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The inverted-U relationship between stress and performance in elite shooting

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This study presents a novel approach to understanding the impact of stress on shooting performance. We utilized the unique qualifying system of shooting competitions, dividing the 60 consecutive shooting results into six sets of 10 shots each. By comparing the differences between these sets, we could examine the influence of stress on performance. Our findings reveal an inverted U-shaped relationship between the athletes' different game stages and shooting performance, with the best performance observed in the middle stage of the game. The game's start (the second set compared to the third set) and end stages (the sixth set compared to the fifth set) are associated with similar performance declines. Based on the assumption that the three different psychological variables stress, arousal, and somatic anxiety will increase with the number of sets, we first provide a sporting example of the nonmonotonic relationship between the three psychological variables mentioned above and performance. To illustrate the inverted-U hypothesis, we reasonably speculate that an athlete achieves optimal performance at an intermediate level of arousal or stress or somatic anxiety. The low and high levels of arousal or stress or somatic anxiety lead to poor performance. These results provide compelling evidence for the inverted-U relationship between arousal, stress, somatic anxiety and performance, underscoring the significance of the inverted-U hypothesis in sports psychology.

Keywords Shooting sport, Inverted-U hypothesis, Stress and performance, Arousal, Anxiety

The relationship between arousal and performance has been a long-standing and intricate psychological issue. In 1908, Yerkes and Dodson were trailblazers in proposing a nonmonotonic relationship between arousal and performance quality[1]. This pioneering concept was further refined by Courts[2], Duffy[3], and Malmo[4], culminating in what we now know as the inverted-U hypothesis. The historical evolution of this idea, spanning over a century, illuminates the connection between arousal and performance and underscores the depth and significance of our current research in the field.

Extensive empirical evidence and multiple theoretical perspectives indicate that elevated levels of stress-related conditions, such as anxiety, arousal, and activation, as well as heightened motivation, might hinder performance. This has been supported by various studies conducted by Anderson[5], Meglino[6], and Zajonc[7]. It is commonly believed that these states have a curvilinear (inverted-U) relationship[8]. This means that initially, increases in stress can improve performance while stress-related states are low. However, there is a point where greater stress starts to hurt performance, especially at high-stress levels.

Inverted-U hypothesis

According to the inverted-U hypothesis, there is an optimal level of arousal at peak performance. As arousal levels increase up to this point, performance also improves, but beyond that, any further increase in arousal leads to a decline in performance quality. This optimal level of arousal is situated in the middle of the arousal spectrum.

Arousal is the level of physiological and psychological activation experienced by a performer[9]. It encompasses both physiological and psychological components. Physiological arousal serves as a robust basis for psychological arousal. Psychological arousal is a subjective sensation and cognitive assessment derived from physiological arousal. Physiological arousal is generally assessed using heart rate, skin conductance, or electroencephalography (EEG). Psychological arousal is generally assessed by inquiring individuals about their degree of enthusiasm, energy, or tension. Furthermore, psychological arousal may manifest as either negative (e.g., anxiety) or positive (e.g., excitement). Anxiety is a negative emotional condition characterized by emotions

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of worry, concern, and apprehension, accompanied by physiological activity or arousal[9]. Anxiety may constitute a negative psychological arousal, representing an emotional response that can be both instigated by arousal and serve to amplify it. Anxiety is not synonymous with arousal; rather, it constitutes a part of arousal.

Somatic anxiety might be referred to as "anxious arousal" , and is marked by immediate vigilance and physical anxiety symptoms like shortness of breath and increased heart rate[10]. Therefore, somatic anxiety characterized by autonomic arousal and negative emotional states like nervousness and tension[11], is not expected to show a linear relationship with performance, and the correlation between them should be near zero. Meta-analyses have consistently supported this[12,13]. A small but significant number of studies have further bolstered the inverted-U hypothesis, finding an inverted U relationship between somatic anxiety and performance in various swimming events[14]. Additionally, the inverted-U hypothesis offers a simple explanation for the relationship between anxiety and performance, which has been supported by empirical evidence. A study of 145 high school basketball players found that their best performances happened when they experienced moderate levels of anxiety[15]. This finding can benefit professionals who train athletes and individuals in high-pressure situations. Maintaining a moderate level of anxiety can lead to optimal performance, trainers can help individuals to channel their anxiety in a positive direction. This can ultimately lead to better results and higher levels of achievement.

