeks training. During the experimental period, all the remaining training days were similar for both groups. Briefly, training included light running, body mass resistance exercises, Kata practise, kicking and punching exercises and Kumite sparring. During the experimental period no extra plyometric exercises were performed by athletes apart from the experimental protocol. Athletes in both groups conclude all training sessions without injuries.

Table 1. Plyometric and Kumite training programs during the 6 weeks training

	Exercises	Weeks 1-2	Weeks 3-4	Weeks 5-6
Plyometric training program	Drop jumps and jumping hurdle Box jumps Long jumps Seated medicine ball throw (1kg)	4 x 4	4 x 6	4 x 8
Kumite training	Sparring	3 x 90 sec	4 x 120 sec	5 x 120 sec

Rest between plyometric sets = 60sec, rest between exercises = 90sec, rest between Kumite combat = 90 sec.

Countermovement jumps

Athletes started with 5 min warm-up on a stationary bicycle at 50Watts and then performed 3 CMJs with submaximal intensity. Subsequently,athletes performed 5 maximal CMJs with 2 minutes rest between jumps (Optojump Modular System, UK) with arms akimbo. Data were recorded and analysed (Optojump Next, UK) to calculate maximum vertical jump height and power output during the push off phase (Sayers et al., 1999). From the 5 CMJs the best and the worst jumps according to jumping height were excluded from the analysis and the mean of the remaining CMJs was used for the statistical analysis. This analysis was performed in order to monitor the neuromuscular status of the athletes before and after the 6 weeks training period (Gustavo Claudino et al., 2017). The ICC for CMJ height and power output were 0.989 (95% CI, lower = 0.957, upper = 0.997) and 0.980 (95%CI: lower = 0.985, upper = 0.990), respectively.

Leg extension isometric force

Ten minutes after the CMJs athletes performed the isometric leg extension force measurement on an isokinetic dynamometer (HUMAC NORM isokinetic extremity system) for the evaluation of quadriceps maximum isometric peak torque (IPT) and RFD. Athletes seated in the upright position and straps were used to ensure the stable position of the shoulders, hips and non-exercising leg. The exercising leg was determined during the familiarization session (Elias et al., 1998). Additionally, both hips were at 110º flexion while knee angle was set at was set at 60◦ flexion (0◦ = full extension) (Andersen et al., 2010; Marcora et al., 2000). Three submaximal efforts were performed with progressively increasing force. Then, four maximal efforts were allowed. Athletes were instructed to apply their maximum force as fast as possible and to sustain it for 3 seconds. Real-time visual feedback of the force applied was provided for each effort via a computer monitor placed just in front of the isokinetic dynamometer. Data from the isometric measurement were recorded and analysed to calculate the maximum isometric torque and the RFD from the torque-time curve. Maximum IPT was calculated as the greater force generated from the torque-time curve. RFD was calculated as the mean tangential slope of the torque-time curve in specific time windows of 0-20, 0-60, 0-80, 0-100, 0-120, 0-160, 0-200 and0-260 milliseconds. From the four maximum attempts the best and the worst were removed and the mean of the remaining trials was used for the statistical analysis. The ICC for IPF was 0.990 (95% CI: Lower = 0.964, Upper = 0.998) and for RFD was 0.893 (95% CI: Lower = 0.649, Upper = 0.972).

Standing longjump

One day after the laboratory measurements athletes visited the training facilities and performed the field tests. All athletes were familiar with standing long jumps since they had previously used long jumps during their training sessions. After a warm up with light running and stretching, athletes placed their toes in the beginning of the measuring tape in front of a mattress in an attempt to push with their feet and jump with arm swing as fast and long as possible (Almuzaini et al., 2008). Three standing long jumps were performed for warm up and athletes were instructed to progressively increase their jumping velocity to maximum. Then, four maximum standing long jump trails were performed with one minute rest between each trial. The distance of the best jump was measured to the nearest centimetre from the take-off point to the mark where the heels landed on the mattress. Marks were placed on the mattress as goal-reaching feedback. From the four maximum jumps the best and the worst were excluded and the mean of the remaining jumps was used for statistical analysis. Analysis also included the calculation of work production during the long jump with the equation: W = F • S • g (W = work in joules, F = force which is the body mass in Newton's, S = distance of the long jump in meters and g = the gravity 9.81 m•sec-1, [Baker, 1995; Zaras et al., 2019]). The ICC for the standing long jump was 0.961 (95% CI: Lower = 0.884, Upper = 0.987).

