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KINESIOLOGY & COACHING

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Examining the effects of post-activation performance enhancement on boxers' visual reaction time

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Key words: combat sports, refractory period, warm-up, training protocol

Abstract
Background. There is strong evidence suggesting that Post-Activation Performance Enhancement (PAPE) can acutely enhance various aspects of sports performance, such as strength, endurance, speed, and agility. However, there is a gap in research regarding the effects of PAPE on reaction time performance. Therefore, the aim of this study was to investigate the effects of PAPE on the visual reaction time performances of amateur boxers.
Material and Methods. A cross-sectional study was conducted with 17 amateur boxers. Anthropometric measurements were taken, and participants performed a 1-RM Bench Press performance test preceded by 5 minutes of low-intensity running. The PAPE pro-

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tocol was then administered 72 hours later after another 5 minutes of low-intensity running to avoid fatigue. Visual reaction time was measured immediately before the PAPE protocol and six times at 3-minute intervals afterward. Data were analyzed using IBM Statistics (SPSS, ver. 26.0, Armonk, NY, USA) software.
Results. The study found that although there was a difference in the mean visual reaction time performance of participants before and after the PAPE protocol, this difference was not statistically significant (p > 0.05). Therefore, it can be concluded that PAPE does not have an enhancing effect on the visual reaction time performance of boxers.
Conclusions. In conclusion, this study suggests that PAPE does not significantly affect visual reaction time performance in amateur boxers. Further research may be warranted to explore other factors that may influence reaction time in this population.

Introductıon

Warm-up exercises have a positive effect on many physiological and metabolic functions for sportive performance. One effect under intense scientific scrutiny is the phenomenon of post-activation performance enhancement, characterized by an increase in muscle force at submaximal calcium saturation following high-intensity muscle contractions [Blazevich, Babault 2019]. Additionally, during submaximal exertion, reaction time, which is an indicator of human response speed to visual and auditory stimuli, can change [Mulhim, Akcan 2022]. Undoubtedly, post-activation performance enhancement (PAPE) is considered a forward-looking training method that can bring potential benefits to athletes [Doma *et al.* 2019]. PAPE applications are performed to maintain the activation level of athletes with maximum voluntary contraction after the end of warm-up and just before the start of the competition [Conrado de Freitas *et al.* 2021]. In this context, plyometric and ballistic movements and high-intensity resistance exercises are the most common exercise practices used to create the PAPE effect [Cormie *et al.* 2010; Mina *et al.* 2019; Ciocca *et al.* 2021].

There is research showing that resistance exercises used at the end of a warm-up provide a greater power production in a more acute way than the improvement obtained with a submaximal warm-up alone [Van den Tillaar *et al.* 2019]. The implementation of resistance exercises in a training session can increase the maximum dynamic contraction output and explosive power. Furthermore, resistance exercise can trigger muscle pennation angle from a morphological perspective, aerobic-anaerobic capacity and fibre type combination from a cellular and metabolic adaptations perspective, and motor unit activation/participation and synchronisation from a neural perspective [Cormie *et al.* 2010; Cormier *et al.* 2022].

Recently, systems that combine intense resistance training with a PAPE response generated using intense resistance preload stimulation in training have attracted attention (75-90% RM) [Evetovich *et al.* 2015; Scott *et al.* 2017; Sanchez-Sanchez *et al.* 2018]. The studies mentioned in the literature reveal the physiological effects of PAPE, especially detailing the mechanisms within the central nervous system and the pathway that ends with the motor end plate. The number of studies on the processes affecting performance, especially those related to the peripheral nervous system, is quite limited [Gunay *et al.* 2023].

It is known that reaction time is one of the skills closely related to both the peripheral nervous system and the central nervous system in sportive performance [Williams, Walmsley 2000; Balakrishnan *et al.* 2014]. In addition, reaction time measurement is a reliable indicator of the processing of sensory stimulus by the central nervous system and its implementation in the form of a motor response [Aley *et al.* 2007; Muhil *et al.* 2014]. On the other hand, in sports performance, fast reaction time is crucial for both competitive manoeuvres and for successfully preventing or reducing the frequency and severity of injury [Eckner *et al.* 2011].

