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Effects of Conditioning Exercise Protocols Using Upper-Body, Lower-Body, or Combined Upper- and Lower-Body Exercises on Acute Performance Enhancement of Judo-Specific Performance: A Randomized Crossover Trial

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ABSTRACT

Background: Performing conditioning activities in addition to warm-ups may acutely enhance performance and is termed as post-activation performance enhancement (PAPE). **Objective:** This study aimed to investigate the PAPE of the special judo fitness test (SJFT) of youth judo athletes using various conditioning exercises (CE). **Methods:** Fourteen females (age = 16.5 ± 0.8 years) and nine males (age = 17.0 ± 0.9 years) performed the three CEs (i.e., upper-body [isometric push-ups], lower-body [standing broad jumps], or their combination) or a control condition (i.e., judo-specific warm-up) in a counterbalanced randomized crossover method. The SJFT was conducted one minute after the CE or control condition. **Results:** All CEs significantly increased the number of throws in sets 1, 2, and 3 and the total number of throws compared to the control condition. In addition, the combined CE showed a greater performance enhancement effect on the number of throws in set 1 and the total number of throws compared to the upper-body CE alone. Immediately after the SJFT, the heart rate was lower in the upper body CE compared to the control and combined CE. The SJFT index improved after all the CEs compared to the control condition, with no differences between CEs. No significant difference was observed in the rating of perceived exertion between CEs. There was no significant interaction between biological sex and CE for any of the dependent variables. **Conclusion:** All CEs (i.e., upper-body, lower-body, or their combination) may induce a PAPE effect for judo performance, with combined CE providing a superior enhancement in the number of throws compared to upper-body CE.

Key words: Athletic Performance, Sports Medicine, Physical Fitness, Plyometric Exercise, Muscle Strength, Isometric Contraction, Martial Arts

INTRODUCTION

Judo is a competitive combat sport where the athletes (i.e., judokas) performs high-intensity efforts to throw their opponents to the mat or to establish dominance during ground techniques, with the duration of each bout varying from few seconds to up to eight minutes (depending on the points scored during the bout) (Callan, 2018). These high-intensity efforts require integration of responses, intra- and inter-muscular coordination, and correct execution timing (Krstulović et al., 2006). Therefore, to be effective in bouts, judokas must execute the techniques precisely and accurately within the 'window of opportunity' (i.e., appropriate timing) with the appropriate integration of force and velocity (Kons et al., 2018). This amalgamation of strength, velocity, power, and precision makes judo an ideal sport for investigating the applicability of conditioning exercise for

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post-activation performance enhancement (PAPE). PAPE is defined as the short-term enhancement of performance (e.g., jumps) following a conditioning exercise (Sale, 2002; Ulloa-Sánchez et al., 2024). Mechanistically, PAPE may be linked to post-activation potentiation occurring ~28 seconds after performing the conditioning exercise, associated with increased phosphorylation of myosin regulatory light chains, and heightened recruitment of fast-twitch motor units, while PAPE lasting longer duration may be attributed to multifactorial factors, such as increased muscle temperature, intramuscular fluid accumulation (i.e., muscle blood flow and/or water), neural drive (i.e., greater muscle activation), and decreased muscle pH (Blazevich & Babault, 2019). To increase its effectiveness, PAPE-aimed conditioning exercises should be as specific as possible regarding the exercise that is aimed to improve (Gossen & Sale, 2000). Moreover, as there is co-existence of potentiation as well as fatigue after conditioning exercises, an appropriate timing (i.e., rest interval) should be considered between the application of the PAPE-aimed stimuli and the competition (or aimed performance) activity; otherwise, fatigue may mask the potentiation effects (Blazevich & Babault, 2019).

Although the PAPE has gained significant attention from researchers in the recent years, only two studies were conducted in judo (Lum, 2019; Miarka et al., 2011). In both studies, the dependent variable was the special judo fitness test (SJFT), a reliable test to replicate the demands of a typical judo match (Franchini et al., 2009; Franchini et al., 1998) requiring the participants to perform three sets of throws of varying duration (i.e., set 1 of 15 seconds, set 2 of 30 seconds, and set 3 of 30 seconds). Miarka et al. (2011) reported that PAPE-aimed contrast training exercises (two repetition maximum [RM] squat + five horizontal jumps) improved the SJFT index among male judo athletes. The authors also noted that plyometric box jumps with incremental height (i.e., 20 cm to 40 cm to 60 cm) improved the number of throws in the first set of the SJFT compared to the control condition (i.e., traditional warm-up) (Miarka et al., 2011). Similarly, Lum (2019) reported that, compared to a traditional warm-up (i.e., control condition), male judo athletes improved the number of throws in the first set of the SJFT after lower body conditioning exercises (i.e., 3 sets × 5 repetitions standing broad jumps) and after combined upper-lower body exercises (i.e., 2 sets × 5 repetitions standing broad jumps and 2 sets × 5 repetitions resistance band pulls).

