Ünver *et al. BMC Sports Science, Medicine and Rehabilitation* (2025) 17:51
https://doi.org/10.1186/s13102-025-01103-8

BMC Sports Science, Medicine and Rehabilitation

RESEARCH Open Access

The impact of fatigue and different environmental conditions on heart rate responses and shooting accuracy during laser run event in elite modern pentathletes

Mustafa Ünver[1], Elif Cengizel[2*], Hacı Ahmet Pekel[2], Çağdaş Özgür Cengizel[2], Aylin Özge Pekel[1] and Veli Ozan Çakır[1,3]

Abstract

Background The final event in modern pentathlon, the laser run, determines the final ranking, and it is not known whether the athletes' heart rates (HRs) and success rates during the shooting in the laser run are affected by environmental conditions. Although heart rate (HR) affects shooting performance, exercise-induced muscle fatigue accompanying increased HR can affect shooting speed and accuracy. The aims of this research were (a) to compare the HRs of pentathletes before and after fatigue, (b) to compare the shooting performance of pentathletes in the field vs. laboratory environment, and (c) to compare the HRs of pentathletes during successful and unsuccessful shootings.

Methods The HRs and shooting performances of the seven national team pentathletes were measured in two separate sessions under laboratory conditions (pre- and post-fatigue) and in the field (laser run event). Bruce protocol was used to create exercise-induced fatigue and the internal loads of the pentathletes were determined with the 10-point Borg scale. The first session consisted of pre- and post-fatigue shooting in the laboratory environment, and the second session consisted of shooting in the laser run event in the field environment. The pentathletes' HRs were monitored in all sessions.

Results The shooting accuracy of pentathletes in the laboratory is not affected by fatigue, although the HRs before and after the fatigue protocol differ significantly ($p < .001$). The unsuccessful shot count in the field was not significantly different between laps, and the HR decreased significantly towards the last successful shot in each lap ($p < .001$). Although shooting accuracy was not significantly different between the field and laboratory, the HRs in the field were significantly higher than those in the scenarios performed in the laboratory ($p < .05$).

Conclusion The findings revealed that HR was significantly affected by different environmental conditions and fatigue, but this was not accompanied by shooting accuracy, and significantly higher HR was achieved in unsuccessful shots compared to successful shots. We recommend that pentathletes perform running-shooting training in different

*Correspondence:
Elif Cengizel
elifoz@gazi.edu.tr

Full list of author information is available at the end of the article

© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

weather and field conditions before the competition to adapt to different environments, especially during the competition seasons, instead of shooting in a polygon or laboratory.

Keywords Modern pentathlon, Heart rate, Shooting performance, Fatigue protocol, Laser run

Introduction

The modern pentathlon consists of five different disciplines, including shooting, fencing, swimming, riding and running [1]. In addition, the laser run is the final stage of the modern pentathlon and consists of running and shooting activities combined [2]. The aim of this stage is to reach the finish line as quickly as possible and to make five successful shots to the target with a laser gun from a distance of 10 m [3]. The new final format implemented in the 2024 Paris Olympic Games starts with riding, with 5–15 min breaks between each discipline, followed by the fencing bonus round and swimming, and finally, after every 600 m run, it is completed with a 5-lap laser run. Athletes shoot until they get five successful shots in each round or move on to the next running lap if they cannot reach this score within 50 s in laser run event.

Physiological changes are observed in pentathletes after each event [4]. One of these changes is heart rate variability (HRV), the variation in time between repetitive heartbeats over time, mostly due to exogenous regulation of heart rate (HR) [5, 6]. HRV is used extensively in sports sciences to monitor the physical condition of athletes and is assumed to be an indicator of physiological response. It is thought that it can be an objective tool to measure the individual physiological state of an athlete before, during and after the competition [7].

Shooting is a sport that depends on a constant concentration. However, as in other disciplines, physical fitness also helps shooters perform more accurately [8]. HR influences shooting performance [7, 9, 10], and firing speed affects accuracy [11]. In addition, the HR systematically decreases before pulling the trigger to increase shooting accuracy in elite and non-elite shooters [10]. This decline occurs faster in elite athletes than in non-elite athletes [12]. Laser run performance, which is the final stage of the modern pentathlon, significantly affects the success level of the athlete. It is highly recommended to use HR monitors to control the response of the athlete's cardiovascular system to determine the exercise intensity [13]. As exercise intensity increases, various neural mechanisms increase sympathetic tone, leading to further increases in HR, suggesting that HR may have significant potential as a predictor of aerobic fitness and exercise performance, and in monitoring exercise-induced muscle fatigue in elite athletes [14, 15].

To the best of the authors' knowledge, such a study examining HR changes and shooting accuracy in modern pentathletes under different environmental conditions and fatigue scenarios has not been reported previously in the literature. Therefore, the success of the shots (hit the target) made at high HR in this stage is a matter of curiosity. At the same time, it is possible that the athletes are affected by environmental factors and their shooting concentration is lost. For this reason, the laboratory environment, where environmental factors are not variable, and the effects of shootings made under field conditions, where these factors are variable, on HR and success rates are also unknown. Although it is known that modern pentathletes shoot after running in the laser run event, athletes sometimes only practice shooting. This presents different physiological stress and environmental conditions. Thus, this current research focuses on the question "Do fatigue and different environmental conditions have an effect on heart rate and shooting accuracy during the laser run event in elite modern pentathletes?". Therefore, the aims of this research were (a) to compare the HRs of pentathletes before and after fatigue, (b) to compare the shooting performance of pentathletes in the field vs. laboratory environment, and (c) to compare the HRs of pentathletes during successful and unsuccessful shootings.

