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Effects of post-activation potentiation exercises on kicking frequency, fatigue rate and jump performance in taekwondo athletes: a case study

Efectos de los ejercicios de potenciación post activación sobre la frecuencia de pateo, tasa de fatiga y saltabilidad en atletas de taekwondo: un estudio de caso

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Abstract. The aim of the present study was to establish the effects of three conditions of post-activation potentiation (PAP) exercises on kicking frequency, fatigue rate (FR) and jump performance in novice and advanced taekwondo athletes. Secondarily, to establish if the PAP strength plus plyometrics exercises produced a significantly higher increase with respect to exercises of isolated strength and plyometrics. Eight university taekwondo athletes (n=4 novices and n=4 advanced) were randomized into four (one control and three experimental) intervention conditions. Kicking frequency and FR were evaluated with the Frequency Speed of Kicks Test (FSKT), and countermovement jump test (CMJ). Effect size (ES) was calculated and the significance level was stabilized at $p<0.05$. Advanced taekwondo athletes obtained significantly higher results when compared to novices in the control condition for the fifth FSKT-10s (p=0.019; ES=2.382); in the strength condition for the second FSKT-10s 2 (p=0.028; ES=2.590); and in the strength plus plyometrics condition for the first FSKT-10s (p=0.037; ES=1.805) and third FSKT-10s (p=0.027; ES=2.117). Furthermore, the control condition showed a difference when compared to strength plus plyometrics: on the first (p=0.040; ES=0.552) and second FSKT-10s (p=0.032; ES=0.687), respectively. The FR and CMJ did not significantly differ between the athletes nor between the intervention conditions. In conclusion, the PAP exercises did not improve kick frequency, FR and jump performance in the taekwondo athletes evaluated. However, these exercises did not produce adverse effects in the FR; thus, they could be used in taekwondo athletes with previous strength training.
Keywords. Post-activation potentiation, strength, taekwondo, combat sports, martial arts.

Resumen. El objetivo del presente estudio fue establecer los efectos de tres condiciones de ejercicios de potenciación post-activación (PAP) sobre la frecuencia de pateo, tasa de fatiga (TF) y saltabilidad en atletas de taekwondo novatos y avanzados. Secundariamente, establecer si los ejercicios de PAP de fuerza más pliometría producen un aumento significativamente mayor respecto a los ejercicios de fuerza y pliometría aislados. Ocho atletas universitarios de taekwondo (n=4 novatos y n=4 avanzados) fueron asignados aleatoriamente a cuatro condiciones de intervención (una control y tres experimentales). La frecuencia de pateo y TF se evaluaron con el *Frequency Speed of Kicks Test* (FSKT) y la saltabilidad con el salto contramovimiento (CMJ). Se calculó el tamaño del efecto (TE) y se estableció un nivel de significancia de p<0,05. Los atletas de taekwondo avanzados obtuvieron resultados significativamente mayores en comparación con los novatos en la condición control para el quinto FSKT-10 (p= 0,019; TE=2,382); en la condición de fuerza para el segundo FSKT-10s 2 (p=0,028; TE=2,590); y en la condición de fuerza más pliometría para el primer FSKT-10 (p=0,037; TE=1,805) y el tercer FSKT-10 (p=0,027; TE=2,117). Además, la condición control mostró diferencias al compararla con la condición de fuerza más pliometría en el primer (p=0,040; TE=0,552) y segundo FSKT-10s (p=0,032; TE=0,687), respectivamente. La TF y CMJ no presentaron diferencias significativas entre los atletas ni entre las condiciones de intervención. En conclusión, los ejercicios de PAP no mejoran la frecuencia de pateo, TF y saltabilidad en los atletas de taekwondo evaluados. Sin embargo, estos ejercicios no produjeron efectos adversos en la TF, lo que podría favorecer su uso con entrenamiento previo en fuerza.
Palabras clave. Potenciación post activación, fuerza, taekwondo, deportes de combate, artes marciales.