Hardy and Fazey[16] introduced the 'catastrophe' model of performance, predicting interactions between cognitive anxiety, physiological arousal, and performance. According to the theory, athletes may experience a sudden and severe drop in performance due to high levels of cognitive anxiety. This anxiety can determine whether increased physiological arousal will have a minor or significant impact on performance. When cognitive anxiety is low, the effect of physiological arousal is also low. However, when cognitive anxiety is high, the effect on performance is significant and abrupt. Hardy et al.[17] examined this hypothesis by manipulating cognitive anxiety levels and physiological arousal in experienced crown green bowlers. However, the Zone of Optimal Functioning theory posits that an athlete achieves peak performance when their somatic anxiety level resides inside an "optimal functioning zone."[18]. Certain athletes may excel with minimal somatic anxiety, while others may achieve optimal performance with moderate or high levels of somatic anxiety. If the athlete's somatic anxiety level deviates from their optimal range, it may adversely impact their performance.

In summary, the inverted-U hypothesis posits that best athletic performance is achieved at moderate degrees of arousal, rather than at peak levels. The Catastrophe Theory posits that an athlete's performance may abruptly and significantly deteriorate if their arousal above a specific threshold.

Testing the inverted-U hypothesis

Various designs have been used to test the inverted-U hypothesis, indicating different conceptions of the same construct. In the initial research conducted by Yerkes and Dodson[1], arousal was manipulated through caffeine intake in rats, while performance was assessed based on their ability to find a reward. Subsequent research involving human subjects has likewise utilized caffeine as a proxy for arousal[19–21], but alternative indicators, including eye movement patterns, have also been utilized[22]. Performance has been evaluated across various domains, including memory recall[23], motor coordination[19], and decision accuracy[24]. Unlike the above studies that used objective measurement of arousal level, the study of the relationship between anxiety and performance used self-report methods to measure anxiety levels. To assess the impact of pre performance anxiety on performance, the CSAI-2[25] and the SAS[26] were administered prior to testing. Some studies have used A-trait as the variable of interest to examine the relationship between individual differences in chronic, dispositional anxiety and performance at pursuit rotor and mirror-tracing tasks[27]. As Klavora[28] indicated, the inverted U-curve concept implies the relationship between immediate anxiety states and performance. Other studies have created experimental situations with low, moderate, and high stress levels; Martens involved junior high school boys in a motor-tracing task at three stress levels[29]. Moderate stress-level subjects performed significantly better than low or high-stress subjects, thus supporting the inverted-U hypothesis[29].

Another consideration is that the psychological aspect is only investigated using questionnaires and recording emotionality. Instead, each subject is often only tested under some stress conditions. In light of these shortcomings, this study investigates shooting performance and its association with game progress in a real competitive setting where shooters at a national and international level compete with each other. Different from the pregame measurement mechanism previously studied, the in-game measurement we introduced provides a new research perspective. The pressure shooters endure before each set is acute stress, which is sudden, unfamiliar, intense, and short-lived. This type of stress disrupts goal-directed behavior and requires an immediate response. Acute stress is best illustrated by emergencies where events unfold rapidly, tasks must be completed quickly, and the consequences of poor performance are immediate. On the other hand, it's important to note that there are situations in which stress can improve performance. For instance, insufficient stress caused by a dull or unchallenging environment, can lead to under-stimulation. A moderate stimulation level is necessary to keep an individual alert and focused. This idea is a variation of the inverted-U hypothesis, which suggests that an optimal stress level is needed for effective functioning.