Methods

Participants

Seven modern pentathlon national team athletes (one 2020 Olympic Games 5th, 2024 Olympic Games 6th & World 3rd, one World 3rd &, Olympian at 2024 Olympic Games, one World 4th, one 3rd European junior team, two World and European U24 finalists, one World Championship participant, mean and *SD*, respectively: age = 21.1 ± 3.6 years, experience = 13.6 ± 3.9 years, body height = 169.7 ± 8.9 cm, body mass = 59.0 ± 10.8 kg, body fat = 16.3 ± 2.3%) voluntarily participated in the research. According to the 2023 data on the official website of the Union Internationale de Pentathlon Moderne, the number of competitors in the world is 194 for women and 216 for men, and with the participants we reached in our research, we included 2.6% of the population in women and 1% in men and 1.7% in total.

The study proposal was presented to the participants, and the possible risks and benefits were explained before their participation. Each athlete signed an informed consent form to confirm their voluntary participation and approved the use and disclosure of their information for research purposes. The inclusion criteria were (a) actively competing in the modern pentathlon discipline and being a national athlete, (b) training at least 6 days a week, and (c) having been trained in the modern pentathlon discipline for at least 8 years. The exclusion criteria were (a) having any musculoskeletal injury or operation in the last six months, (b) having any cardiovascular disease, or (c) not completing any of the protocols. The participants were asked to rest before the measurement days, not to consume stimulants or alcohol 24 h before the measurement, to stop eating for the last 2 h, to stop consuming water for the last half hour, and to return to sleep at 23:00 the day before the measurement. The research was conducted in accordance with the Declaration of Helsinki and was approved by the local ethics committee.

Study design

The two experiments were separated by at least a 3-day interval and were completed within a one-week period (Fig. 1). The resting HR was taken after the characteristics of the athletes (age, body height, body mass, BMI) were measured on the first measurement day. A

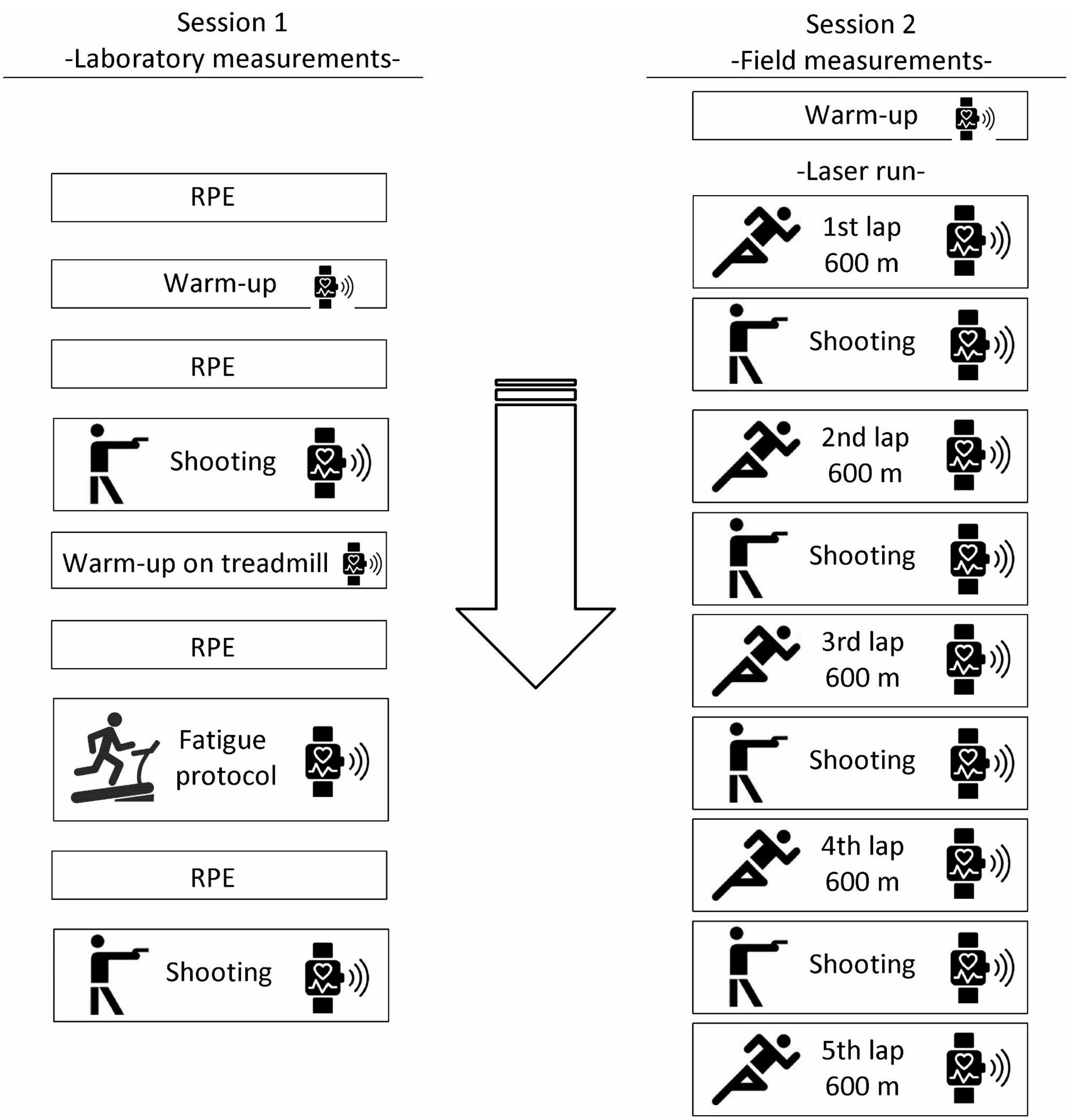

Fig. 1 Study design

stadiometer (SECA 217, Seca Ltd., Vogel & Halke, Hamburg, Germany) was used to measure body height, and a bioelectrical impedance analyser (Tanita BC 418, Tanita, Japan) was used to measure body mass, BMI and body fat. HR was monitored continuously during all laboratory and field measurements through the use of a Polar V800 HRM (Polar Electro OY, Kempele, Finland) with a Polar H9 HR Sensor chest strap (henceforth, V800). Afterwards, the athletes were asked for a 15-minute self-selected warm-up protocol, consisting of pre-fatigue shot, a warm-up protocol on the treadmill (h/p/Cosmos Saturn 4.0, Germany) and a fatigue protocol, which was performed immediately after the shot.