However, previous studies in judo included adults (age = 19 ± 1 years) (Miarka et al., 2011) or a mix of youth and adult athletes (age range = 16 – 29 years) (Lum, 2019). Additionally, previous studies (Lum, 2019; Miarka et al., 2011) included only male judo athletes and did not assess the effects of isolated upper-body conditioning exercises on SJFT performance enhancement. Upper-body isometric exercises may possess comparatively lower metabolic costs than dynamic exercises (Duchateau & Hainaut, 1984), possibly limiting the detrimental effects of fatigue on subsequent PAPE. Indeed, isometric conditioning activities can induce PAPE of dynamic variables (Esformes et al., 2011; Vargas-Molina et al., 2021). Evidence supports the benefits of PAPE-aimed conditioning exercises for youth athletes in sports like tennis and basketball (Fernández-Galván et al., 2022; Tsimachidis et al., 2013). However, extrapolating results to judo athletes may be inappropriate, particularly for females, as the evidence is lacking. Moreover, a previous study demonstrated the PAPE effect to be age- and biological sex-dependent (Arabatzi et al., 2014). Thus, this study seeks to address this notable research gap by evaluating the acute effects of different conditioning exercise protocols (compared to a control judo-specific warm-up): i) upper body isometric exercise, ii) lower body dynamic exercise, and iii) combined (i) and (ii), on youth male and female judo athletes' SJFT performance, as well as in their psycho-physiological responses (i.e., rating of perceived exertion [RPE]). Based on the available evidence (Fernández-Galván et al., 2022; Lum, 2019; Miarka et al., 2011; Tsimachidis et al., 2013), it was hypothesized that the conditioning exercise protocols would induce a PAPE effect on the performance measures during the SJFT and RPE compared to a control condition.

METHODS

Experimental Approach

The study was designed and carried out following the guidelines of the CONSORT extension for randomized crossover trials. A randomized crossover design was implemented to evaluate the impact of three PAPE-focused conditioning exercises on SJFT performance. Throughout the study, the participants attended a total of five sessions. The first session was used to familiarize the participants with the PAPE-aimed conditioning exercises (i.e., isometric push-up holds, standing broad jumps or their combination [independent variables]). The participants had previous experience with the SJFT; however, the SJFT protocol (i.e., dependent variable) was re-explained and performed by the participants during the familiarization session. The use of the RPE scale was also explained during this session, and anthropometric and demographic data were collected. Participants performed the three experimental protocols (i.e., upper-body, lower-body, combined) and the control condition (i.e., judo-specific warm-up) in four separate sessions (≥48 hours of recovery between sessions) in random order (www.randomizer.org). The randomization process was performed by an author who was not involved in collecting the data. The allocation sequence remained concealed from both the researchers conducting data collection and the participants until the day of testing. All the testing sessions were conducted between 1400 and 1600 hours at the participants' habitual judo training facility (dojo), under an environmental temperature of approximately 28 °C.

Participants

Using the G*power software (version 3.1.9.7; University of Düsseldorf, Düsseldorf, Germany), assuming an effect size $f = 0.40$ (i.e., large, after conversion of Cohen $d = 0.7$) (Lum, 2019), alpha error probability of 0.05, power of 0.80, one group, four measurements, a correlation among repeated measures of 0.5, and nonsphericity correction of 1, it was estimated that a minimum of 10 participants would be required to achieve statistical significance. However, considering potential dropouts and logistical constraints, 14 female and nine male judo athletes were recruited for this study. Demographic details of the participants are provided in Table 1. The inclusion criteria required the participants to be proficient at performing the ippon seoi-nage throwing (judo) technique and have resistance training experience for at least three years. Due to the nature of the sport (i.e., individual and weight category-based), the inclusion criteria were not restricted to the playing level of the judokas. However, all the participants had a minimum of 4 years of judo training and competition experience at a local academy, with eight (three females and five males) with 1st Kyu rank, nine (seven females and two males) with 2nd Kyu rank, and six (four females and two males) with 3rd Kyu rank according to judo grading. They were actively practicing the sport and preparing for a regional-level competition during the time of data collection. Eighteen athletes (11 females and seven males) actively competed at the national level; eight were medallists and can be classified as Tier 3 level participants (McKay et al., 2022). Five athletes (three females and two males) were competing at the regional level at the time of the study and can be classified as Tier 2 level participants (McKay et al., 2022). Participants were excluded if they (i) had any major injury in the last six months that could restrict them from performing exercise or (ii) were unwilling to complete the experimental and familiarization sessions. Before the study, all the participants and their legal guardians were briefed about the requirements and risks involved with the study. Afterward, the guardians and participants signed the informed consent form and provided verbal assent. The study was approved by the Internal Review Board of the School of Physical Education and Sports, Rashtriya Raksha University (IRB/SPES/NOC/2023-24/03) and was conducted in accordance with the updated guidelines of the Declaration of Helsinki.