Purpose of the present study

The present study emphasized a design incorporating repeated performance measurements on the same people through the dynamic game progress of elite shooters in a series of significant competitions. We use the shooting competition's qualifying format (6 sets and 60 shots) to reasonably speculate that the decisiveness of the outcome will gradually increase as the number of sets increases. On this basis, we assume that arousal level or anxiety is related to such decisiveness. We believe that shooters experience the least arousal or anxiety in the first set, and this arousal and anxiety continues to increase as the match progresses until it reaches its highest point in the last set near the end of the match. Stress is the physiological and psychological response resulting from circumstances or events that are difficult to control or endure[30]. Ivancevich and Matteson[31] propose that stress and demands are fundamentally equivalent: "Individuals seem to perform best under conditions of moderate demand (also known as stress)." From this perspective, stress must be treated as the absolute demand level ranging from none to great.

In the qualifying rounds, the average score for the 10 m air rifle shooters was 10.4 (out of 10.9), and the average score for the 10 m air pistol shooters was 9.2 (out of 10). The level of the shooters was so close that the uncertainty of the competition ran through the entire process, and only after completing 6 rounds of 60 shots could the 8 finalists be decided. Considering the extreme situation of missing the target (Matthew Emmons missed a gold medal in the 50-m three-position rifle shooting event at the 2004 Olympic Games in Athens as he shot at the wrong target), the shooter cannot guarantee that s(he) will qualify for the finals even before the last shot. In this way, we define the most decisive set of a competition as the set that has most influence in the eventual victory in the tournament. As the game progresses, the shooter's room for error continues to decrease. For example, if a shooter performs poorly in the first set, s(he) can still make up for it in the next five sets, but if s(he) performs poorly in the last set, s(he) cannot make up for it, and it may even lead to her(his) elimination. So the last set has most influence in the eventual victory in the tournament. In this study, we believe that as the number of sets increases, its decisiveness on the final outcome of the game also increases accordingly, which intensifies the demand for shooters to perform well. We assume that set number can be an objective, non-self-reported stress measure.

Methods

Shooting sports require precision as a non-confrontational sport, which means elite shooters must be able to maintain a stable body posture. Shooters use relaxation techniques to lower their heartbeat to hit the targets as accurately and as close to the center (the bullseye) as possible. This provides a good sample for us to study athlete psychology. As the data used in this study were obtained from publicly available online sources, an ethical review was not required.

Samples

Comprehensive shot-by-shot data for all shooters who participated in the major competitions (the Olympic Games, ISSF World Shooting Championships, ISSF World Cup series, ISSF Grand Prix competition, Asian Cup, and XIII CAT Championship) from 2018 to 2023 were obtained from the International Shooting Sports Federation (ISSF) Database. This yielded a total of 319,910 (179,040 for rifle, 140,870 for pistol) individual observations for 1997 shooters (1053 for rifle, 944 for pistol). Among the 1,053 10 m air rifle shooters, 474 were male and 579 were female, of which 815 were adults and 324 were youths. 86 shooters participated twice, both as youths and adults. Among the 944 10 m air pistol shooters, 492 were male and 452 were female, of which 735 were adults and 285 were youths. 76 shooters participated twice, both as youths and adults.

The 10-m Air Rifle (individual—men and women) is an International Shooting Sport Federation (ISSF) event where shooters shoot from a distance of 10 m while standing. The competition consists of two stages: qualification and final. During the qualification round, shooters have 1 h and 15 min to fire 60 shots. The top eight shooters advance to the final. The target has a total diameter of 45.5 mm with the tenth ring measuring 0.5 mm (Fig. 1). The maximum score per shot is 10.9 points due to an additional set of 10 rings within the tenth circle that increase the score by 0.1 points as it approaches the center. In 2018, the ISSF expanded women's qualification phase from 40 to 60 shots, with the highest possible score being 654.0 points.

The 10-m air pistol is an Olympic shooting event governed by the International Shooting Sport Federation (ISSF). It is similar to the 10-m air rifle in that it is shot with 4.5 mm caliber air guns at a distance of 10 m. The match consists of a qualification round of 60 competition shots within 75 min (Fig. 1). The maximum score per shot in the qualification round is 10 points.

Variables

Dependent Variable: The dependent variable, Point, records the total score of 10 shots per set.

Independent Variables: Set. The set is separated into six categories: "1st set" (the reference category), "2nd set," "3rd set," "4th set," "5th set," and "6th set."