In the fatigue protocol, participants underwent a warm-up protocol including 5 min of running at 8 km/h on the treadmill, walking for 1 min, and then a fatigue protocol, respectively. The standard Bruce protocol was used to create fatigue. The Bruce protocol is a continuous, incremental treadmill protocol consisting of 7 stages, with inclines and speed increases every 3 min. The treadmill is started at 2.74 km/h (1.7mph) & at an inclined gradient of 10%. After 3 min incline of the treadmill is increased by 2%, and the speed increases. In stage 7, the incline is 22% and the speed is 9.65 km/h (6.0 mph). The rating of perceived exertion (RPE) of all athletes pre-warm-up, post-warm-up on the treadmill, and at the end of the fatigue protocol were determined with the 10-point Borg scale [16]. Participants were familiarized with the Borg scale and were asked to only consider their feelings of physical exertion and not specifically offer any psychological/psychic contribution to these feelings [17]. All of the athletes exercised until they reached exhaustion and voluntarily decided to stop. The secondary criteria for ending the protocol were at least two of the following: (1) RPE: ≥9 on the Bruce protocol test; (2) age-predicted maximal HR (calculated with the following formula: $220 - \text{age} = HR_{max}$); and (3) respiratory exchange ratio (RER): ≥1.10. During the protocol, the VO_{2max} was determined with a Cosmed Quark CPET breath-by-breath gas analyser (Cosmed, Albano Laziale, Rome, Italy). The ambient temperature during testing was 25.0 ± 0.4 °C. For shooting performance, all the athletes were asked to complete 5 successful shots at the target at a distance of 10 m in accordance with the official competition rules, and the HR was recorded for each successful and unsuccessful shot.

The field performance of the athletes was measured one week after the laboratory measurement at the maximum. Athletes continued their routine training between the measurements, but the intensity was kept low (50–70% of HR_{max}) during training. The laser run event was performed according to the modern pentathlon official competition rules. The participants applied a self-selected warm-up for 15 min before the laser run. The laser run was completed as a 5 × 600 m run, and 5 successful shots were taken at the target at a distance of 10 m after each run. The HRs (including successful and unsuccessful shots) were recorded in all running sequences and shooting performances of the athletes.

Data analysis

The data are presented as the mean ± *SD*, 95% confidence interval (CI), significance level (p) and effect size (ES). The normality of the data was tested via the Shapiro−Wilk test. Repeated measures analysis of variance was used to compare the HR response between laps in the field, and paired sample t-test was used to compare pre- vs. post-fatigue, field vs. laboratory, and successful vs. unsuccessful shots between the laps, independently. The ES was classified using the Cohen's d [18] according to the following scale in the laboratory environment in comparisons of pre-post-fatigue, field vs. laboratory, and successful vs. unsuccessful shots: trivial < 0.2, small 0.2–0.5, moderate 0.5–0.8, and large > 0.8. Partial eta squared effect sizes (η^2) were classified as follows in the comparison of repeated measurements in the field environment: small (0.01), moderate (0.06), and large (0.14) [19]. All the statistical analyses were performed using SigmaPlot 11.0 software (from Systat Software, Inc., San Jose, California, USA). The significance level was set at 5%.

Table 1 HRs, VO_{2max}, and shooting performance of elite modern pentathletes before and after fatigue protocol in the laboratory

		mean ± SD	min	max	95% CI
Laboratory	Resting HR (bpm)	73.1 ± 6.5	64	82	68.3–77.9
	Post-warm-up HR (bpm)	91.0 ± 12.9	77	108	81.4-100.6
	Post-warm-up on treadmill HR (bpm)	128.4 ± 12.8	108	144	118.9-137.9
	HR_{max} during the fatigue protocol (bpm)	188.7 ± 6.3	180	198	184.0-193.4
Field	Running time (sec)	130.7 ± 10.7	114.4	139.2	122.8-138.6
	Running speed (m/sec)	4.62 ± 0.41	4.31	5.25	4.32–4.92
	Shooting time (sec)	14.5 ± 3.1	11.8	21.0	12.2–16.8
	HR_{mean} during running (bpm)	166.1 ± 1.2	164	167.2	165.2–167.0

Data are presented as mean ± *SD*. min: minimum, max: maximum, CI: confidence interval, HR: Heart rate

Results

In laboratory measurements, the RPEs of modern pentathletes before and after the warm-up and pre- and post-fatigue protocol were 0, 0.3 ± 0.8, 1.0 ± 1.0, and 9.3 ± 0.8, respectively. RPE after fatigue protocol was significantly higher than that before the protocol ($p < .001$). The maximum HR was reached after the fatigue protocol (Table 1), and the mean VO_{2max} of modern pentathletes was 55.4 ml. kg. min^{-1} (minimum = 50.3, maximum = 60.3, 95% CI = 51.5–59.3 ml. kg. min^{-1}). Pentathletes' mean laser run time, running speed, shooting time, HR_{mean}, and HR_{max} in the field measurements during the laser run are presented in Table 1. HR_{max} during a laser run event is lower than HR_{max} during the fatigue protocol.

There was no significant difference in the unsuccessful shots ($p = .395$) and shooting accuracy ($p = .424$) of the pentathletes between pre- and the post-fatigue protocol applied in the laboratory. There was no significant difference between laps in either unsuccessful shots or shooting accuracy in the laser run event (Fig. 2). The unsuccessful shot count per lap averaged 3.3 ± 1.4, and the shooting accuracy averaged 63.4 ± 8.9% in the field conditions. However, there was no significant difference in shooting accuracy between the field and laboratory environments (field vs. pre-fatigue, $p = .498$; field vs. post-fatigue, $p = .640$).