Seated medicine ball throw

Five minutes after the standing longjump evaluation, athletes performed the seated medicine ball throws. The mass of the medicine balls was 1.5 and 3kg. Athletes were seated on the floor with their knees straight and their back positioned against a wall. The medicine ball was held in front of their chest and they performed maximum throws using only their upper extremities (Van den Tillaar and Marques, 2013; Zaras et al., 2016b). Three warm-up trials were allowed in random order, and then, athletes were instructed to throw the medicine ball as far as possible. Medicine balls with different masses were thrown in random order. Throwing distance was measured to the nearest centimeter from the nearest mark of the ball to the wall where the athlete was seated (Zaras et al., 2016b). Four maximum attempts were allowed with each medicine ball with 1 minute rest between each trial. From the four throws the best and the worst were eliminated and the mean of the remaining two attempts was used for the statistical analysis.The intraclass correlation coefficient for the seated medicine ball throw was ICC = 0.988 (95% CI: Lower = 0.959, Upper = 0.972).

Statistics

All data are presented as mean ± SD. A 2-way analysis of variance for repeated measures (2 x 2 group x time), with Bonferroni post hoc correction, was used to evaluate differences for each variable between groups. Calculation of effect sizes (η^2) was also performed. Independent sample T-Test was used to detect changes in percentage differences between the PG and KG. All data were analysed using SPSS 21, whilst, $p \leq 0.05$ was used as a 2-tailed level of significance.

Results

Results for body mass, CMJs and standing long jump are presented in Table 2. Performance in CMJ height, power and power per body mass remained unaltered for both groups after 6 weeks training ($P < 0.05$). However, standing long jump was significantly increased only in PG ($P = 0.042$, $\eta^2 = 0.351$), whilst the percentage increase was significantly greater in PG compared to KG(PG: 4.32 ± 4.97% vs. KG: 2.30 ± 0.35%, $P = 0.04$). No significant change was observed for standing long jump expressed as work production between groups ($P = 0.883$, $\eta^2 = 0.003$).

Table 2. Changes in body mass, CMJ and standing long jump after 6 weeks training in plyometric and Kumite group.

Variables	Plyometric Group		Kumite Group	
	T1	T2	T1	T2
Body mass (kg)	65.1±10.2	65.7±10.2	67.1±9.6	68.1±9.7
CMJ height (cm)	33.5±8.4	32.9±7.1	33.1±7.4	33.7±6.7
CMJ power (W)	2913.2±886.1	2914.3±796.2	2990.7±800.2	3067.6±745.7
CMJ p/kg (W/kg)	43.9±8.5	43.7±7.2	43.9±7.0	44.5±5.8
Long Jump (cm)	2.28±0.26	2.37±0.29*	2.32±0.29	2.30±0.35
Long Jump (J)	14431.5±3535.2	15193.2±3732.4	15121.8±3548.4	15530.1±4004.2

*$P \leq 0.05$, difference between pre and post measurements, #$P \leq 0.05$, difference between groups, CMJ = countermovement jump

Significant change was found between groups for maximum IPT (Fig. 1). Specifically, PG increased IPT by 9.52±3.64% ($P = 0.004$, $\eta^2 = 0.582$), compared to KG;where no change was found following training intervention (1.75 ± 6.91%, $P = 0.655$, $\eta^2 = 0.021$). In addition, percentage increase for IPT followingPG was significantly greater than KG ($P = 0.035$). No significant difference was found for RFD measurement in all time frames (Table 3).

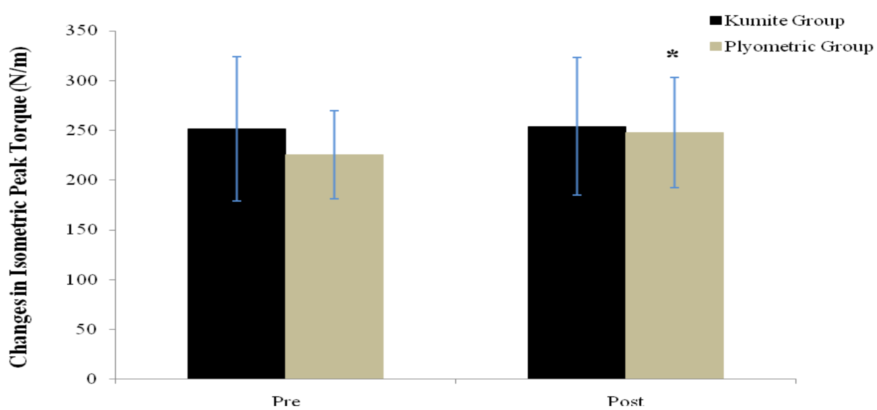

Figure 1. Changes in isometric peak torque after 6 weeks Plyometric or Kumite training in young Karate athletes. Significant increase after plyometric training (* $P \leq 0.05$).