Control Variables: Tournament. The tournament types are divided into five categories: the Olympic Games (Olympic), the ISSF World Shooting Championships (Championship), the ISSF World Cup series (World Cup), the Asian Cup and XIII CAT Championship (others), and the ISSF Grand Prix competition (Grand Prix).

Type: Type is a dummy variable; 0 represents adult players, and 1 represents junior players.

Gender: Gender is a dummy variable equal to zero if the athlete is a woman and one if a man.

Year: Year is a continuous variable that records the year the competition was held.

Model specification

During the qualification phase, the course of fire was 60 competition shots for both women and men. The top eight female or male shooters from the qualification round moved on to a finals event. That means the performance measurement was taken repeatedly over time on the same individuals. Observations from an individual tend to be correlated, and the correlation must be considered for valid inference. The generalized estimating equations (GEE) method is often used to analyze longitudinal and other correlated response data. GEE is a statistical method for analyzing time series data involving measurements at different points in time. It models the temporal correlation between observations. The quasilikelihood under the independence model criterion (QIC) can be used to select an appropriate working correlation structure in GEE[32]. The QIC is calculated for different candidate working correlation structures and then picks the "exchangeable-within-subject observations are equally correlated" with the smallest QIC (Model rifle: [autoregressive correlation structure: 60,596.7; exchangeable-within-subject observations are equally correlated: 60,585.3; unstructured-

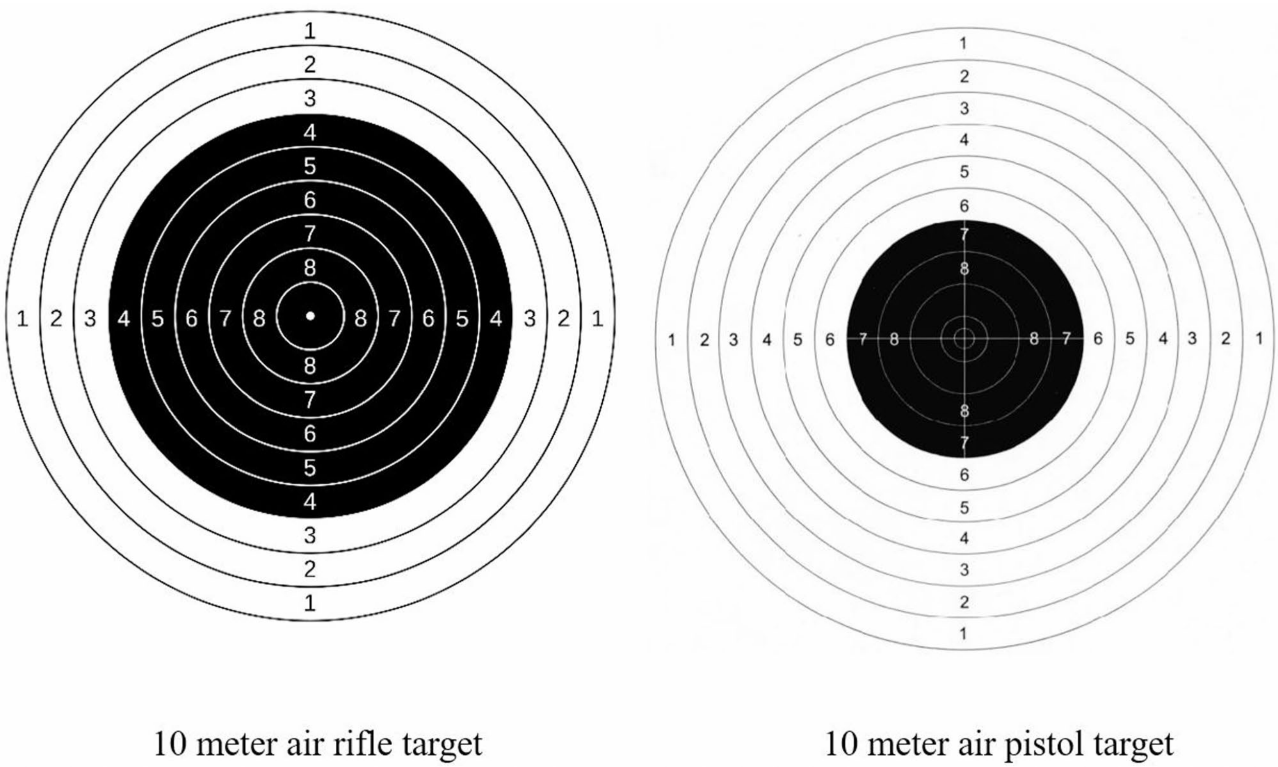

Fig. 1. Target for air rifle and pistol at 10 m shooting range.