Intervention Protocols

The control condition included general warm-up exercises (i.e., five minutes jogging, five minutes stretching) and judo-specific exercises that included 10 repetitions of *ukemi* drills (i.e., front, back, side, and rolling), two sets of 10 repetitions of "rapid" *uchikomi* drills (i.e., throwing drills), two sets of one minute of *kumikata* fight (i.e., grip fight), and two sets of 10 repetitions of *nagekomi* (i.e., practice throws).

For the experimental conditions, the conditioning exercises replaced 50% of the total repetitions in the judo-specific warm-up. The standing broad jump (with arm swings) was selected for the lower-body conditioning exercise. Participants were instructed to flex their knees and hips to their preferred angles before pushing off and jumping as far as they could. A total of three sets with six repetitions in each set was performed with a recovery period of 30 seconds between sets. For the upper body, isometric-hold push-ups were selected as the conditioning exercises. The participants assumed the starting position with their elbow making an angle of 90°, and their chest close to the floor. They were instructed to hold their body in a straight line, and maintain this position isometrically for 10 seconds. Three sets were performed with 30 seconds of rest between sets. For the combined conditioning exercise, the participants completed three standing broad jumps followed by five-second isometric-hold push-ups. Three sets were performed with inter-set recovery of 30 seconds. A schematic representation of the study protocol is presented in Figure 1.

Table 1. Participant characteristics

	Male (n=9)	Female (n=14)
Age (years)	17.0±0.9	16.5±0.8
Height (cm)	160.8±5.8	151.9±3.8
Body mass (kg)	55.4±6.1	47.8±5.1

Test Procedure

The protocol of the SJFT was carried out following the procedure established in a previous study (Sterkowicz, 1999). After the control and experimental conditions, the SJFT was conducted following one minute of passive rest. During the SJFT, the participants wore a heart rate monitor at the chest (Polar H10, Kempele, Finland) linked to the Polar Beat mobile application. The heart rate was monitored during the SJFT, immediately after the SJFT, and one minute after the SFJT. The SJFT index was calculated using the following equation: (heart rate immediately + heart rate after one minute)/number of throws (Franchini et al., 1998), with a lower SJFT index representing better performance. The variables derived from the SJFT were (i) number of throws in set 1, (ii) number of throws in set 2, (iii) number of throws in set 3, (iv) heart rate immediately, (v) heart rate after one minute, (vi) heart rate peak, and (vi) SJFT index. In addition, 30 minutes after completion of each testing session, the participant recorded the rating of perceived exertion using the modified Borg scale (0 to 10 point scale) (Foster et al., 2001).

Statistical Analysis

All statistical analyses (unless stated differently) were performed using the SPSS software (version 24.0.0, IBM, New York, USA). The normal distribution of the data was tested using the Shapiro-Wilk test. Normally distributed data are presented as mean and standard deviation. Non-normally distributed data are presented as median and interquartile range. A two-way repeated measure analysis of variance was used to compare the effects between the control and three experimental conditions and the interaction between male and female participants. Friedman's two-way analysis of variance by ranks was conducted for non-normally distributed data. Further, post-hoc analyses were conducted using paired-sample t-tests with Bonferroni correction to detect possible differences between the experimental conditions. Hedge's g effect sizes (ES) were calculated to assess the magnitude of differences. Hedge's g was interpreted as trivial (<0.2), small (0.2-0.6), moderate (>0.6-1.2), or large (>1.2-2.0) (Hopkins et al., 2009). Statistical significance was set at $p \leq 0.05$.

RESULTS

The study's statistical results are presented in Table 2, and relative changes compared to the control condition are graphically illustrated in Figure 2. The main analysis and the post hoc comparisons are presented in the following sub-sections. $\chi^2 = 7.03$.

Number of Throws (Sets 1, 2, 3, and Total Throws)

For the number of throws during the three sets of the SJFT, a significant main effect of time was for number of throws in set 1, $\chi^2(3) = 30.4$, $p < 0.001$, $W = 0.44$, set 2, $\chi^2(3) = 23.3$, $p < 0.001$, $W = 0.34$, and set 3, $\chi^2(3) = 20.3$, $p < 0.001$, $W = 0.30$, and the total number of throws, $F(3,63) = 25.27$, $p < 0.001$, $\eta^2 = 0.55$. Post hoc analyses revealed that, compared to the control condition, a greater number of throws were achieved after the conditioning exercise for the upper body (Set 1: $p = 0.031$, $g = 0.42$ [small ES]; Set 2: $p = 0.016$,