It is known that reaction time, which is of great importance in terms of athlete performance, is one of the most difficult sportive performance indicators to develop. Reaction time performance in athletes may differ according to the sports branch in terms of development. Especially in combat sports such as boxing and wrestling, reaction time is so important that it can directly or indirectly affect the outcome of the competition [Dincer *et al.* 2022]. Therefore, it is important to determine effective methods for improving reaction time performance. Although there are studies examining the effects of PAPE on the performance of strength, endurance, change of direction, speed, and coincidence anticipation timing, there is no research examining the effects of PAPE on reaction time performance as far as we know [Blagrove *et al.* 2019; Krzysztofik *et al.* 2021; Pereira *et al.* 2022; Biel *et al.* 2023; Gunay *et al.* 2023]. In this context, how reaction time will be affected by PAPE is an important question waiting to be explained. Therefore, the aim of this study was to determine how PAPE affects visual reaction performance in boxers.

Materıal and methods

Participants

To determine the number of participants in the study, the "ANOVA: repeated measures, within factors" test, one of the F family tests, was used using the G*Power 3.1.9.7 (University of Dusseldorf, Dusseldorf, Germany) program. In this context, with an α error rate of 0.05, effect size of 0.25, and power (1−β error probability) set at 0.80, it has been determined that a participant group with a minimum of 17 individuals is required for a confidence level of 81%. The research participant group (n=17) was determined within the framework of the inclusion and exclusion criteria previously determined. In this regard, the inclusion criteria for the research are as follows: a) being over 18 years old, b) having a male gender c) engaging in boxing for at least 2 years, d) having no health problems, e) currently implementing resistance training for at least 1 years. All criteria outside the inclusion criteria for the research are considered exclusion criteria. The demographic characteristics of the participants in Table 1 are presented.

Table 1. Demographic characteristics of the participants (n = 17).

Variable	n	X̃	SD	Min	Max
Age [years]	17	21.35	2.42	18.00	25.00
Height [cm]	17	176.05	3.41	170.00	181.00
Weight [kg]	17	67.76	3.99	60.00	75.00
1-RM performance [kg]	17	84.11	6.66	75.00	95.00

n sample size; **X̃** arithmetic mean; **SD** standard deviation; **Min** minimum; **Max** maximum

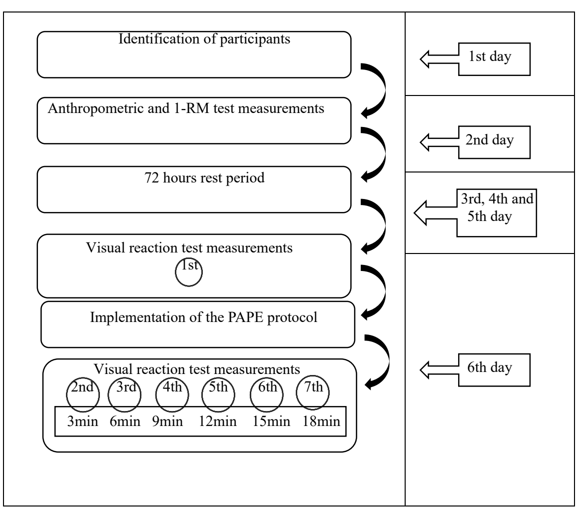

Fig. 1. The course of the study.