In the laboratory, the pre-fatigue HR of pentathletes was significantly lower than the post-fatigue HR (pre- and

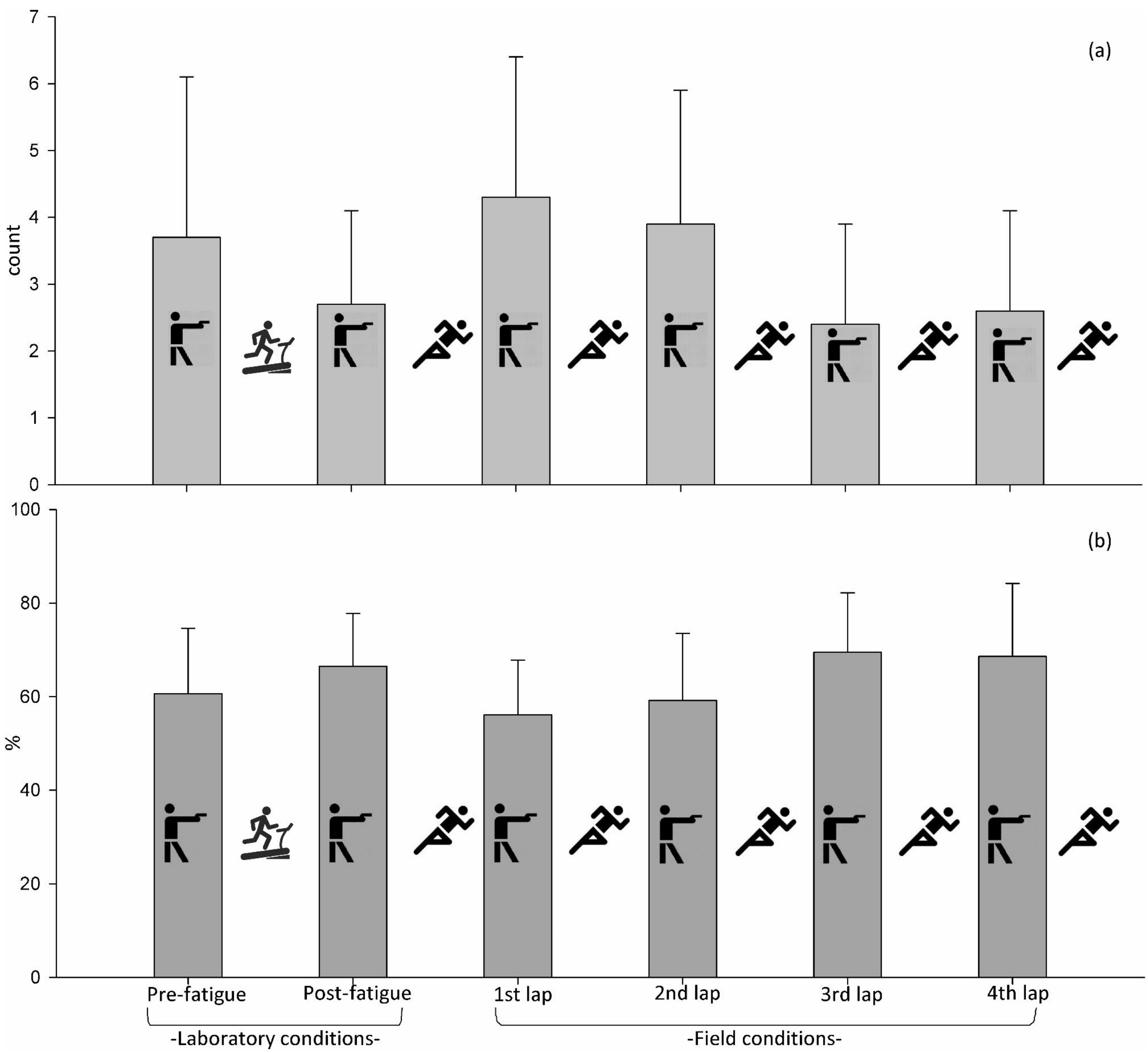

Fig. 2 Unsuccessful shoots (**a**) and shooting accuracy (**b**) of elite modern pentathletes in the laboratory and field conditions. The "count" refers to how many times the shot occurred. The "%" is the ratio obtained by dividing successful shots by total shots