Introduction

Taekwondo is an Olympic combat sport characterized by a great variety of kicks (Torres, Molina-García, Falcó Pérez & Álvarez, 2010; Avakian, Miarka & Achour, 2016; Kazemi, de Ciantis & Rahman, 2013; Kazemi Waalen, Morgan & White, 2006), a fact that demands that athletes develop a high level of power and speed to achieve their highest sporting performance (Kazemi et al., 2013; Campos, Bertuzzi, Dourado, Santos & Franchini, 2012). Despite the diversity of kicks or punches, the most frequent technique used in competition corresponds to the roundhouse kick or *bandalchagui* (Torres et al., 2010; Torres, 2009; Morieria, Goethel & Goncalves, 2016), due to its simplicity (Torres, 2009) and high effectiveness (Avakian et al., 2016), besides allowing a favorable distance for the exchange of blows (Torres et al., 2010).

On the other hand, several physical fitness strategies specific to athletes of combat sports specialties, including strength and plyometrics exercises, have shown beneficial results when used as a pre-requisite to specific actions in fencing (Tsolakis, Bogdanis, Nikolaou & Zacharogiannis, 2011), judo (Miarka, del Vechio & Franchini, 2011) and taekwondo athletes (Da Silva Santos et al., 2015; Da Silva Santos & Franchini, 2016a; Jakubiak & Saunders, 2008). These strategies significantly improved maximum strength, muscle power, and jump performance. This set of exercises is used to generate a transient increase in muscle power prior to a driving action (Ojeda, Chirosa, Barrilao, Rios & Serrano, 2016), a fact that is known as post-activation potentiation (PAP) (Dobbs, Tolusso, Fedewa & Esco, 2018; Ojeda et al., 2016;

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Martínez, Medrano, Cortell-Tormo & Cardozo, 2019). In elite taekwondo athletes, significant improvements have been reported in the Frequency Speed of Kicks Test (FSKT), when PAP exercises are implemented with a 10-minute rest interval (Da Silva Santos et al., 2015). While the full version of the FSKT (i.e., multiple FSKT) shows a good response to a 9-week training program (Da Silva Santos & Franchini, 2016a), no acute improvements have been observed in 50% and 90% strength conditioning using one-repetition maximum (1RM) with 10-minute of rest.

Despite the favourable results that PAP exercises have shown in elite taekwondo athletes (Da Silva Santos et al., 2015; Da Silva Santos, Loturco & Franchini, 2018), to the best of our knowledge, the possible effect it might have for taekwondo athletes with a lower level of experience is unknown and it has been reported that athletes of higher competitive level have a greater chance of triggering PAP (Seitz & Haf, 2016). Previous work has shown that muscle activity response differs between novice and advanced athletes in roundhouse kick (Valdés-Badilla et al., 2018), a situation that could affect performance and leads to consideration the analysis of other types of variables, in this group of athletes. Thus, the aim of the present study was to establish the effects of three PAP exercise conditions on kicking frequency, fatigue rate (FR) and jump performance in novice and advanced taekwondo athletes. In addition, the secondary objective was to establish whether PAP strength plus plyometrics exercises produced a significantly higher increase for isolated strength and plyometrics exercises.

Material and Methods

Study Design

It was conducted a quasi-experimental design, which was considered four intervention conditions: one control and three experimental conditions (strength, plyometrics and strength plus plyometrics exercises). The athletes were randomized and was given 48 hours interval between the experimental conditions (Figure 1).