Survey design

The study was conducted according to the Declaration of Helsinki and was approved by the Bioethics Committee at the District Medical Chamber in Krakow (No. 226/KBL/OIL/2023). This study was carried out with the participation of boxers who have been practising resistance training for at least 1 year and boxers with at least 3 years of boxing experience. Participants were instructed to avoid different types of exercise the day before the measurements, not to consume stimulant drinks such as tea, coffee, alcohol, and carbonated drinks and to eat their last meal at least 2 hours before the measurements. Firstly, anthropometric measurements of the participants were taken and then a One-repetition maximum (1-RM) Bench Press performance test was performed by applying 5 min low-intensity running. In order to avoid fatigue that may occur after the 1-RM Bench Press performance test, PAPE protocol was applied 72 hours later after 5 min of low-intensity running. The visual reaction time test was measured once immediately before the PAPE protocol was administered and 6 times at 3 min intervals after PAPE (3 min, 6 min, 9 min, 12 min, 15 min, 18 min) was administered. The data obtained were recorded in milliseconds and analysed. The course of the study is shown in Figure 1.

Test procedures

Anthropometric Measurements

In the study, all anthropometric measurements of the participants were conducted in accordance with the techniques and standards recommended by the International Society for the Advancement of Kinanthropometry (ISAK). In this context, the participants' height was measured barefoot using a stadiometer (SECA, Germany) with a precision of 0.01 m. Body weights were measured with an electronic scale (Tanita, SC-330, Japan) wearing only shorts, with a precision of 0.1 kg.

1-RM (One rep max) Protocol

For the determination of 1-RM performance, the 1-RM bench press test was conducted. During the test, free weights and a barbell (Ohio Power Bar, USA) were utilized. Participants grasped the bar at their preferred width while performing the test. The use of equipment such as lifting belts, wrist support, elbow support, and chalk was not permitted. To prevent the possibility of injury in case of failure during lifting, two experienced bodybuilding athletes were ready on both sides of the bar to assist.

Participants began the test with a weight of their own choosing, as they were already familiar with the bench press movement. However, prior to starting the 1-RM test, it was strongly recommended that participants begin with approximately 30-40% of their body weight, following the guidelines proposed by Baechle *et al.* [Baechle *et al.* 2008]. This ensured the prevention of potential muscle injuries during the 1-RM test. Throughout the test, participants were instructed to repeat the movement by adding 2.5-5 kg based on the difficulty they felt (Borg Scale), and strength values were obtained. The process of increasing weight was continued until participants could no longer perform a single repetition. The test was concluded when participants indicated they could not lift any further. All test results were recorded in kilograms.

Perceived Difficulty Level

The Borg Scale was utilized in determining the perceived difficulty level, serving as a valuable indicator to monitor an individual's exercise tolerance. The scale allows the participant to express the fatigue felt during exercise on a range from nothing (6), very, very light (7-8), very light (9-10), light (11-12), somewhat hard (13-14), hard (15-16), very hard (17-18), very, very hard (19), to exhaustion (20). It is particularly useful for tracking an individual's progression towards maximal effort, especially during an exercise test [Borg 1982].

PAPE Protocol

Due to studies highlighting the potential reduction in the effects of PAPE when applied after an extensive warm-up [Tillin, Bishop 2009; Mina *et al.* 2019], the PAPE application was specifically performed following a brief 5-minute low-intensity run. The loading intensity for the PAPE application was implemented in line with the intensities prescribed by Masel *et al.* [Masel, Maciejczyk 2022]. In this context, participants performed a set of 3 repetitions with 50% 1-RM load, followed by a recovery period of 180 seconds, 3 repetitions with 70% 1-RM load and finally, after 180 seconds of recovery, participants performed a set of 3 repetitions with 80% 1-RM load. After 180 seconds of recovery, visual reaction tests were performed.

Reaction Time Measurement

As there is currently no information in the literature regarding the optimal duration for showcasing visual reaction performance after PAPE, the test was conducted once immediately before PAPE and then six times with 3-minute intervals afterward (3 min, 6 min, 9 min, 12 min, 15 min, 18 min). Reaction time measurements took place in an environment with sufficient light and no noise. The Moart Reaction Time Measurement device (Lafayette Ins., Sagamore, USA) was used for the measurements. In the visual reaction time test, participants were asked to respond by pressing the button on the lower panel of the device with the index finger of their dominant hand to complex light stimuli sent at irregular intervals, without equal time intervals between them. A 3-trial practice test was conducted before the main test. The visual reaction time measurement for the participants was performed five times consecutively. The arithmetic mean of the remaining three values, excluding the best and worst values, was recorded as the visual reaction time. Measurements were recorded in milliseconds (ms).