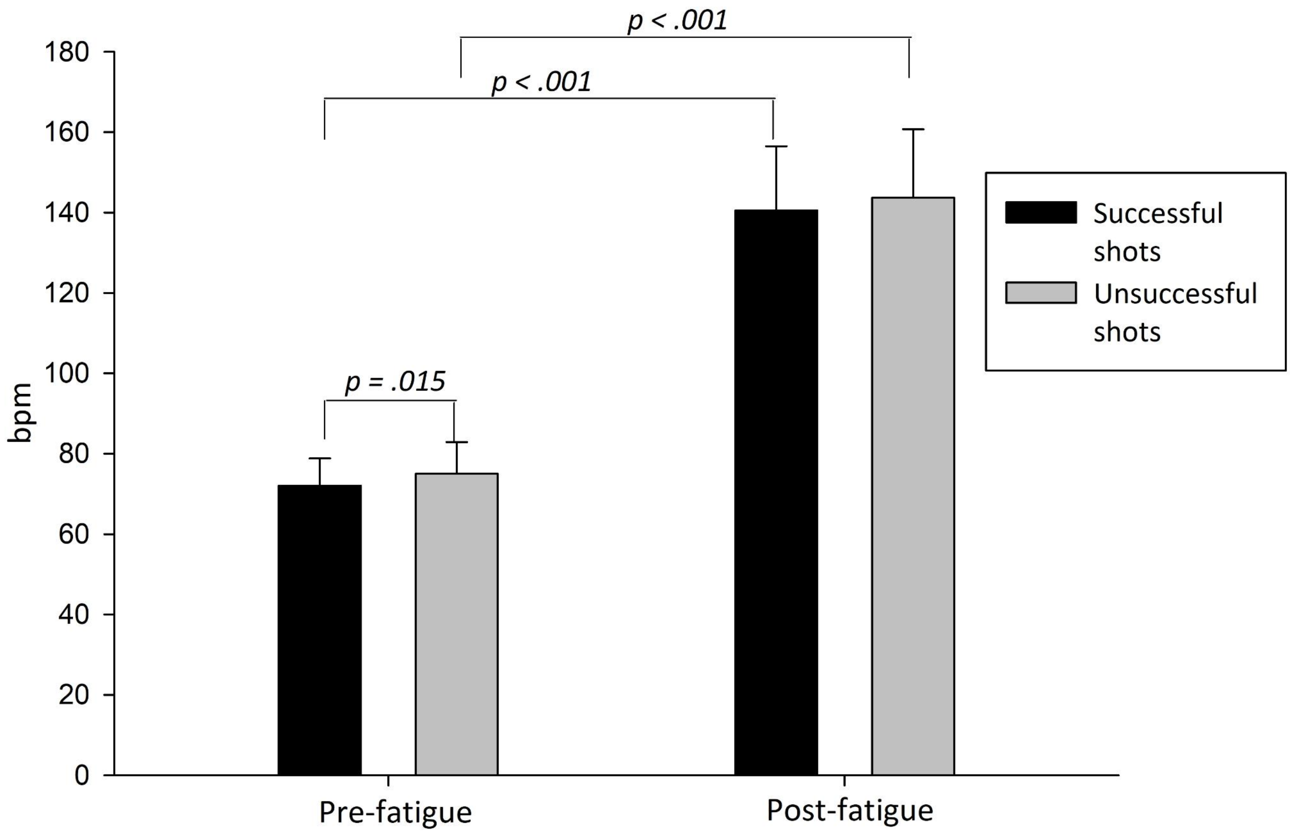

Fig. 3 The HR responses of elite modern pentathletes pre- vs. post-fatigue protocol, and successful vs. unsuccessful shots in the laboratory ($p < .05$)

post-fatigue HR = 72.0 ± 6.8 vs. 140.5 ± 16.0 bpm, $p < .001$, ES = 5.572 "large" in successful shots, 75.0 ± 7.9 vs. 143.7 ± 17.0 bpm, $p < .001$, ES = 5.183 "large" in unsuccessful shots; (Fig. 3)). The participants' pre-fatigue HR was significantly higher in unsuccessful shots than for successful shots (HR in successful vs. unsuccessful shots = 72.0 ± 6.8 vs. 75.0 ± 7.9 bpm, $p = .015$, ES = 0.407 "small", respectively). Although the post-fatigue HR in unsuccessful shots was quantitatively higher than the HR in successful shots, this difference was not significant (successful vs. unsuccessful = 143.7 ± 17.0 bpm vs. 140.5 ± 16.0 bpm, respectively).

In the field, the HRs of pentathletes were not significantly different between successful shots and unsuccessful shots on each lap (Fig. 4). For all laps, the HR_{mean} for successful shots was 162.0 ± 10.0 bpm, and the HR_{mean} for unsuccessful shots was 162.5 ± 9.7 bpm.

However, there was a decrease in HR from the first successful shots to the end when the HRs was compared by separating the performances of 5 successful shots in 4 shooting intervals (e.g., 1st successful shot, 2nd successful shot, etc.). The HR of the athletes in the 1st successful shots was significantly higher than the HR in the 4th ($p < .001$, "large" F = 6.01, $\eta^2 = 0.461$) and 5th successful shots ($p < .001$, "large" F = 6.00, $\eta^2 = 0.450$), and the HR in the 2nd successful shots was significantly higher than the HR in the 5th successful shots ($p < .001$, "large" F = 6.01, $\eta^2 = 0.451$) (Fig. 5). The HR reduction between the 1st and 5th shots is 12.0%. Athletes started their shooting performance with an average HR of 172.8 ± 3.0 bpm and the next running lap with an average HR of 152.0 ± 6.6 bpm.

There was a significant difference in all the parameters between the HRs of pentathletes in the field and those in the laboratory (Table 2). The pre-fatigue HR of the pentathletes in the laboratory was significantly lower than the HR in the field (mean and max) in both successful and unsuccessful shots. In all of the shots (successful and unsuccessful shots) of the pentathletes in the field competition protocols, significantly higher HRs were obtained from the scenarios realized in the laboratory.

Discussion

The aim of this study was to compare the HRs of pentathletes before and after the fatigue protocol. Furthermore, this study investigated the shooting performance of pentathletes in a field environment vs. a laboratory environment and compared the HRs of pentathletes during successful and unsuccessful shootings. One of the main findings of the current study was that the shooting performance of pentathletes in the laboratory was not affected by fatigue, although the pre- and post-fatigue HRs differed significantly. Furthermore, the unsuccessful

Fig. 4 The HR responses of elite modern pentathletes in laser run shooting performance by laps in the field

