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ORIGINAL ARTICLE

Post-Activation Performance Enhancement of Croatian Track and Field Athletes

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ABSTRACT

Background. Post-activation potentiation (PAP) occurs after a previous potentiating stimulus (PP) and causes a sudden increase in muscle strength and performance. After muscular effort, this acute phenomenon manifests itself only if the athlete has rested enough. Fatigue is the ratio between excitation and contraction, dependent on physical activity. If, after performing physical activity with the purpose of potentiation, fatigue is present together with potentiation, fatigue will always prevail. **Objectives.** This study examined two different isometric methods for enhancing post-activation performance in track and field athletes. **Methods.** The study sample consisted of 25 Croatian track and field athletes who compete in speed-explosive disciplines. The athletes were divided into two groups. One group performed a maximal isometric half-squat protocol (HS; pushing a stationary Olympic bar), and the second group performed maximum voluntary contraction (MVC) on the quadriceps and femoris muscles. **Results.** Both groups performed an initial test, then a potentiating stimulus, and after a 5-minute rest, performed the final test again. The dependent t-test results showed no statistically significant difference between the initial and final measurements in the MVC group (p=0.39) and the HS group (p=0.80). **Conclusion.** The isometric preparation protocols cannot positively influence the post-activation performance increase in the best Croatian athletes. No single protocol is more effective than the other.

INTRODUCTION

Sports coaches and athletes often individualize the process of warming up and preparing for a performance or training, considering the athlete's morphological status, injury history, training level, and personal preferences to increase the chances of optimal performance (1) Achieving post-activation potential is one of the latest trends in individualizing and optimizing preparation for sports performance.

According to Chiu et al., post-activation potentiation (PAP) is a phenomenon that occurs after a previous potentiating stimulus (PP) and causes a rapid increase in muscle strength and performance (2). PP is a biomechanical activity often performed with a load, and its movement structure is similar to the movement performed without a load (2).

Post-activation potential (PAP) is a short-term improvement in muscle function preceded by submaximal or maximal neuromuscular activity (3, 4). Zimmermann et al. state that PAP does not increase the ability to exert maximum force but increases the speed with which it is produced (5).

Due to its acute duration, PAP finds a place in quick-explosive character sports where the performance is short (6). Such a sport is athletics; all sprinting, jumping, and throwing disciplines represent this category. The idea that the ability to exert maximum force can be increased quickly creates many applications of PAP in sports training.

Many authors who have studied PAP have examined it in different ways. Of all the tested methods, only variants of running, jumping, and isometric contractions without external load are independent of material conditions, while only isometric contractions do not require much space for implementation. Protocols for achieving PAP using isometric contractions, in addition to being practical, do not expose athletes to the risk of injury during implementation. The performance protocol of most research that studied PAP is as follows: initial performance testing, potentiating stimulus, rest, and final performance testing. Such research examines only performance improvement, but it is known that performance success is extremely multivariate and may depend on several factors. Cuenca-Fernandez et al., based on these observations, proposed the term "post-activation performance enhancement" (PAPI) to describe the improvement in task performance that occurs after a potentiating contraction (7).

Athletes in track and field competitions must go through the registration center after warming up before entering the athletic arena. During this time (cca. 25 min), athletes are limited by space and equipment and cannot prepare additionally for their performance. Also, a big problem for athletes involved in technical disciplines is the long breaks between competition attempts. The disadvantages of current methods of achieving PAPI are requiring special equipment or space to be implemented.

This study compared two isometric methods for achieving PAPI: maximal voluntary contraction (MVC) of the quadriceps femoris muscle and maximal isometric half-squat (HS). The maximal isometric half-squat is a method that has been proven successful in achieving PAPI, while the MVC is still an unexplored method, potentially representing the most practical solution for PAPI.

The research aims to determine a statistically significant association between the protocol for achieving post-activation performance increase and the results of vertical jumping in place without swinging the arms.

MATERIALS AND METHODS

Participants. The participants consist of 25 healthy athletes (16 males and 9 females) who have been actively involved in athletics for at least two years and, in the previous season, were placed from first to fifth place in one of the Croatian Championships or Cups. They were aged between 16-29 years. None of the subjects participated in heavy physical activity 48 hours before the research. They were instructed not to supplement creatine or consume alcohol 48 hours before the research and not to consume caffeine-containing products eight hours before the research. When conducting the research, all male and female athletes were physically healthy.