Table 3. Changes in rate of force development and isometric peak torque after 6 weeks training in plyometric and Kumite group.

RFD N/m/Sec	Plyometric Group		Kumite Group	
	T1	T2	T1	T2
RFD20ms	1530.8±212.2	1411.3±391.4	1647.5±553.0	1598.2±309.1
RFD60ms	1432.1±338.3	1386.3±356.7	1453.6±478.5	1478.8±301.9
RFD80ms	1386.5±353.8	1377.5±296.4	1403.7±445.2	1390.6±290.4
RFD100ms	1303.9±305.0	1303.7±300.0	1370.7±412.8	1355.3±297.7
RFD120ms	1228.0±272.1	1225.1±273.6	1287.6±382.4	1289.8±280.1
RFD160ms	1114.0±248.0	1117.2±260.7	1150.9±348.4	1166.5±254.4
RFD200ms	1004.2±204.6	1013.3±234.0	1029.1±312.4	1052.5±239.4
RFD260ms	827.3±165.0	847.9±196.8	865.5±264.5	892.7±216.9
IPT (N/m)	225.4±44.4	247.8±55.2	251.3±72.4	254.1±69.0*

*$P \leq 0.05$, difference between pre and post measurements, #$P \leq 0.05$, difference between groups, RFD= rate of force development, IPT = isometric peak torque.

Performance in seated medicine ball throws was increased only in the PG, for the 1.5kg medicine ball by 4.8±3.55% (pre: 6.3±1.32m, post: 6.6±1.26m, $P = 0.017$, $\eta^2 = 0.452$) compared to KG (pre: 6.8±1.17m post: 7.0±1.23m, $P = 0.103$, $\eta^2 = 0.244$). Performance with 3kg medicine ball remained unaltered for both groups (PG: pre 5.03±1.1m, post 5.0±1.0m $P = 0.613$, $\eta^2 = 0.027$, KG: pre 5.0±0.98m, post 5.0±0.96m, $P = 0.987$, $\eta^2 = 0.000$).

Discussion

The purpose of the present study was to investigate the effect of 6 weeks plyometric vs. Kumite traditional training on power, muscle strength and RFD performance in young competitive Karate athletes. The novel finding of the current study was that lower body muscle power performance increased significantly more in PG compared with KG. In addition, maximum IPT in leg extension was significantly increased after plyometric training compared with Kumite training. Lower body increases in muscle power and strength were accompanied by a concomitant increases on upper body muscle power as measured here with the seated medicine ball throw test. Interestingly, CMJ performance remained unaltered between groups while no significant change was observed for RFD in all time frames. Taking together, these results suggest that plyometric training may increase lower and upper body power capacity compared with the Kumite traditional training one. Consequently, the implementation of plyometric method in the training microcycles is recommended for Karate coaches for increasing neuromuscular explosiveness performance of young competitive Karate athletes.

Standing long jump performance was significantly increased in the PG when compared withthe KG. As mention above, during a Kumite competition athletes performfast movements and various direction changes(especially side, front and backward movements) for gaining a better defence position advancing simultaneously their position for a reflex-respond kick to the opponent's offence. From practical perspective, coaches focus on these horizontalmovement patterns during Kumite training and competitions.However,in the current study, it was observed that Kumite training *per se* may not enhance the horizontal movement ability of the athletes. On the other hand, when plyometric training (long jumps)was progressively supplemented (jumping bounds ranged from 32 to 64 per week) into the traditional karatetraining program,the ability of the horizontal movement was significantly enhanced. However, no significantdifference was observed for CMJ. Consequently, standing longjump testmight be more appropriate for evaluating Kumite performance than the CMJ test. Indeed, a previous study reported that CMJ may not be a specific power test for Karate athletes since by using this particular test, it was unable todistinguish thewinners and losers competitors (Roschel et al., 2009); although, CMJ is frequently used by coaches to monitor changes in power capacity of their athletes. In contrast, an alternative studyhad showed that 9 weeks of strength-power training increased CMJ performance in female Karate athletes (Yazdani et al., 2017). Consequently, CMJ might be used as a regular and easily executed test for evaluating power capacity of the athletes.However,based on the current results, standing long-jump test, which is also an easily executed test, may be a more functional test for monitoring Karate athletes' power progress and performance.