free estimation on the within-subject correlation: 60,585.5]; Model pistol: [autoregressive correlation structure: 123,936.5; exchangeable-within-subject observations are equally correlated: 123,928.7; unstructured-free estimation on the within-subject correlation: 123,929.4]).

The model was specified as follows:

$$Y_{ij} = \beta_0 + \beta_1 Set_{ij} + \beta_2 Gender_{ij} + \beta_3 Tournament_{ij} + \beta_4 Type_{ij} + \beta_5 Year_{ij} + \varepsilon_{ij}$$

Y_{ij} represents the total scores for each shooter, *i*, measured at different sets ($j = 1, 2, \ldots, 6$). β_0 is the intercept. β_1 is the regression coefficient for the set variable.ε_{ij} is gaussian random noise.

In all GEE analyses in this paper, means were separated by pairwise comparison with the multcomp package[33]. Statistical analyses were performed using R Statistical Software (v4.3.3; R Core Team 2024). All models were estimated using the "geepack" package[34].

Results

Rifle

Summary statistics are shown in Table 1. The set variable significantly affects the set 1 group against all other groups. The shooter's score in the first set is considerably lower than in the different sets, controlling for other variables (all $p < 0.0001$; Table 2). For set 1 compared to set 5, the estimated coefficient is 0.336, indicating the average score in the fifth set is 0.336 points higher than that in the first set, controlling for other variables ($\beta = 0.336$ [95% CI: 0.278–0.393], $p < 0.0001$, Table 2).

Shooting performance exhibits an inverted-U relationship with set number: shooting performance increases from the second to the fifth set but decreases, moving further down in the final set (Fig. 2A). In the final set, the shooting scores are not significantly different from those in the second set. The shooting performance in the second and sixth sets is markedly lower than in the third, fourth, and fifth sets (Fig. 2B).

Pistol

Summary statistics are shown in Table 3. As can be seen from Fig. 3. A, the shooting performance showed a clear upward trend from the first to the fourth round. From the fifth to the sixth round, the performance continued to decline. It is apparent from this picture that the average scores from the first to the sixth set form an inverted U-shaped curve. Further analysis showed that the average scores of the fourth and fifth sets were significantly higher than those of the first and second sets ($p < 0.0001$, Table 4, Fig. 3B). The average score of the last set is significantly lower than that of the fourth set but substantially higher than that of the first set.

Variable	Name	Type	Classification	Mean	Median	Std	Min	Max
Dependent variable	Point	Continuous	Shooter's points on their shooting	103.590	103.9	1.468	47.3	107.3
Independent variable	Set	Categorical	Set 1(n = 2984)	103.357	103.7	1.951	66.9	106.9
			Set 2(n = 2984)	103.546	103.9	1.920	70	106.9
			Set 3(n = 2984)	103.667	104	1.789	72.7	107.2
			Set 4(n = 2984)	103.682	104	1.807	71.7	107.3
			Set 5(n = 2984)	103.693	104	1.79	63.4	107.1
			Set 6(n = 2984)	103.594	103.9	1.941	47.3	107.2
	Gender	Dummy	0 = Male(n = 7908)	103.529	103.9	2.068	47.3	107.1
			1 = Female(n = 9996)	103.638	103.9	1.698	79.6	107.3
	Tournament	Categorical	Grand Prix(n = 2850)	103.869	104	1.327	94.8	106.6
			Olympic(n = 576)	103.952	104.2	1.301	97.5	106.7
			Championship(n = 3732)	103.463	103.8	2.366	47.3	106.9
			World Cup(n = 9840)	103.622	103.9	1.756	79.6	107.3
			Others(n = 906)	102.651	102.9	2.183	85	106.9
	Type	Dummy	0 = Adult(n = 15,162)	103.661	104	1.835	47.3	107.3
			1 = Junior(n = 2742)	103.194	103.6	2.016	89.5	106.8
	Year	Continuous	2018(n = 1338)	103.398	103.6	1.547	93.9	106.7
			2021(n = 576)	103.952	104.2	1.301	97.5	106.7
			2022(n = 7914)	103.463	103.8	2.168	47.3	107.2
			2023(n = 8076)	103.719	104	1.610	89.5	107.3