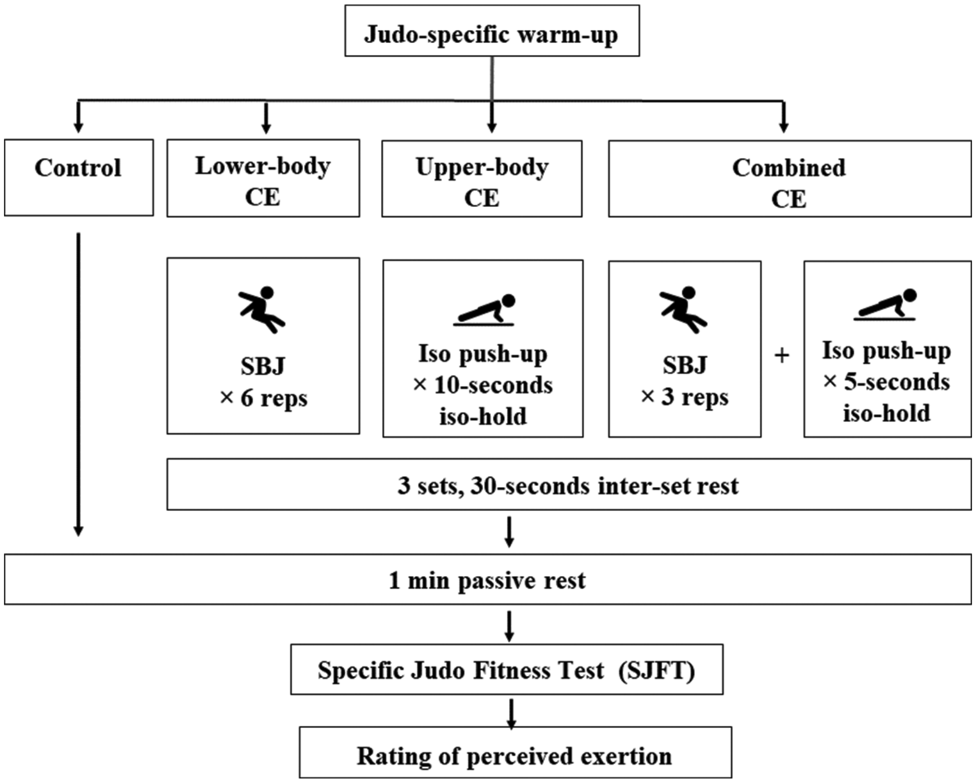

Figure 1. Experimental study design. Note: CE: conditioning exercise; SBJ: standing broad jump; Iso: isometric; reps: repetitions

Table 2. Statistical analysis results comparing the experimental and control conditions

Variables	Control	Upper-body CE	Lower-body CE	Combined CE	RANOVA# *P* – value [η_p^2]
	Mean±standard deviation/median (IQR)				
No. of throws (set 1)	6 (1)	6 (2)*	6 (1)*	7 (1)*†	<0.001 [0.44]
No. of throws (set 2)	10 (2)	11 (1)*	11 (2)*	11 (2)*	<0.001 [0.34]
No. of throws (set 3)	9 (2)	10 (1)*	9 (1)*	10 (2)*	<0.001 [0.30]
Total throws	24.8±2.3	26.4±2.4*	26.8±2.0*	27.4±2.3*†	<0.001 [0.55]
HR immediately	187.5±7.9	183.1±9.4*	186.0±8.6	188.5±7.7†	<0.001 [0.28]
HR one-minute	155.0±8.8	146.0±12.2*	145.5±13.6*	153.6±8.3†‡	<0.001 [0.40]
HR peak	189.4±8.2	184.4±9.0	187.3±8.6	189.7±8.1	0.034 [0.13]
SJFT index	13.9±1.5	12.6±1.4*	12.5±1.3*	12.6±1.2*	<0.001 [0.61]
RPE	7 (3)	7 (1)	7 (1)	7 (2)	0.071 [0.10]

- Friedman's two-way ANOVA was used for non-normally distributed data, * - significantly different from control condition, † - significantly different from upper-body PAPE conditioning exercise, ‡ - significantly different from lower-body conditioning exercise, HR immediately – heart rate immediately after the SJFT, HR one-minute – heart rate one-minute after SJFT, HR peak – peak heart rate during the SJFT, IQR – interquartile range, RANOVA – repeated measures analysis of variance, RPE - rating of perceived exertion, η_p^2- partial eta squared, W – Kendall's W