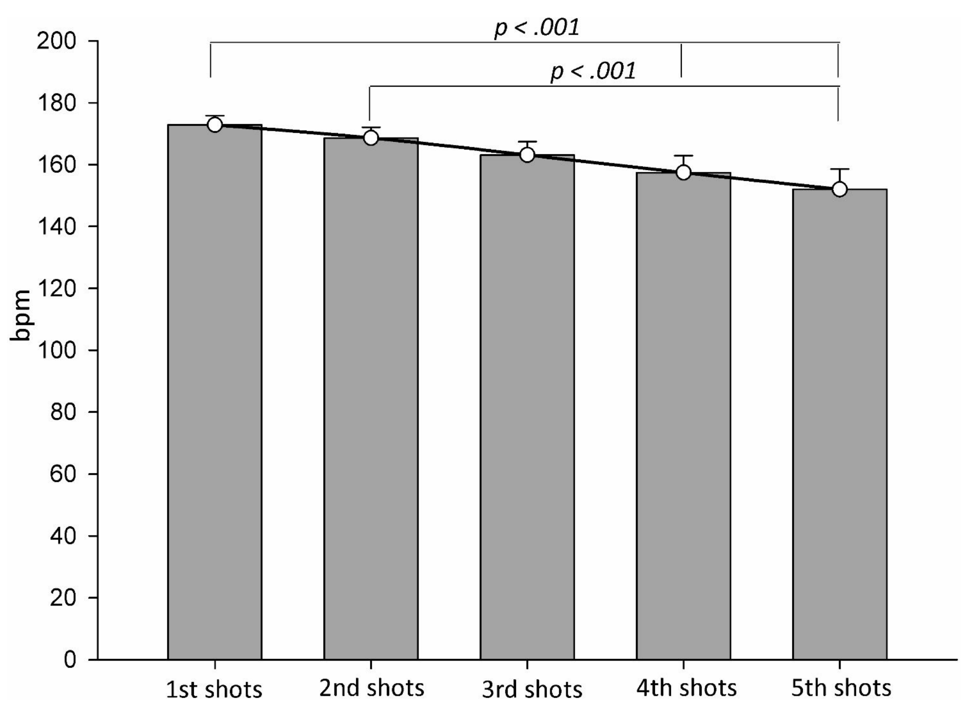

Fig. 5 The HR responses of elite modern pentathletes during successful shots in the field ($p < .05$)

Table 2 Comparison of HR responses of elite modern pentathletes in the laboratory vs. in the field, during successful vs. unsuccessful shots

		Laboratory				
		Pre-fatigue S shots	**Post-fatigue S shots**		**Pre-fatigue US shots**	**Post-fatigue US shots**
Field S shots	HR_{mean}	< 0.001	0.007	Field US shots	< 0.001	0.015
	HR_{max}	< 0.001	< 0.001		< 0.001	0.001
	1st lap	< 0.001	0.021		< 0.001	0.029
	2nd lap	< 0.001	0.017		< 0.001	0.035
	3rd lap	< 0.001	0.005		< 0.001	0.018
	4th lap	< 0.001	0.007		< 0.001	0.016

Data are presented as significancy level (p). S: Successful, US: Unsuccessful, HR: Heart rate. $p < .05$

shot count in the field was not significantly different between laps, and the HR decreased significantly towards the last successful shots in each lap. Although shooting accuracy was not significantly different in the field and laboratory comparisons (shooting accuracy in the field increased quantitatively with each lap, and the last two laps were higher than the laboratory conditions), the HRs in the field environment were significantly higher than those in the scenarios performed in the laboratory.

The effect of fatigue

Although there was no significant difference in the unsuccessful shot count ($p = .395$), and shooting accuracy ($p = .424$) between the pre- and post-fatigue protocol in the laboratory of pentathetes, the post-fatigue HRs for successful and unsuccessful shots were significantly higher than the pre-fatigue HRs (pre- vs. post-fatigue HRs = 72.0 ± 6.8 vs. 140.5 ± 16.0 bpm, $p < .001$, ES = 5.572 "large" for successful shots; 75.0 ± 7.9 vs. 143.7 ± 17.0 bpm, $p < .001$, ES = 5.183 "large" for unsuccessful shots). In addition, although there was no significant difference in the unsuccessful shot count and shooting accuracy of the pentathletes with high HRs after fatigue compared with the pre-fatigue protocol, a decrease in the unsuccessful shot count and a quantitative increase in the shooting accuracy were obtained. Although high HR in the cardiovascular system can increase breathing frequency, which may affect postural sway [10, 12, 20–24], pentathletes are accustomed to high-pulse shooting performance in the laser run, and this physiological stress is different from that in disciplines that shoot without running during competition because they carry out similarly with high HR after fatigue. This finding was evaluated as a result of the pentathletes combining their long-term shooting performance with different endurance training during the preparation period for the competition. For this reason, in our study, we observed that pentathletes shot more accurately at high HRs in the field, and the fact that the athletes exhibited increasing shooting accuracy with each lap during the laser run event at a higher HR compared with laboratory measurements also supports this finding. To improve performance in laser shooting, it is necessary to increase the physical strength elements, and it is recommended that pentathletes should be trained for cardiovascular endurance [25]. The optimal shooting performance in endurance running intervals with high intensity and the completion of laser run at high HR during anaerobic training are considered as important factors in the development of key elements such as physiological stress, adaptation and skill. Sadowska et al. [26] reported that the physical load caused by laser running affects an athlete's balance during shooting, but it remains at the same level in the next series of laser shots, and the level of fatigue does not affect postural sway in the laser shooting position. In support of previous studies, we determined that the laser shooting performance of pentathletes at high HRs was not different from that of their resting HRs. This can be evaluated as the pentathletes' ability to cope with high physiological stress and/or adaptation strategies, and they do not perform differently before and after fatigue in laser shooting in the laboratory environment. Whether the same strategy is used in the field environment is an important finding that needs attention, and we determined that the laser shooting accuracy of pentathletes under field conditions was not affected by fatigue towards the final laps and even increased gradually.

Comparison of successful shots and unsuccessful shots

The shooting performance of the pentathletes after the first lap on the field was lower than that of the others. This situation may also be a result of the process brought about by different conditions in the process called "adaptation" as a result of long years of training, which can be divided into two types: indoor and outdoor environments. These results show that although the physical loads arising from running may affect shooting performance, they may be a result of the athletes' adaptation to the additional physical load [27, 28]. In support of our findings, Park et al. [29] reported that there was a significant difference between laps in terms of shooting accuracy and consistency between the 1st lap and the other laps, whereas there was no significant difference between the 2nd, 3rd and 4th laps. Perhaps the improvement in the first-lap shooting performance of the athletes can give them an advantage over their opponents at the end of the competition. In fact, pentathletes have long been trained for the best performance in all modern pentathlon events under different conditions (ground, weather conditions, etc.). Therefore, the function of pentathletes shows that they can keep laser shooting performance constant to some extent even as physiological and physical loads continue to increase [20, 25–27, 29].