In the current study, upper body muscle power performance was significantly increased in the PG when compared with the KG.This however, increase was observed only with the lighter medicine ball (1.5kg). This finding was partially expected, since PG utilized this particular exercise pattern during the training program usingthe 1-kg ball. Karate offensive movements are power demanding actions and characterized as fast velocity unloaded movements (Zehr et al., 1997; Arazi and Izadi, 2017; Kavvoura et al., 2018). Based on this, success in Kumite competition may depend on the high velocity ability of kicking and punching techniques. Consequently, these results suggest that for the upper body power enhancement,punching during a Kumite practice may not be sufficienttraining method to enhance upper body capacity. Additionally, studies in preadolescence Karate athletes showed that basic motor abilities including medicine ball throw, may increase following only Karate training (Ma and Qu, 2007; Padulo et al., 2014, Greco, 2020). Thus, low load medicine ball but with maximum velocity of throw may be used during training in an attempt to enhance upper body muscle power during competition.

IPT, as measured in the present study, was significantly increased only following plyometric training compared with Kumitetraining. Plyometric muscle action involves the lengthening of a muscle leading to concurrently increased strength production. Additionally, specific plyometric training has been suggested to simultaneously increase muscle power, strength and explosive performance in athletes and trained participants (Suchomel et al., 2019; Douglas et al., 2016). However, RFD remained unchanged for both PG and KG. Data regarding the relationship between RFD and Karate athletes are limited while according to our knowledge RFD has never been evaluated in Karate athletes. Explosive performance as measured in the current study, with single-joint isometric leg extension, may partially explain changes of the whole body RFD for both PG and KG compared to multi-joint RFD measurements (Zaras et al, 2016a; Kavvoura et al., 2018).Hence, whether RFD is enhanced following plyometric or Kumite training needs further investigation.

Kumite is characterized by numerous and continuous high velocity muscle actions with no pre-arranged rest periods. A significant aspect of the present study was that during all performance evaluations, the higher and the lower attempts were excluded from the statistical analysis, as previously described (Gustavo Claudino et al., 2017), and the mean value of the remaining attempts were included for evaluating the neuromuscular explosiveness performance of the athletes before and following the training intervention.Consequently, the evaluation of repeated maximum muscle actions may provide a better insight into the neuromuscular adaptation of the athletes. From a practical point, this seems to be a better approach for evaluating the neuromuscular explosives performance condition of the martial arts athletes.

Plyometric training induced significant neural and muscular adaptations. However, no electromyographic data nor muscle biopsies were obtained in the current study. Additionally, a longer training period might have induced further changes in RFD and CMJ performance which would probably illustrate better the degree of these adaptations in response to plyometric or Kumite training in young Karate athletes. Another limitation of the current study was the small sample size participated in both training groups. Future studies may address these issues and provide a more detailed assessment of the effectiveness of the plyometric training in Karate athletes.

Conclusions

The findings of the current study suggest that 6 weeks of plyometric training may increase upper and lower body muscle power and quadriceps maximum strength in young competitive Karate athletes. From a practical perspective, plyometric training may increase the ability of the athletes for fast velocity movements related to Karate performance. This may include faster kicking or punching while in the same time increase thehorizontal movement velocity in different directions during a Kumite competition. When therefore, the training will be focused in increasing both muscle strength and neuromuscular explosiveness performance, plyometric training method should be included in Karate training sessions. Two training sessions per week may effectively increase power capacity of Karate athletes. Consequently, coaches may use the plyometric training program during training mesocycles,before competitions or during tapering for increasing the upper and lower muscle power and strength of young Karate athletes.

Acknowledgement

We express our gratitude to the athletes participated in the study. We also thank the head-coach Vasiliou Andreas, for his technical assistance. All experimental procedures used, comply with local governmental laws for human subjects. This work has never been published anywhere else before, either completely or in part.

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