The research was conducted on a day when none of the respondents had training, and all respondents had at least 24 hours of rest between the last training session and the implementation of the research. The research was conducted according to the standards of the Declaration of Helsinki and was approved by the Faculty of Kinesiology Ethics Committee, Osijek.

Study Design. Participants were randomly divided into two groups (12 and 13 respondents). The first group performed the maximum voluntary quadriceps muscle contraction protocol (MVC group). The second group performed the maximum isometric half-squat protocol (HS group). The preparation for the research began with running at a low intensity for 5 minutes. After the warm-up, the subjects performed general preparatory exercises and dynamically warmed up.

Each subject performed three bilateral vertical jumps without arm swing (countermovement jump - CMJ). Each jump was recorded as a separate video. After performing the initial jumps, each subject passively rested for 5 minutes. At the end of the passive rest, the subjects entered the measurement area and performed one of two protocols. The first (MVC) group was instructed to maximally contract the quadriceps femoris muscle on both legs simultaneously for five seconds. The second (HS) group performed a maximum half-squat for five seconds. Subjects in the HS group were trying to lift an Olympic bar placed on the

underside of the bar lock on the squat rack and, therefore, could not be moved up.

Data Collection. The participants' anthropometric characteristics, body height, and weight were measured using the Martin anthropometer and Omron BF511 diagnostic scales. The subjects' general physical and mental state was assessed with the Wellness questionnaire (8). After completing their protocol, the subjects rested passively for five minutes, following the example of Gago et al. (2014) (9). After the break after the protocol implementation, the subjects re-entered the measuring area to perform three final jumps.

The protocol implementation time was measured with a manual stopwatch (Kalenji ONstart 500), measuring up to 1/100 s.

All attempts were recorded with a Xiaomi Redmi Note 9 Pro mobile device with recording settings at a resolution of 1080 pixels and 60 frames per second. The videos were processed using the free video analysis software "Kinovea" version 0.9.5, which allows for the measurement of the duration of each jump's flight phase. Puig-Diví et al. mentioned Kinovea as a reliable tool for conducting video analysis in four perspectives (10).

Statistical Analysis. The descriptive parameters were calculated for each group. The normality of the distribution was determined by the Shapiro-Wilk test. The significance of the difference in the arithmetic mean deviation between the initial and final measurements for both protocols was tested by the t-test for dependent samples.

The significance of the difference in the deviation of the arithmetic means between the protocols was tested by the Student's t-test for independent samples. Statistical significance was set at $p>0.05$.

RESULTS

The results of descriptive statistics indicate that the respondents are, on average, 19.28 years old. The body height of the subjects is between 170 cm and 195 cm. Given that the sample included all athletes from the athletic disciplines of sprinting, jumping, and throwing, a large variability in the participants' body mass can be observed. The average body weight of the subjects is 69.28 kg, while the range of results is from 53 kg to 125 kg. During the initial tests, it was evident that the results of the HS group were 3.85 cm higher than those of the MVC group. The final tests show a slightly smaller deviation than the initial tests. It amounts to 3.14 cm in favor of the HS group.

In the MVC group, the highest recorded jump in the initial measurement was 48.67 cm, and the lowest jump was 27.09 cm. The average result of the initial testing was 40.04 cm, with a standard deviation of 6.97. In the final measurement, the largest measured jump was 50.23 cm, while the smallest jump was 24.83 cm. The largest jump in the final measurement is 1.56 cm greater than the largest jump in the initial measurement. On the contrary, in the final testing, the lowest jump decreased by 2.26 cm compared to the initial testing (Table 1).

Table 1. Results of descriptive parameters for the MVC group.

	N	Mean	Median	Min	Max	SD
Height (cm)	13	178.92	176.00	172.00	195.00	6.99
Weight (kg)	13	70.62	66.00	59.00	125.00	17.41
Age	13	18.69	17.00	16.00	27.00	3.38
CMJ I	13	40.04	42.69	27.09	48.67	6.97
CMJ F	13	40.55	41.25	24.83	50.23	7.80

N: number of respondents; Min: value of minimal result; Max: value of maximal result; SD: standard deviation; I: initial result; F: final result.