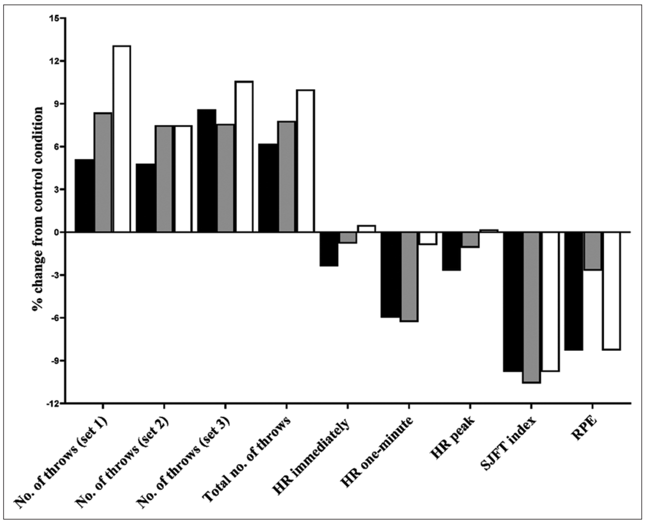

Figure 2. Percent change difference between upper-body (black bars), lower-body (grey bars), and combined (white bars) conditioning exercise compared to the control condition (i.e., judo-specific warm-up) on dependent variables

g = 0.49 [small ES]; Set 3: p = 0.003, g = 0.79 [moderate ES]), lower body (Set 1: p = 0.002, g = 0.82 [moderate ES]; Set 2: p = 0.002, g = 0.78 [moderate ES]; Set 3: p = 0.031, g = 0.70 [moderate ES]), and the combined condition (Set 1: $p < 0.001$, g = 1.21 [large ES]; Set 2: $p < 0.001$, g = 0.78 [moderate ES]; Set 3: p = 0.002, g = 0.98 [moderate ES]). Further, compared to the upper-body conditioning exercise, a greater beneficial effect was noted after the combined conditioning exercise for the number of throws in set 1, p = 0.002, g = 0.65 (moderate ES).

For the total number of throws during the SJFT, a significant main effect of time was observed, $F(3,63) = 25.27$, $p < 0.001$, $\eta^2 = 0.55$. Post hoc analyses revealed a significant difference between the control condition and upper-body conditioning exercise ($p < 0.001$, g = 0.67 [moderate ES]), lower-body conditioning exercise ($p < 0.001$, g = 0.91 [moderate ES]), and combined conditioning exercise ($p < 0.001$, g = 1.11 [moderate ES]). Additionally, a significant difference was found between the combined and upper-body PAPE conditioning exercises ($p < 0.001$, g = 0.42 [small ES]), favoring the combined conditioning exercise. No other significant differences were observed between the conditioning exercises.

Heart Rate

For heart rate measured immediately after the SJFT, a significant main effect of time was observed, $F(3, 63) = 8.31$, $p < 0.001$, $\eta^2 = 0.28$. Post hoc analyses revealed a significant difference between the control and upper-body conditioning exercise, favoring the upper-body conditioning exercise, p = 0.014, g = 0.50 (small ES). A significant difference was also observed between upper-body and combined conditioning exercises, favoring the upper-body conditioning exercise, p = 0.001, g = 0.62 (moderate ES).

For heart rate one minute after the SJFT, a significant main effect of time was observed, $F(3, 63) = 13.93$, $p < 0.001$, $\eta^2 = 0.40$. The post-hoc test revealed a reduced heart rate for the upper body (*all* p = 0.001, g = 0.72 - 0.83 [moderate ESs]) and lower body (p = 0.002 – 0.008, g = 0.71 - 0.82 [moderate ESs]) conditioning exercises compared to the combined conditioning exercise or control condition.

In addition, a significant main effect of time was observed for the peak heart rate during the SJFT, $F(3,63) = 3.09$, $p = 0.034$, $\eta^2 = 0.134$. However, the post hoc comparisons did not yield significant pairwise differences after correcting for multiple comparisons (all adjusted $p > 0.05$)

Special Judo Fitness Test (SJFT) Index

For the SJFT index, a significant main effect of time was observed, $F(3, 63) = 33.35$, $p < 0.001$, $\eta^2 = 0.61$. Post hoc analyses revealed a significant difference between the control condition and upper-body conditioning exercise, $p < 0.001$, g = 0.88 (moderate ES), lower-body conditioning exercise, $p < 0.001$, g = 0.98 (moderate ES), and combined conditioning exercises, $p < 0.001$, g = 0.94 (moderate ES). No significant difference was observed between the conditioning exercises.

Rating of perceived exertion (RPE)

No significant difference in the RPE scores was observed between the conditions, $\chi^2(3) = 7.03$, $p = 0.063$, $W = 0.10$.

DISCUSSION

This study investigated the effects of three different types of conditioning activities (upper-body, lower-body, and combined) on subsequent performance in the SJFT with youth judo athletes. The study's results supported the current hypothesis that the conditioning activities will induce a PAPE effect on the performance measures of the SJFT.