Table 1. Definition and descriptive statistics of dependent and independent variables for rifle ($N = 17{,}904$).

Parameters	β (95% CI)	Stand Error	Wald
Intercept	− 119.131(− 238.553, 0.292)	60.927	3.823
Set: Set 1#			
Set: Set 2	0.188(0.131,0.246)	0.029	41.014***
Set: Set 3	0.31(0.252,0.367)	0.029	112.19***
Set: Set 4	0.325(0.267,0.382)	0.029	122.441***
Set: Set 5	0.336(0.278,0.393)	0.029	130.505***
Set: Set 6	0.237(0.176,0.298)	0.031	57.812***
Gender (Male vs Female)	− 0.104(− 0.217,0.009)	0.058	3.236
Tournament: Grand Prix#			
Tournament: Olympic	0.256(0.035, 0.478)	0.113	5.151*
Tournament: Others	− 1.18(− 1.485, − 0.875)	0.156	57.579***
Tournament: Championship	− 0.07(− 0.34, 0.2)	0.138	0.26
Tournament: World Cup	− 0.144(− 0.254, − 0.035)	0.056	6.633*
Type (Junior vs Adult)	− 0.579(− 0.77, − 0.388)	0.097	35.403***
Year	0.11(0.051, 0.169)	0.03	13.377***
Pseudo-R^2	0.035		

Table 2. Significant Parameters from the GEE Analysis for rifle ($N = 17{,}904$). ***, **, and * denote statistical significance at the 0.1%, 1%, and 5% levels, respectively. β denotes estimated coefficients. # denotes Reference categories.

Discussion

In the current study, the shooter's lowest score on each set was first, the middle score was second and sixth, and higher scores were observed in the middle sets (i.e. third, fourth, and fifth). This showed a curvilinear trend between the game set and performance, similar to the inverted U. This finding is consistent with earlier observations, which showed a curvilinear relationship between somatic anxiety and performance[14,35,36]. A possible explanation for this might be that the somatic anxiety of athletes continues to increase as the competition continues. Such anxiety in the first set was the lowest, the somatic anxiety in the second set increased but was still low, and the last set was the most stressful. Somatic anxiety could be moderate in the middle three sets.

Somatic anxiety is the term used to describe an individual's personal experience of the physiological and emotional aspects of anxiety. This includes signs of autonomic arousal and negative emotional states such as anxiousness and tension (emotional aspects)[11]. In aiming sports such as biathlon shooting[37] and skeet shooting[38],