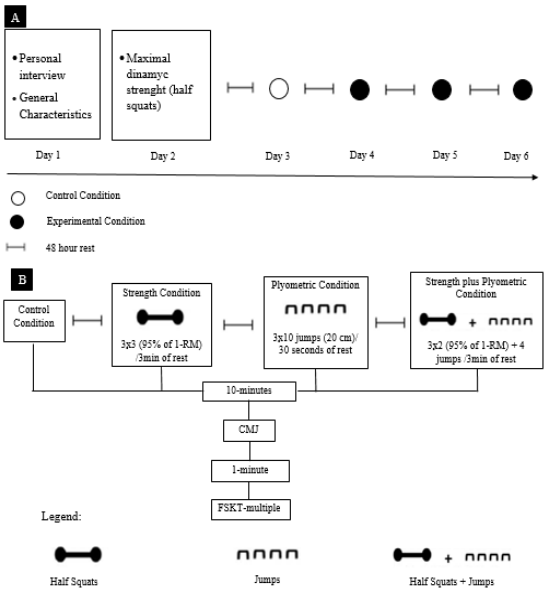

Figure 1. Study design
Abbreviations: a: Experimental design; b: Groups and procedures. Intervention Conditions assignment was randomly for each athlete.

Participants

The sample corresponded of the taekwondo team of a private university in Chile (n=8) who met the following inclusion criteria: a) taekwondo athletes with more than one year of experience; b) trained two or more times per week; c) have participated in national tournaments organized by the National Sports Federation of Taekwondo WT of Chile Federation; d) have represented his home studio in national tournaments. Those who presented: a) any incapacitating illness or injury that prevented their usual physical performance; b) who were in a period of physical rehabilitation were excluded. To categorize athletes in novice (n=4) and advanced (n=4), a previous study was followed (Valdés-Badilla et al., 2018) which considers the years of experience of the athletes. Novices athletes were categorized with less than three years of practice; on the other hand, advanced athletes were characterized by three years or higher of experience in this modality.

All participants were informed of the scope of the investigation and signed an informed consent, authorizing the use of the information for scientific purposes. The research protocol was reviewed and approved by the Scientific Ethics Committee of the Universidad Autónoma de Chile (N° 080-18) and developed according to the Declaration of Helsinki.

General characteristics

In the first session, the participants were interviewed regarding their age (years old), years of practice and weekly hours of training. The participants were weighed using a digital scale (Scale-tronix, USA, accuracy 0.1 kg) and bipedal height measured with a stadiometer (Seca model 220, Germany, accuracy 0.1 cm). Body mass index (BMI) was calculated by dividing the body weight by bipedal height squared (kg / m^2).

One-repetition maximum (1RM) evaluation

Before the intervention, athletes participated in an educational session on the correct technical execution of the half squat. Thus, it was possible to correct the position of the body. Subsequently, participants proceeded through their respective 1RM evaluation. All participants first did a general five-minute warm-up on a treadmill (SportsArt$_s$, T652M, USA) at 9 km/h with a three-minute rest before the performance of two sets of half squats. The following procedure was implemented (Ritti-Dias, Avelar, Salvador & Cyrino, 2011): a) a series of five high-speed repetitions with an Olympic bar (20 kg) and a 20 seconds rest; b) then three series of five repetitions with a rest between series of 2-minute, gradually increasing the weight; c) followed by a controlled-speed repetition, with a rest of 3 to 5 minutes until reaching 1RM.

Jump performance

Jump performance was determined by the countermovement jump test (CMJ) (Bosco, Luhtanen & Komi, 1983), which was carried out using a contact platform (Art Oficio Model: PF.4000/50; Chile). During the test execution, each participant was placed in a standing position, with feet parallel to shoulder width, knees extended, and hands placed

on the waist. After performing a quick downward movement, they flexed their knees and hips, followed by a quick leg extension, resulting in a maximum vertical jump. The participants performed three CMJ repetitions with a rest of 2 minutes between each one; subsequent analyses considered the maximum height of the best attempt.