Number of Throws During the SJFT

The number of throws significantly increased in throwing sets 1, 2, and 3 during the SJFT after all conditioning activities in comparison to the control condition, with higher magnitude improvements observed after combined (i.e., large ES) and lower-body (i.e., moderate ES) compared to upper-body (i.e., small ES) conditioning exercise. Firstly, for the lower-body and combined protocols, plyometric exercise (i.e., standing broad jumps) was one of the components of the conditioning exercise, and plyometric exercises tend to enhance motor efficiency during maximal-effort execution (Fatouros et al., 2000). Previous research has proposed that this phenomenon may lead to heightened neural stimulation of muscles, consequently augmenting power production (McBride et al., 2005). Indeed, in a meta-analysis done by Seitz and Haff (2016), plyometric (ES = 0.47) and traditional high-intensity (i.e., exercises ≥85% 1RM) (ES = 0.41) conditioning exercises elicited considerably larger acute PAPE effects compared to the traditional moderate-intensity (i.e., exercises 30 – 84% 1RM) (ES = 0.19) and maximal isometric (ES = –0.09) conditioning activities. This distinction may be due to plyometric exercises being linked to the selective activation of type II motor units (Desmedt & Godaux, 1977), a crucial mechanism at the central level that underlies PAPE (Güllich & Schmidtbleicher, 1996). Plyometric conditioning exercise could induce less fatigue compared to other resistance exercise conditioning activities (e.g., squat with ≥85% 1RM). The reduced fatigue may facilitate a more pronounced potentiation effect and accelerate the time needed to achieve the maximal PAPE response (Seitz & Haff, 2016). Thus, a plyometric conditioning exercise is favorable in augmenting subsequent performance in the SJFT due to the short 1-minute recovery interval set in the test protocol. This is in line with past recommendations suggesting that a more pronounced PAPE effect can occur sooner (i.e., within 0.3–4 minutes) following plyometric conditioning exercises compared to traditional high- and moderate-intensity conditioning exercises (i.e., >5 min) (Seitz & Haff, 2016). Moreover, plyometric exercises applied over more extended periods (i.e., training interventions) may improve judo athlete's physical fitness performance (Ojeda-Aravena et al., 2023).

Of note, the influence of a lower-body plyometric protocol (i.e., standing broad jumps with arm swings) used in the current study on subsequent judo throwing performance was consistent with that observed in two other studies. Adolescent judo athletes completed more throws (6.4 ± 0.5 vs. 5.7 ± 0.5) in the first set of the SJFT after three continuous box jumps performed with progressively increasing heights (i.e., 20 cm, 40 cm, and 60 cm) compared to the control condition (Miarka et al., 2011). Similarly, male judo athletes also completed more throws (5.3 ± 0.6 vs. 4.9 ± 0.5) in the first set of the SJFT after three sets of five repetitions of standing broad jumps compared to the control condition (Lum, 2019). In our study, the standing broad jumps were performed continuously (without rest between repetitions) with arm swings allowed. The arm swings during the jumps may have also allowed the activation of upper-body muscles, which may have further helped during the throws in the SJFT. However, in contrast to previous studies (Lum, 2019; Miarka et al., 2011), after the PAPE conditioning exercises, our study reported an increase in the number of throws in the SJFT sets 2 and 3 when compared to the control condition. This may be possible due to the differences in the participant's characteristics involved in the study. Both Lum (2019) and Miarka et al. (2011) included adult male participants, whereas our research involved youth male and female participants. It may be possible that youth athletes recover faster compared to adult athletes (Ratel et al., 2006). However, since there was no significant interaction between biological sex and conditioning exercises, these results cannot be directly attributed to the inclusion of female participants. In addition, our findings also suggest that combining lower-body plyometric exercise (e.g., standing broad jumps) with upper-body conditioning exercise (e.g., isometric push-ups) may also enhance the throwing performance during the SJFT. Indeed, Lum (2019) also reported increased throws in set 1 and total throws (i.e., in three sets) after combined upper- and lower-body conditioning exercises compared to the control condition.

Furthermore, for the upper-body protocol, we used isometric-hold-based PAPE conditioning exercises (i.e., the isometric-hold push-ups). The findings suggest that isometric push-ups improve the number of throws in sets 1, 2, and 3 and the total number of throws compared to the control condition. No previous study has reported using upper-body conditioning exercise, specifically the isometric hold, to induce the PAPE effects on the SJFT performance of judo athletes. However, a previous study (Esformes et al., 2011) has reported upper-body isometric conditioning exercises to induce the PAPE effect on upper-body power output. Indeed, a previous meta-analysis (Finlay et al., 2022) on upper-body conditioning exercises to induce PAPE suggests isometric exercises as one of the methods.