In the PC group, the highest recorded jump in the initial measurement was 55.05 cm, and the most minor jump was 28.25 cm. The average result of the initial testing was 43.89 cm, with a standard deviation of 8.03. In the final measurement, the largest measured jump was 55.05 cm, while the smallest jump was 31.89 cm. The highest jump in the final measurement is as high as in the initial measurement. Contrary to the MVC group, in the final testing of the HS group, the lowest jump increased by 3.64 cm compared to the initial testing (Table 2).

Table 2. Results of descriptive parameters for HS group.

	N	Mean	Median	Min	Max	SD
Height (cm)	12	179.83	179.50	170.00	193.00	6.03
Weight (kg)	12	67.83	68.50	53.00	75.00	6.45
Age	12	19.92	18.50	16.00	29.00	3.73
CMJ I	12	43.89	46.39	28.25	55.05	8.03
CMJ F	12	43.69	44.15	31.89	55.05	7.22

N: number of respondents; Min: value of minimal result; Max: value of maximal result; SD: standard deviation; I: initial result; F: final result.

The t-test for dependent samples determined no statistically significant difference between the results obtained in the initial testing and those obtained in the final testing (Table 3). A p-value of 0.39 was determined for the MVC group, which exceeds the set criterion of $p<0.05$. A p-value of 0.80 for group HS was determined, which exceeds the set criterion of $p<0.05$.

The t-test for independent samples determined no statistical significance of the difference between the final testing of the MVC protocol and the HS protocol (Table 4). Levene's test determined The homogeneity of variances, which showed that the assumptions for the t-test were met.

None of the protocols proved to be more effective than the other, which is the opposite of what was expected, considering that the HS protocol is a repeatedly tested method for achieving post-activation performance increase in many works. In the final testing, the HS group recorded an average of 2.55 cm more jumps than the MVC group.

Table 3. Results of T test for independent samples for MVC and HS group.

	Mean	SD	N	Diff.	SD Diff.	t	df	p*	Confi -95.000%	Confi +95.000%
CMJ MVC I	40.04	6.97								
CMJ MVC F	40.55	7.80	13	-0.51	2.09	-0.88	12	0.39	-1.78	0.75
CMJ HS I	43.89	8.03								
CMJ HS F	43.69	7.22	12	0.20	2.70	0.25	11	0.80	-1.52	1.91

SD: standard deviation; N: number of respondents; Diff.: difference between means of initial result and final result; SD Diff.: Standard deviation of difference between means of initial result and final result; t: t value; df: degrees of freedom; p: p value; Confi 95.000%: confidence interval; I: initial result; F: final result.

Table 4. Results of T test for independent samples between two protocols (MVS vs. HS).

	Mean MVC	Mean HS	SD MVC	SD HS	t	df	p*	t separ. var.est.	P two-sided	p Variances	Levene F(1,df)	p Levene
CMJ F	40.55	43.10	7.80	7.26	-0.82	22	0.42	-0.83	0.42	0.83	0.00	0.99

t: t value; df: degrees of freedom; p: p value; t separ. var. est.: t value separate variable estimation; P two-sides: p value for two sided test; Levene F: test statistic of Levene's test; p Levene: p value for Levene test; F: final result.

DISCUSSION

In the protocol of maximal voluntary contraction of the quadriceps femoris muscle, the initial measurement established an average result of 40.038 cm with a standard deviation of 6.974. The final measurement showed an average of 40.551 with a standard deviation of 7.803, indicating an improvement of only 0.513 cm. Although papers (11-15) found positive changes in the subjects' performance, none of those papers examined changes in the MVC of the quadriceps femoris during full knee extension. Clamann (1993) (16) states that the greatest activation of motor units occurs when a large force is overcome. The MVC protocol in this study did not contain external load, and the quadriceps femoris muscle was contracted in the position it was most shortened, which means that the potential recruitment of motor units was not fully utilized.

In the case of the maximum isometric half-squat protocol, the initial measurement showed an average result of 43.89 with a standard deviation of 8.028. The final measurement showed an average of 43.69 with a standard deviation of 7.22, which indicates a negative shift of 0.197 cm.