Laboratory vs. field comparison

Although the HRs of pentathletes in successful and unsuccessful shots during laser run performances in the field were not significantly different, we determined that as the number of laps increased, the HR also increased, but in successful shots per lap, the HR decreased in the period from the 1st successful shot to the 5th successful shot. However, the HRs of the pentathletes obtained after the fatigue protocol in the laboratory environment was significantly lower than the HRs in the field (as HR_{mean} and HR_{max}) in both successful and unsuccessful shots. In all of the shots (successful and unsuccessful shots) of the pentathletes in the field laser run, significantly higher HRs were obtained from the scenarios realized in the laboratory (HR_{mean} = 166.1 ± 1.2 bpm in the field, HR_{mean} = 72.0 ± 6.8 bpm pre-fatigue, 140.5 ± 16.0 bpm post-fatigue in the laboratory). This may be associated with the fact that the pentathletes may be adapted in terms of physiological stress in the field, as the field environment prepares for the competition in terms of concentration, resulting in more motivating conditioning. On the other hand, the fatigue protocol in our study was maximal and therefore different from the submaximal nature of pentathlon laser running, which may have influenced the findings. Park et al. [29] comprehensively examined the relationships among accuracy, speed and consistency in modern pentathlon shooting events and reported that athletes had higher consistency and accuracy and faster shooting and speed in finals than in qualifying rounds. This result is similar to the fact that athletes renew their records more frequently in finals than in qualifying races; however, the conditions faced by athletes, pressure, stress and physiological response [30] can also be considered. Therefore, these results may reflect the psychological and physiological characteristics on shooting characteristics depending on the type of competition [26]. Studies have emphasized that factors such as HR, motivation, self-confidence and anxiety play critical roles in reaching optimal performance levels [31, 32]. Considering these internal and external conditions affecting performance during the competition, it is recommended that pentathletes perform running-shooting training in different weather and field conditions before the competition to adapt to different environments, especially during the competition seasons, instead of shooting in the polygon or laboratory environments in resting situations.

It is clear that shooters improve their self-regulation in HR as they gain more experience [7]. On the other hand, there are researchers who suggest that training is an important key for athletes to reach elite performance and that it supports the planned training accordingly [33, 34]. In the modern pentathlon discipline, which requires pentathletes to shoot and run together with changing rules, it is important that the training content should be determined based on specific demands and competition characteristics to achieve better performance during laser running. Brown et al. [35] reported that HR during laser shooting was not significantly related to shooting accuracy or precision and suggested that pentathletes should develop their own strategies when trying to improve shooting performance. In our study, there was no significant difference in HRs between successful and unsuccessful shots in pre- and post-fatigue and field environments, but shooting at significantly higher HRs in the field was the most remarkable and supportive finding of previous studies.

Limitations

This current cross-sectional study has several limitations. The first of these is the sample size. However, all of the pentathletes in the sample are participants in international competitions; most of them have international rankings, and two are Olympians. Moreover, according to official data from the Union Internationale de Pentathlon Moderne, we reached 2.6% of the international pentathletes in the world. In addition, to the best of the authors' knowledge, there is no previous research with this research design. With respect to this research, we present important findings to elite pentathletes, coaches, athletes and practitioners in the modern pentathlon discipline. Our second limitation is that we did not use RPEs under field conditions, but we used RPE findings as indicators of internal load to determine fatigue in the laboratory. Another limitation is the use of lactate measurements as a more accurate predictor of fatigue under laboratory and field conditions.

Conclusions

The findings revealed that HR was significantly affected by different environmental conditions and fatigue, but this was not accompanied by shooting accuracy, and significantly higher HR was achieved in unsuccessful shots compared to successful shots. In conclusion, pentathletes should include shooting training in endurance-based training or anaerobic training, such as intensive intervals, instead of performing shooting training with resting HR or high HR scenarios in laboratory environments. It is thought that adding post-run shooting to the training process in the style of a method is important for adapting to laser running. Therefore, it is recommended that pentathletes perform running-shooting training in different weather and field conditions before the competition to adapt to different environments, especially during the competition season, instead of shooting in polygon or laboratory environments in resting situations. Due to different physiological stress and environmental conditions, it may be an important factor in improving the performance of modern pentathletes to combine running and shooting training, as in the laser run event, instead of performing an isolated shooting training.

Abbreviations

BMI	Body mass index
CI	Confidence interval
ES	Effect size
HR	Heart rate
HRV	Heart rate variability
RPE	Rating of perceived exertion
SD	Standard deviation
VO_{2max}	Maximal oxygen consumption

Acknowledgements
The authors would like to thank the athletes who participated in the study and the coaches who supported the research.

Author contributions
MÜ, EC, HAP and ÇÖC: study concept and design; MÜ, EC, ÇÖC and AÖP: data acquisition; MÜ, EC, HAP and VOÇ: data analysis, interpretation; MÜ, EC, ÇÖC and AÖP: article preparation. MÜ, EC, HAP and VOÇ: critical revision of the article. All authors read and approved the final article.

Funding
This study was conducted without any funding from companies, manufacturers or outside organizations. Open access funding provided by Gazi University.

Data availability
The data generated and analysed during the present study are not publicly available due to ethical restrictions but are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The study was approved by the Gazi University Ethics Committee and provided with the following reference number: 2022-056. Participants provided informed consent after the risks and benefits of the study were explained.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Physical Education and Sport, Faculty of Sport Sciences, Gazi University, Ankara, Turkey
[2]Department of Coaching Education, Faculty of Sport Sciences, Gazi University, Ankara, Turkey
[3]Department of Recreation, Faculty of Sport Sciences, Gazi University, Ankara, Turkey

Received: 18 August 2024 / Accepted: 28 February 2025
Published online: 15 March 2025