Statistical analysis

The data were analyzed using IBM Statistics (SPSS, version 26.0, Armonk, NY, USA). The Repeated Measures ANOVA test was employed to determine the impact of PAPE on visual reaction time performance over time. The Mauchly Test was used to assess the homogeneity of variances, and the Sphericity Assumed correction factor was applied for variance corrections. The significance level was set at $p<0.05$. Additionally, the effect size of PAPE on visual reaction time performance over time was determined through Partial Eta Squared (ES). Descriptive statistics were also applied to record minimum (Min), maximum (Max), mean ($\tilde{X}$), and standard deviation (SD) values.

Results

Repeated Measures ANOVA test results of the effects of PAPE on visual reaction performance are presented in table below.

Table 2. Repeated Measures ANOVA Results for Participants' Visual Reaction Time Performances.

Time	Measurements	$\tilde{X}$	SD	Min	Max	F	p	ES
Before PAPE	Reaction Time (1st)	388.11	97.31	265.00	519.00	0.061	0.999	0.004
3 minutes later	Reaction Time (2nd)	392.23	86.84	298.00	541.00			
6 minutes later	Reaction Time (3rd)	381.17	76.61	280.00	514.00			
9 minutes later	Reaction Time (4th)	380.52	94.90	268.00	554.00			
12 minutes later	Reaction Time (5th)	380.05	99.12	274.00	541.00			
15 minutes later	Reaction Time (6th)	391.29	94.44	270.00	515.00			
18 minutes later	Reaction Time (7th)	391.05	72.77	280.00	503.00			

$\tilde{X}$ arithmetic mean; **SD** standard deviation; **Min** minimum; **Max** maximum; **F** ANOVA coefficient; **p** significance level; **ES** partial eta squared

Upon examining Table 2, it is observed that although there is a difference in the mean visual reaction time performance of participants both before and after the PAPE protocol, this difference is not statistically significant ($p>0.05$).

Discussion

This research was conducted to determine how the visual reaction performance of boxers is affected by PAPE. Upon examining the research data, it was observed that although the participants' mean visual reaction time performance varied, this variation was not statistically significant ($p>0.05$). Therefore, it can be stated that the visual reaction performance cannot be acutely enhanced by applying the PAPE protocol. However, we still believe that further research in this area is essential, and testing different exercise protocols as well as measuring reaction performance through different methods is crucial for a comprehensive understanding.

When examining the research conducted on improving reaction performance in the literature, while there may not be a direct study specifically investigating the impact of PAPE, there is a considerable number of studies on enhancing reaction performance in athletes [Witkowski *et al.* 2022; Szczepanik *et al* 2023]. However, we are not discussing the details of these studies here as they are beyond the scope of the current research. Nevertheless, we attempt to shed light on why reaction performance is not affected by PAPE by presenting some studies related to reaction time performance in this context.

As previously mentioned, two main factors that acutely influence PAPE are fatigue and potentiation, and the balance between these two factors determines the level of muscle performance [Seitz, Haff 2016]. It is clear that potentiation enhances performance, while fatigue has a negative impact on performance [Tsoukos *et al.* 2016; Bogdanis *et al.* 2017]. In this context, since there is currently no information in the literature regarding the optimal rest period for maximal display of visual reaction performance after PAPE, visual reaction performance tests were conducted at 3-minute intervals (3 min, 6 min, 9 min, 12 min, 15 min, 18 min) six times after PAPE. However, no statistically significant difference was observed among these tests ($p>0.05$). At this point, the lack of an effect on visual reaction time performance after PAPE cannot be explained by an association with the post-PAPE rest period.