***Multiple Frequency Speed of Kicks Test* (mFSKT)**

The mFSKT is a specific taekwondo test that measures kick frequency in a given time (Da Silva Santos & Franchini, 2016). It consists of five sets of 10 seconds (10s) of kicking with both legs and a rest of 10s between sets (FSKT-10s). In each set, the athlete must conduct as many *bandalchagui* kicks as possible (Da Silva Santos & Franchini, 2016; Da Silva Santos et al., 2015). To perform the test, each athlete stood in front of a punching bag equipped with a taekwondo chest protector (Daedo, Spain). Two evaluators were used: a person in charge of stimulating the athletes to obtain their greatest effort and time the five sets and another person who held the bag and counted the number of correctly executed kicks.

The mFSKT also estimates the FR in athletes, through the use of the following mathematical formula (Girard, Méndez-Villanueva & Bishop, 2011; Da Silva Santos, Herrera-Valenzuela, Ribeiro & Franchini, 2016):

$$FR\ \% = 1 - \frac{FSKT1 + FSKT2 + FSKT3 + FSKT4 + FSKT5}{\text{Best FSKT} \times \text{Number of Sets}} \times 100$$

Intervention

The intervention was composed of four conditions, one control and three experimental conditions that had PAP exercises (see Figure 1). All conditions began with the same general and specific warm-up. A general five-minute warm up on a treadmill (SportsArt$_{s,}$ T652M, USA) at 9 km/h, followed by a specific five-minute warm-up that included joint mobility and dynamic flexibility exercises with displacements (forward, back, diagonal, with change of side and turns), and technical movements without knee extension (Valdés-Badilla et al., 2018). Specific details of each condition are provided below.

Control condition: After a 10-minute rest, the athletes performed the jumping assessment by means of three CMJ jumps, followed by a one-minute rest before completing the mFSKT.

Strength condition: After a three-minute rest, athletes performed three sets of three squat repetitions at 95% of the 1RM with a three-minute rest between the sets. Then, after a 10-minute rest, the athletes completed the CMJ jumps and rested for one-minute before completing the mFSKT.

Plyometrics condition: After a three-minute rest, the athletes performed three sets of 10 jumps over fences 20 cm of high, with a 30 seconds rest between sets. Following this, they rested for 10-minute before the evaluation of CMJ jumps. After a one-minute rest, athletes completed the mFSKT.

Strength plus plyometrics condition: After a three-minute rest, the athletes performed three sets of two squat repetitions at 95% 1RM, plus four jumps over fences 20 cm high with 30 seconds rest between the sets. After a 10-minute rest, the CMJ jumps were evaluated and athletes rested for one-minute, before ending with the mFSKT.

Statistical analysis

The SPSS (*Statistical Package for the Social Sciences*) version 23.0 was used to analyze the data. The variables were tested for normality using the Shapiro-Wilk test. A descriptive analysis was conducted by calculating the mean, median, standard deviation, and 95% confidence interval. The Spearman correlation test was used to assess relationships between the general characteristics of the sample. To compare kicking frequency, FR and jump performance between novice and advanced athletes and between the intervention conditions (control, strength, plyometrics and strength plus plyometrics), the Kruskall-Wallis non-parametric test and the Dunn's post hoc test were used. To compare the intervention conditions in each group (novices, advanced and total), Friedman's test was carried out with the objective of performing an analysis of repeated measures. The effect size (ES) was determined using Cohen's d (Cohen, 1992), with a small effect considered as 0.20 - 0.49, a moderate effect as 0.50 - 0.79, or a large effect when >0.80. The statistical significance was established at $p<0.05$.

Results

Table 1 presents the general characteristics of the sample. Statistically significant differences were observed in the years of practice and the hours of weekly training between novice and advanced athletes.