References

1. Dadswell CE, Payton C, Holmes P, Burden A. Biomechanical analysis of the change in pistol shooting format in modern pentathlon. J Sports Sci. 2013;31(12):1294–301.
2. UIPM. Competition rules and regulations. 2017. Rule 33.
3. Chirico A, Fegatelli D, Galli F, Mallia L, Alivernini F, Cordone S, et al. A study of quiet eye's phenomenon in the shooting section of laser run of modern pentathlon. J Cell Physiol. 2019;234(6):9247–54.
4. Saini AS, Kushwah GS. Heart rate and blood lactate analysis among pentathletes after each event of modern pentathlon. Int J Physiol Nutr Phys Educ. 2019;4(2):41–4.
5. Acharya RU, Joseph KP, Kannathal N, Lim CM, Suri JS. Heart rate variability: A review. Med Biol Eng Comput. 2006;44(12):1031–51.
6. Krittayaphong R, Cascio WE, Light KC, Sheffield D, Golden RN, Finkel JB, et al. Heart rate variability in patients with coronary artery disease: differences in patients with higher and lower depression scores. Psychosom Med. 1997;59:231–5.
7. Ortega E, Wang CJK. Pre-performance physiological State: heart rate variability as a predictor of shooting performance. Appl Psychophysiol Biofeedback. 2018;43(1):75–85.
8. Aydın AS, Arıkan Ş, Revan S. Havalı Tabanca Atıcılarının Somatotip Özelliklerinin incelenmesi. Gaziantep Üniversitesi Spor Bilim Derg. 2019;4(2):222–8.
9. Groslambert A, Candau R, Grappe F, Dugue B, Rouillon JD. Effects of autogenic and imagery training on the shooting performance in biathlon. Res Q Exerc Sport. 2003;74(3):337–41.
10. Konttinen N, Lyytinen H, Viitasalo J. Preparatory heart rate patterns in competitive rifle shooting. J Sports Sci. 1998;16(3):235–42.
11. Maddalena T, Bacot V, Cohen C, Clanet C. Optimal shooting cadence in the laser-run trial of modern pentathlon. Proceedings. 2020;49:46.
12. Wang MQ, Landers DM. Cardiac response and hemispheric differentiation during archery performance-a Psychophysiological investigation of attention. Psychophysiology. 1986;23(4):469.
13. França A, Roudaut C, Bartu J. Start coaching modern pentathlon. First. Spain: Union Internationale de Pentathlon Moderne; 2017. p. 94.
14. Schmitt L, Regnard J, Parmentier AL, Mauny F, Mourot L, Coulmy N, et al. Typology of fatigue by heart rate variability analysis in elite nordic-skiers. Int J Sports Med. 2015;36(12):999–1007.
15. Schmitt L, Regnard J, Desmarets M, Mauny F, Mourot L, Fouillot JP, et al. Fatigue shifts and scatters heart rate variability in elite endurance athletes. PLoS ONE. 2013;8(8):e71588.
16. Borg G. Borg's perceived exertion and pain scales. Champaign, IL: Human Kinetics; 1998.
17. Swart J, Robert Lindsay T, Ian Lambert M, Craig Brown J, David Noakes T. Perceptual cues in the regulation of exercise performance-physical sensations of exercise and awareness of effort interact as separate cues. Br J Sports Med. 2012;46(1):42–8.
18. Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2nd Editio. New York: Routledge; 2013.
19. Cohen J. Statistical power analysis for the behavioral sciences. New York, NY: Routledge Academic; 1988.
20. Dadswell C, Payton C, Holmes P, Burden A. The effect of time constraints and running phases on combined event pistol shooting performance. J Sports Sci. 2016;34(11):1044–50.
21. Goonetilleke RS, Hoffmann ER, Lau WC. Pistol shooting accuracy as dependent on experience, eyes being opened and available viewing time. Appl Ergon. 2009;40(3):500–8.
22. Hall JE, Hall ME. Guyton and hall textbook of medical physiology. 14th ed. Philedelphia, USA: Elsevier Inc.; 2021. p. 82.
23. Helin P, Sihvonen T, Hanninen O. Timing of the triggering action of shooting in relation to the cardiac cycle. Br J Sports Med. 1987;21(1):33–6.
24. Kruse P, Ladefoged J, Nielsen U, Paulev PE, Sorensen JP. Beta-blockade used in precision sports: effect on pistol shooting performance. J Appl Physiol. 1986;61(2):417–20.
25. Lim C, Yoon J, Jeong C, Kim Y. An analysis of the performance determinants of modern pentathlon athletes in laser-run, a newly-combined event in modern pentathlon. Exerc Sci. 2018;27(1):62–70.
26. Sadowska D, Lichota M, Sacewicz T, Krzepota J. Influence of running phases on the postural balance of modern pentathlon athletes in a laser run event. Int J Environ Res Public Health. 2019;16(22):4440.
27. Bao D, Chen Y, Yue H, Zhang J, Hu Y, Zhou J. The relationship between multiscale dynamics in tremulous motion of upper limb when aiming

and aiming performance in different physical load conditions. J Sports Sci. 2019;37(22):2625–30.
28. Meur LY, Dorel S, Baup Y, Guyomarch JP, Roudaut C, Hausswirth C. Physiological demand and pacing strategy during the new combined event in elite pentathletes. Eur J Appl Physiol. 2012;112(7):2583–93.
29. Park J, Lee S, Chun S. Relationship between accuracy, speed, and consistency in a modern pentathlon shooting event. Appl Sci. 2022;12(15):7852.
30. Blanco-García C, Acebes-Sánchez J, Rodriguez-Romo G, Mon-López D. Resilience in sports: sport type, gender, age and sport level differences. Int J Environ Res Public Health. 2021;18(15):8196.
31. Besharat MA, Pourbohlool S. Moderating effects of self-confidence and sport self-efficacy on the relationship between competitive anxiety and sport performance. Psychology. 2011;02(07):760–5.
32. Moreira da Silva F, Malico Sousa P, Pinheiro VB, López-Torres O, Refoyo Roman I, Mon-López D. Which are the most determinant psychological factors in olympic shooting performance? A self-perspective from elite shooters. Int J Environ Res Public Health. 2021;18(9):4637.
33. Gobet F, Campitelli G. The role of domain-specific practice, handedness and starting age in chess. Dev Psychol. 2007;43:159–72.
34. Ward P, Hodges NJ, Starkes JL, Williams MA. The road to excellence: deliberate practice and the development of expertise. High Abil Stud. 2007;18(2):119–53.
35. Brown MJ, Tandy RD, Wulf G, Young JC. The effect of acute exercise on pistol shooting performance of Police officers. Motor Control. 2013;17:273–82.

Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.