The maximal isometric half squat was precisely chosen as a comparison protocol to MVC because of its repeated reliability in inducing PAP. The unexpected results of this protocol in this study can be explained by how potentiating activity was performed during measurement. In the MVC protocol, 5-6 seconds was chosen as the duration of the potentiating activity based on previous research (14, 15). To compare the MVC protocol with the HS protocol as faithfully as possible, 5 seconds was chosen for the duration of the potentiating activity in the HS protocol. The authors who used the maximum isometric half-squat protocol in their research performed the potentiating activity in several series with a duration of up to 5 seconds (17-19).

Although previous research has confirmed that isometric contractions can induce post-activation potentiation, several things should be considered when interpreting the results.

Although all subjects are highly trained and have experience in training with external loads, the part of the season in which the research was conducted must be considered. Given that the respondents are athletes who compete in different disciplines, athletic form varies during the season depending on the discipline in which they compete. For this reason, the research was conducted in a general preparatory period during which all respondents were in a similar training regime. The disadvantage of the term in which the research was conducted is the great fatigue at the central nervous system level, which accumulates due to the high training volume.

The way of recording the jump performance was a major limiting factor. The camera settings were set to 60 frames per second, following the example of other works that used Kinove software in their analyses. In the recent studies (20-22) 30 and 50 frames per second was used when recording. This way of setting up the camera proved insufficient during the video analysis. The low number of frames per second causes Kinovea to be too sensitive to motion. The vertical jump test in place should have recorded the smallest difference in performance between the initial and final testing, which was impossible due to the small number of frames per second. Due to that analysis program's insufficient sensitivity; several jumpers achieved identical values in the test, which is very unlikely.

CONCLUSION

The results of this research reject the hypothesis that isometric preparation protocols can positively influence the post-activation performance increase in the best Croatian athletes. In the protocol of maximal voluntary contraction of the quadriceps femoris muscle, the measurements showed a small but insignificant improvement in the jump height after the protocol was implemented. With the maximum isometric half-squat protocol, the measurements showed a small but statistically insignificant regression in the results. No single protocol has been shown to be more effective than the other.

Although Kinovea is a reliable tool for this kind of measurement, the quality of the analyzed video also plays a significant role. The number of frames per second emerges as the most important quality factor. Post-activation performance enhancement is still a relatively unknown concept that requires further research and interpretation.

APPLICABLE REMARKS

- The measurements of the maximal voluntary contraction of the quadriceps femoris muscle protocol showed a small but insignificant improvement in the jump height after the protocol was implemented. With the maximum isometric half-squat protocol, the measurements showed a small but statistically insignificant regression in the results. No single protocol has been shown to be more effective than the other.
- All jump height measurements were made in the Kinovea program, which has been repeatedly proven reliable and valid. Although Kinovea is a reliable tool for this kind of measurement, the quality of the analyzed video also plays a significant role. The recommendation for future research would be to set the camera settings to more than 240 frames per second when recording the subjects' attempts.

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AUTHORS' CONTRIBUTIONS

Study concept and design: Hrvoje Ajman, Atila Salaj. Acquisition of data: Atila Salaj, Zoran

Špoljarić. Analysis and interpretation of data: Hrvoje Ajman, Atila Salaj. Drafting the manuscript: Hrvoje Ajman, Atila Salaj, Zoran Špoljarić. Critical revision of the manuscript for important intellectual content: Hrvoje Ajman. Statistical analysis: Atila Salaj, Zoran Špoljarić. Administrative, technical, and material support: Zoran Špoljarić. Study supervision: Hrvoje Ajman.

CONFLICT OF INTEREST

The authors present no conflict of interest.

FINANCIAL DISCLOSURE

The authors do not have any financial interests related to the material in the manuscript.

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ETHICAL CONSIDERATION

The research was conducted according to the standards of the Declaration of Helsinki and was approved by the Faculty of Kinesiology Ethics Committee, Osijek.

ROLE OF THE SPONSOR

None of the sponsors have been involved in this study.

ARTIFICIAL INTELLIGENCE (AI) USE

AI was not used to write and conduct this research.

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