Table 1.
Sample characteristics

	Novice (n= 4)		Advanced (n= 4)		
	Mean (SD)	95% CI	Mean (SD)	95% CI	*p*
Age (years)	20.50 (2.38)	16.71 – 24.29	24.75 (4.27)	17.95 – 31.55	0.133
Body weight (kg)	80.10 (18.31)	50.97 – 72.28	66.40 (4.93)	58.55 – 74.25	0.199
Bipedal height (m)	1.72 (0.11)	1.54 – 1.89	1.71 (0.14)	1.48 – 1.94	0.916
BMI (kg/m2)	26.88 (3.66)	21.06 – 32.69	22.98 (2.58)	18.87 – 27.08	0.132
Years of practice	1.50 (0.58)	0.58 – 2.42	8.50 (2.52)	4.50 – 12.50	0.002**
Training per week (hours)	4.25 (1.26)	2.25 – 6.25	9.50 (1.00)	7.91 – 11.09	0.001**

BMI: body mass index; CI: confidence interval; SD: standard deviation; p: p value. **Statistically significant differences; Spearman correlation test.

The Figure 2 illustrates the differences in kick frequency, FR and jump performance among athletes and among the intervention conditions evaluated. When making the comparison between the groups of advanced athletes and novices, the advanced athletes obtained significantly higher results with a large ES when compared to novice athletes in the control condition for the fifth FSKT-10s (p=0.019, ES=2.382); in the strength condition for the second FSKT-10s (p=0.028, ES=2.590); and in the strength plus plyometrics condition for the first FSKT-10s (p=0.0 37, ES=1.805) and third FSKT-10s (p=0.027, ES=2.117). While the mFSKT had a significantly higher performance with a large ES in advanced athletes only in the control condition (p=0.038, ES=1.906). FR and CMJ tests reported no significant differences between taekwondo athletes evaluated ($p>0.05$).

Moreover, when analyzing the differences between the intervention conditions in each group, it was observed that only when considering the total sample there were significant differences. For both the novice group and the advanced group there were no differences between the intervention conditions. In the total sample (n=8) the control condition had significantly better results with a moderate ES regarding the strength plus plyometrics condition for the first FSKT-10s (p=0.040; ES=0.552) and for the second FSKT-10s

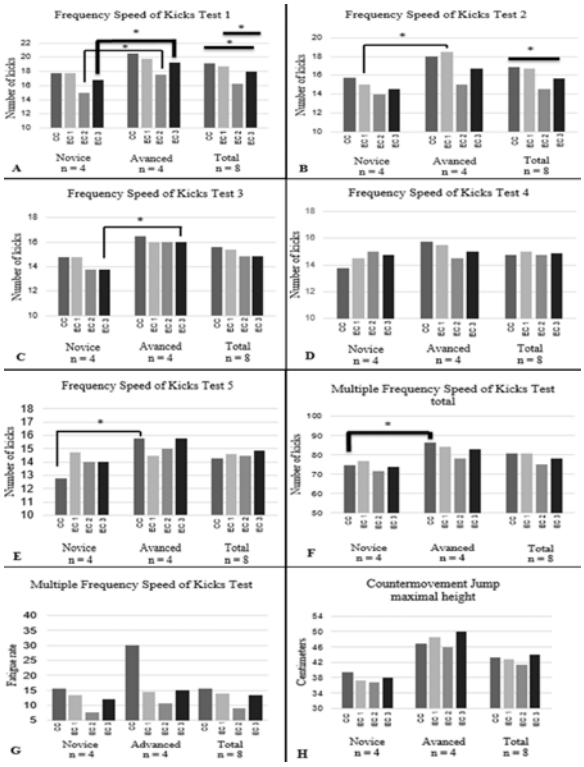

Figure 2. Differences in kicking frequency, fatigue rate, and jump performance between taekwondo athletes and intervention group

Abbreviations: A: Frequency Speed of Kicks Test 1; B: Frequency Speed of Kicks Test 2; C: Frequency Speed of Kicks Test 3; D: Frequency Speed of Kicks Test 4; E: Frequency Speed of Kicks Test 5; F: Multiple Frequency Speed of Kicks Test total; G: Fatigue rate of Multiple Frequency Speed of Kicks Test; H: Countermovement jump maximal height. ■ CC: Control Condition; ■ EC1: Experimental Condition 1; ■ EC2: Experimental Condition 2; ■ EC3: Experimental Condition 3. *Statistically significant difference (p<0.05). Kruskal-Wallis with Dunn's post hoc tests.