On the other hand, we emphasized that reaction time performance is closely associated with both the peripheral nervous system and the central nervous system [Williams, Walmsley 2000; Balakrishnan *et al.* 2014]. In this context, processes contributing to reaction time involve the transmission of a stimulus from the external environment through vision, hearing, or touch to the central nervous system, analysis of the stimulus in relevant areas of the central nervous system, decision-making related to the processing, transmission of the signal generated in response to the stimulus to the relevant muscles through the peripheral nervous system, and stimulation of the muscles to produce a mechanical action [Balakrishnan *et al.* 2014]. Considering the positive effects of PAPE on both the central nervous system and the peripheral system, a positive impact on reaction time performance was expected. However, this did not occur. Therefore, it can be stated that visual reaction performance is not affected by the acute effects on the central nervous system and peripheral nervous system associated with PAPE. Nevertheless, since the exact nature of the effects of PAPE on both the central nervous system and the peripheral nervous system has not been clearly established, we believe that further studies in this area would be beneficial.

The findings and implications of this study have been presented within the limitation of the research. In order to guide future research, various limitations of this study have been detailed. In this context, the limitations of this study are as follows:

a) the application of only the Bench Press exercise to induce PAPE in the upper extremities, b) the use of loading intensity at 80% of 1-RM to induce PAPE, c) limiting the measurements of PAPE effects to the initial 18 minutes, c) measuring visual reaction time performance solely using the Moart Reaction Time Measurement device (Lafayette Ins., Sagamore, USA), d) the research group consisting exclusively of male boxers.

Conclusıons

The conclusion of this study is that PAPE does not affect visual reaction time performance. These findings indicate the difficulty of acutely enhancing visual reaction time performance after PAPE. Moreover, due to the insufficient research on how visual reaction time performance is influenced by PAPE, the mechanisms explaining the relationship between PAPE and visual reaction time performance remain a subject of curiosity. It is recommended that future research should focus on this topic. Additionally, researchers are advised to consider the limitations of this study when designing their own research.

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Badanie wpływu wzmocnienia wydajności po aktywacji na czas reakcji wzrokowej bokserów

Słowa kluczowe: sporty walki, okres refrakcji, rozgrzewka, protokół treningowy

Streszczenie

Tło. Istnieją silne dowody sugerujące, że Wzmocnienie Wydajności po Aktywacji (PAPE) może w sposób doraźny poprawić różne aspekty wydajności sportowej, takie jak siła, wytrzymałość, szybkość i zwinność. Jednak istnieje luka w badaniach dotyczących wpływu PAPE na wydajność czasu reakcji. Dlatego celem tego badania było zbadanie wpływu PAPE na czas reakcji wzrokowej u amatorskich bokserów.

Materiały i metody. Przeprowadzono badanie przekrojowe z udziałem 17 amatorskich bokserów. Dokonano pomiarów antropometrycznych, a uczestnicy wykonali test wydajnościowy 1 powtórzenia maksymalnego (RM) wyciskania na ławce poprzedzony 5 minutami biegu o niskiej intensywności. Protokół PAPE został następnie przeprowadzony 72 godziny później po kolejnych 5 minutach biegu o niskiej intensywności, aby uniknąć zmęczenia. Czas reakcji wzrokowej został zmierzony bezpośrednio przed protokołem PAPE oraz sześciokrotnie w odstępach 3-minutowych po jego zakończeniu. Dane były analizowane za pomocą oprogramowania IBM Statistics (SPSS, wersja 26.0, Armonk, NY, USA). Wyniki. Badanie wykazało, że choć średni czas reakcji wzrokowej uczestników przed i po protokole PAPE różnił się, to różnica ta nie była statystycznie istotna ($p > 0,05$). Można zatem stwierdzić, że PAPE nie ma wpływu na poprawę czasu reakcji wzrokowej u bokserów. Wnioski. Podsumowując, badanie sugeruje, że PAPE nie ma znaczącego wpływu na wydajność czasu reakcji wzrokowej u amatorskich bokserów. Warto przeprowadzić dalsze badania, aby zbadać inne czynniki, które mogą wpływać na czas reakcji w tej populacji.