Special Judo Fitness Test Index

The SJFT index exhibits correlations with parameters of both anaerobic power, such as the 30-second Wingate test, and aerobic capacity, including graded treadmill exercise test (Sterkowicz, 1999). This underscores the practical value of the SJFT as an ecologically valid assessment tool that can effectively gauge effort tolerance in judo athletes, particularly when standard laboratory tests are not readily accessible (Sterkowicz, 1999). Moreover, the SJFT is sensitive to strength and conditioning interventions. Our study reported a significantly lower SJFT index after all conditioning activities compared to the control condition (all ES = moderate), highlighting improved fitness and sport-specific performance. The findings from the current study suggest that an average trained youth judo practitioner with an SJFT index of 12.24 to 14.73 can benefit from the investigated PAPE conditioning exercise to augment subsequent judo performance (Sterkowicz-Przybycień et al., 2019). However, how elite junior judo athletes with a lower SJFT index (e.g., SJFT ≤11.04) (Sterkowicz-Przybycień et al., 2019) will respond to the conditioning activities needs further investigation as more experienced athletes (i.e., training age and strength levels) were reported to be able to better capitalize on the effects of PAPE (Seitz & Haff, 2016). Of note, previous studies did not report similar findings. Lum (2019) reported no difference in SJFT index after a lower-body (3 sets × 5 repetitions standing broad jumps) or an upper-body (2 sets × 5 repetitions resistance band pull) compared to a control condition. One possible reason for a contradictory finding is that Lum (2019) incorporated a high-pull test as a dependent variable before executing the SJFT. Three maximal-effort repetitions of the high pull test were performed after five minutes of completing the PAPE protocols, following which, after two minutes, the SFJT was conducted (Lum, 2019). Including the high pull tests may have affected the results as the balance between potentiation and fatigue is essential while trying to induce the PAPE effects (Lum, 2019). Similarly, Miarka et al. (2011) reported no improvement in the SJFT index after a jump protocol that required participants to jump onto different boxes with progressively increasing height (i.e., 20 cm, 40 cm, 60 cm) one after another and a maximal strength protocol that included 95% one-repetition squats. However, the authors (Miarka et al., 2011) reported improvement in the SJFT index after a contrast exercise protocol that involved 90% of one-repetition maximum squats and standing broad jumps.

Heart Rate

For heart rate immediately and one minute after the SJFT, a higher performance level would require the athletes to achieve lower heart rate values (Sterkowicz-Przybycień et al., 2019). Based on percentile ranking in the SJFT classificatory table of international junior judo athletes (≤21 years old) (Sterkowicz-Przybycień et al., 2019), the participants in the current study can be ranked as "Regular," with average fitness levels or middle 60% or 20th to 80th percentile of the worlds› judo athlete cohort. Of note, more experienced athletes (i.e., training age and strength levels) may be able to better optimize the impact of PAPE conditioning exercises (Seitz & Haff, 2016). Albeit this, the athletes in our study could capitalize on the upper-body conditioning exercise to significantly decrease the heart rate immediately after the SJFT compared to the control condition. For the recovery heart rate one minute after the SJFT, the heart rate significantly decreased after the upper-body and lower-body conditioning activities compared to the control condition. Whether the role of training experience on the effect of PAPE conditioning exercises (Seitz & Haff, 2016) is greater on neuromuscular-dependent variables rather than cardiovascular-dependent variables is yet to be clarified.

Heart rate recovery is subject to various factors, with aerobic fitness emerging as a significant determinant (Kenney et al., 2012). Specifically, individuals with a higher level of aerobic training tend to exhibit a faster heart rate recovery after exercise (Kenney et al., 2012). The SJFT is primarily anaerobic (15 to 30 seconds work with 10 seconds rest), with past research suggesting a correlation between the total number of throws and anaerobic fitness (e.g., Wingate test) (Franchini et al., 2011). This relationship can be attributed to the substantial power generation demanded for the execution of judo throws and the requisite sprints and change of direction performed between throws, emphasizing the integral role of short duration and maximal effort (e.g., anaerobic fitness) in this test (Sterkowicz-Przybycień et al., 2017). As both the upper-body and lower-body conditioning exercises contributed to a subsequent improved heart rate recovery post-one-minute duration (similar magnitude of ES), it can be concluded that both PAPE strategies can augment subsequent cardiovascular output if heart rate recovery is the critical competition strategy for youth athletes.

Nevertheless, improving aerobic and anaerobic fitness qualities is essential for judo athletes. A reduced heart rate following the SJFT, or a quicker heart rate recovery one minute after the SJFT, has been construed as indicative of enhanced cardiovascular fitness (Henríquez et al., 2013; Sterkowicz-Przybycień et al., 2017). Considering the synthesis of data derived from these variables, the SJFT holds significance in judo performance, given that many judo movements necessitate utilizing all energy systems (e.g., aerobic, anaerobic) (Franchini et al., 2013).

Rating of Perceived Exertion and Interaction of Biological Sex

Our findings reported no significant difference in the RPE, suggesting that including conditioning activities (isometric push-ups, standing broad jumps, or both combined) by replacing some part of the judo-specific warm-up does not increase the perception of load. This finding implies that the conditioning activities improved the SJFT performance without increasing the perception of load during the warm-ups. In contrast, Lum (2019) reported a significantly lower RPE after conditioning activities than the control condition. These contradictory findings may be associated with the timing of the RPE scores collection. Lum (2019) collected the RPE score immediately after the warm-up/PAPE protocol. However, a previous study reported RPE as a better indicator after 30 minutes post-exercise (Singh et al., 2007). The last exercise of the protocol may have influenced the results for Lum (2019). For example, in the control condition, the previous exercise during warm-up was 2 sets × 10 repetitions of Nagekomi (i.e., practice throws) (Lum, 2019). For PAPE protocols, the previous activities were either standing broad jumps or resistance band pulls (Lum, 2019). Moreover, another important finding was that there were no significant interaction between biological sex and conditioning exercises on improving any of the dependent variables. Therefore, male and female youth judo athletes respond similarly to our study's conditioning exercise.