(p=0.032; ES=0.687). Besides, the strength condition presents significantly higher results with a small ES when compared to the strength plus plyometrics condition for the first FSKT-10s (p=0.015; ES=0.417). There were no significant differences in the FR and CMJ tests between the intervention conditions (p>0.05).

Discussion

The present study evaluated the effects of three PAP exercise conditions on kick frequency, FR and jump performance in novice compared to advanced taekwondo athletes, in addition to analyzing whether PAP exercises of strength plus plyometrics produced a significantly higher increase with respect to strength and plyometrics exercises alone. The main results indicated that advanced athletes achieved a significantly higher performance when compared to novices and the control condition exhibits a better response in the kicking frequency followed by the strength condition. This situation contrasts with that reported in elite taekwondo athletes, who achieved a significantly higher increase (p=0.008) in kick frequency after the strength plus plyometrics condition when compared to control condition and the strength and plyometrics conditions by themselves (Da Silva Santos, Valenzuela & Franchini, 2016a).

In this study, the control condition showed the best results for PAP exercises when faced with specific taekwondo tests. The literature suggests that athletes with three or more years of experience in strength training would have favorable responses in potentiation after a rest interval (Wilson et al., 2013; Da Silva Santos et al., 2016b); this was also true of elite taekwondo athletes (Da Silva Santos et al., 2015). It is likely that the athletes evaluated in the current study do not receive strength and plyometrics training, which could have influenced their performance in kicking frequency and jump performance.

Regarding the comparison of the PAP exercise intervention conditions, the strength condition was the one that achieved the best results compared to the plyometrics and strength plus plyometrics conditions. This may be related to the fact that the strength condition uses only one type of exercise (the half squat), representing the lower intensity and/or workload. In turn this condition may reduce muscle fatigue in comparison to the plyometrics and strength plus plyometrics conditions (Da Silva Santos et al., 2016b). While the strength condition exhibited a better response in the athletes compared to other experimental conditions, this phenomenon occurred only in the first set of the mFSKT, which could be explained by the load percentage of 1RM (i.e., 95% of 1RM). In this way, Wilson et al. (2013) suggests that a rest interval according to the intensity of the exercise is needed to generate potentiation. In addition, the recommended rest time for strength sports is between seven until 12 minutes (Ojeda et al., 2016; Wilson et al., 2013; Martinez et al., 2019). In this sense, future investigations that apply PAP exercises should specify the rest times before a specific activity according to athlete experience level (Da Silva Santos et al., 2016b).

FR was not significantly altered after the PAP exercises. In fact, FR was higher in the control condition. In a study conducted with judo athletes, no significant changes in FR were reported after acute strength training (Miarka et al., 2011). The results obtained in our study imply that strength training does not negatively affect FR in short-duration exercises, which could mean that PAP could be used before a specific taekwondo training.

Jump performance did not significantly change in the athletes evaluated in the current study. This result is like that of Da Silva Santos et al. (2016b), who studied elite taekwondo athletes. Fact that could be attributed to the times of rest between PAP exercise conditions with respect to CMJ (Moreno, 2020), or due to the lack of specificity of the jump test used in this study with the specific taekwondo activities.

Among the main strengths of the study are reliability and validity of assessments and the randomization to intervention conditions, which increased internal consistency. The sample size was a limitation and inhibited our ability to conduct analyses stratified by sex, use the same height for the fences (20 cm) limited the individualization of the workload. However, this paper is novel in that it compared taekwondo athletes with different levels of experience.

Conclusion

The PAP exercises did not improve kick frequency, FR and jump performance in the taekwondo athletes evaluated. However, these exercises did not produce adverse effects in the FR; thus, they could be used in taekwondo athletes with previous strength training. However, the findings require

caution in the data interpretation, since studies with larger and homogeneous sample numbers are required.

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