Limitations and Future Recommendations

The findings of this study should be interpreted with consideration of certain limitations. Firstly, a standardized recovery interval (i.e., one minute) between the conditioning exercises and the SJFT may have masked the effects of PAPE, as different contraction types influence the balance between fatigue and performance enhancement. Previous investigations have used recovery intervals ranging from 0 to 18.5 minutes to determine the optimal PAPE protocol (Hodgson et al., 2005). Future studies should incorporate different recovery intervals to better understand how PAPE conditioning exercises can be utilized. Secondly, although Tier-3 and Tier-2 level youth academy judo athletes were recruited for this study, their SJFT index paled in contrast to international junior norms. Athletes with a higher SJFT index (i.e., higher fitness and judo performance) may be more capable of leveraging the effects of PAPE to enhance their performance. However, future studies should confirm this hypothesis on Tier 4 and Tier 5 judo athletes. Lastly, different isometric contraction types (e.g., hold vs. push) influence the intensity levels of the stimulus induced in the isometric protocols. The utilization of an isometric push protocol has the potential to offer an elevated intensity level, thereby enhancing overall performance in the SJFT. Therefore, future studies should investigate whether the isometric push protocol may provide superior PAPE effects.

Moreover, the variation in the upper- and lower-body conditioning activities, i.e., isometric versus dynamic exercise, may also have confounded the results. The results of this study highlight the need for further research to investigate the use of various conditioning exercises (e.g., plyometric push-ups) to augment PAPE effects, further improving athletic performance in judo. This need arises from the observation that the connection between the requisite level and method of potentiation for improving judo performance is variable and currently needs a comprehensive understanding.

CONCLUSION

Although all conditioning exercises (i.e., upper-body isometric, lower-body dynamic, and combination of upper-and-lower-body) induced a PAPE effect on subsequent performance in the SJFT, a large effect size was only observed in the first set of throw performances after the combined conditioning exercise. This may be a valuable strategy for youth judo athletes to capitalize on as a priming strategy just before the start of competition, especially for the first fight. Aligned with other studies investigating the use of conditioning activities to augment subsequent SJFT, a conditioning exercise that involves a plyometric protocol is recommended. The plyometric exercise is an ideal conditioning stimulus to balance both the development of potentiation and fatigue in a PAPE intervention, as indicated in the short recovery intervals prescribed in the SJFT protocol. As both the lower-body plyometric conditioning exercise and upper-body isometric conditioning exercise significantly improved heart rate recovery after the throwing performance, either strategy may be used if this indicates success in competition. Overall, the SJFT provides confidence to junior judo athletes to utilize the conditioning activities to augment subsequent fitness and judo performance.

PRACTICAL APPLICATION

Implementing PAPE before a competition can significantly benefit athletes more than conventional warm-up methods, improving performance in high-intensity activities like jumping, throwing, and sprinting. This acute priming approach holds promise for enhancing judo performance, particularly in competitive events. Notably, the plyometric (i.e., standing broad jump) and isometric (i.e., push-up) protocols employed in our study can be seamlessly incorporated into the competition setting, requiring no additional training equipment for implementation. As such, this innovative approach equips judo coaches and strength and conditioning practitioners with a valuable tool to integrate into their pre-competition warm-up routines, granting their judo athletes (both males and females) a competitive advantage.

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AUTHOR CONTRIBUTIONS

Study Design: MH and RKT; Data Collection: MH, AK, and BS; Statistical Analysis: RKT; Data Interpretation: RKT; Manuscript Preparation: MH, BS, AK, JL, JA, RRC, and RKT wrote or revised the manuscript draft. All authors have read and agreed to the published version of the manuscript.

DATA AVAILABILITY

All data generated or analyzed during this study are included in the published article as Table(s) and Figure(s). Any other data requirement can be directed to the corresponding author upon reasonable request.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

THE study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the School of Physical Education and Sports, Rashtriya Raksha University (protocol code IRB/SPES/2023-24/03 and date of approval 05/01/2023). All participants and their legal guardians were informed about the purpose, content, and potential benefits and risks associated with the study, and the legal guardians signed the informed consent forms, and participants provided their verbal assent.

TRIAL REGISTRATION

The trial was registered in Clinicaltrials.gov (NCT06768723) on 06/01/2025. Project link: https://clinicaltrials.gov/study/NCT06768723. “Retrospectively registered”.

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