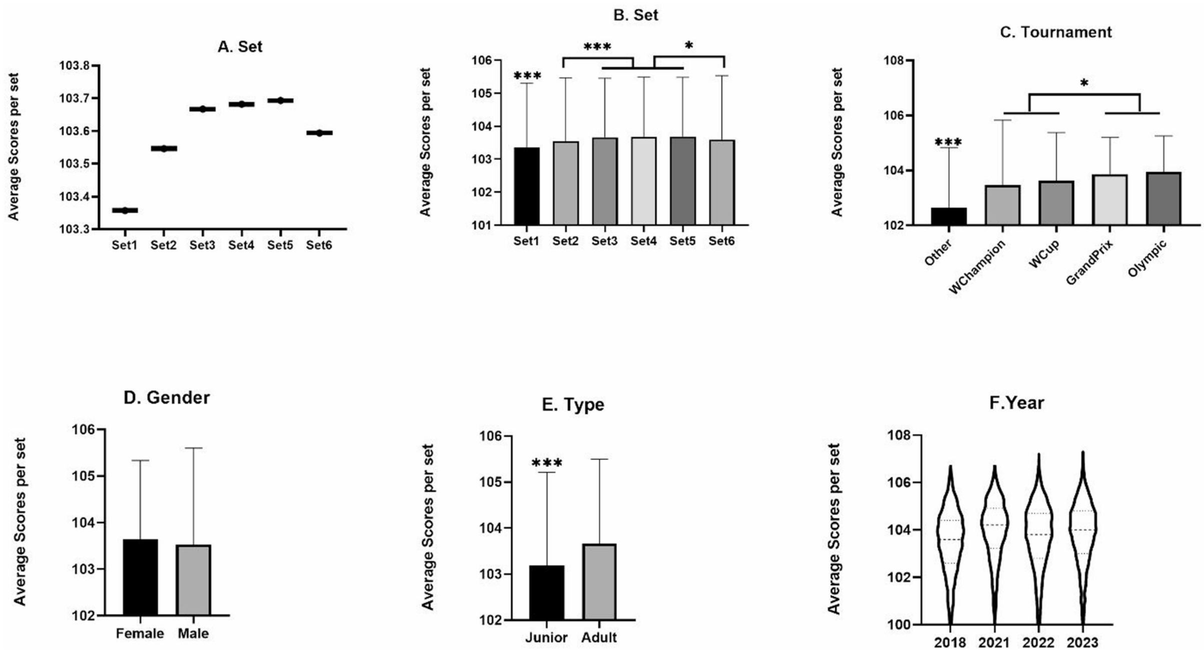

Fig. 2. Graphical plots for rifle. (**A**) The scores per set versus Set. (**B**) he scores per set versus Set(statistics). (**C**) The scores per set versus Tournament. (**D**) The scores per set versus Gender. (E) The scores per set versus Type. (**F**) The scores per set versus Year.

Variable	Name	Type	Classification	Mean	Median	Std	Min	Max
Dependent variable	Point	Continuous	player's points on their shooting	94.19	95	3.073	0	100
Independent variable	Set	Categorical	Set 1(n = 2348)	93.92	94.00	3.002	67	100
			Set 2(n = 2348)	94.07	94.00	3.020	56	100
			Set 3(n = 2348)	94.30	95.00	2.806	73	100
			Set 4(n = 2348)	94.39	95.00	2.890	56	100
			Set 5(n = 2348)	94.33	95.00	3.073	48	100
			Set 6(n = 2348)	94.15	95.00	3.568	0	100
	Gender	Dummy	0 = Male(n = 7206)	94.67	95.00	2.720	64	100
			1 = Female(n = 6882)	93.70	94.00	3.333	0	100
	Tournament	Categorical	Grand Prix(n = 1830)	94.27	94.00	2.494	84	100
			Olympic(n = 528)	95.03	95.00	2.297	87	100
			Championship(n = 3378)	94.32	95.00	2.847	73	100
			World Cup(n = 7626)	94.14	95.00	3.282	0	100
			Others(n = 726)	93.43	94.00	3.430	77	100
	Type	Dummy	0 = Adult(n = 11,754)	94.44	95.00	2.997	0	100
			1 = Junior(n = 2334)	92.95	93.00	3.152	74	100
	Year	Continuous	2018(n = 1272)	94.59	95.00	2.540	73	100
			2021(n = 528)	95.03	95.00	2.297	87	100
			2022(n = 6240)	94.06	94.00	3.267	46	100
			2023(n = 6048)	94.17	95.00	3.010	0	100

Table 3. Definition and descriptive statistics of dependent and independent variables for pistol (N = 14,088).

anxiety can reduce the time an individual spends focusing on their target, which can ultimately lower their performance.

On the other hand, these results further support the inverted-U hypothesis[1]. The Inverted U Hypothesis in sports suggests that an athlete's low or nonexistent arousal will result in a low-performance level. For instance, a low arousal level at the first set would result in poor performance. As an athlete's arousal level increases, performance will progressively improve until it reaches its peak. Similarly, shooting scores experienced an upward trend from the second to the fifth set. The inverted-U hypothesis suggests that performance will decrease gradually if arousal continues to increase after the optimum point, also known as the peak performance point.

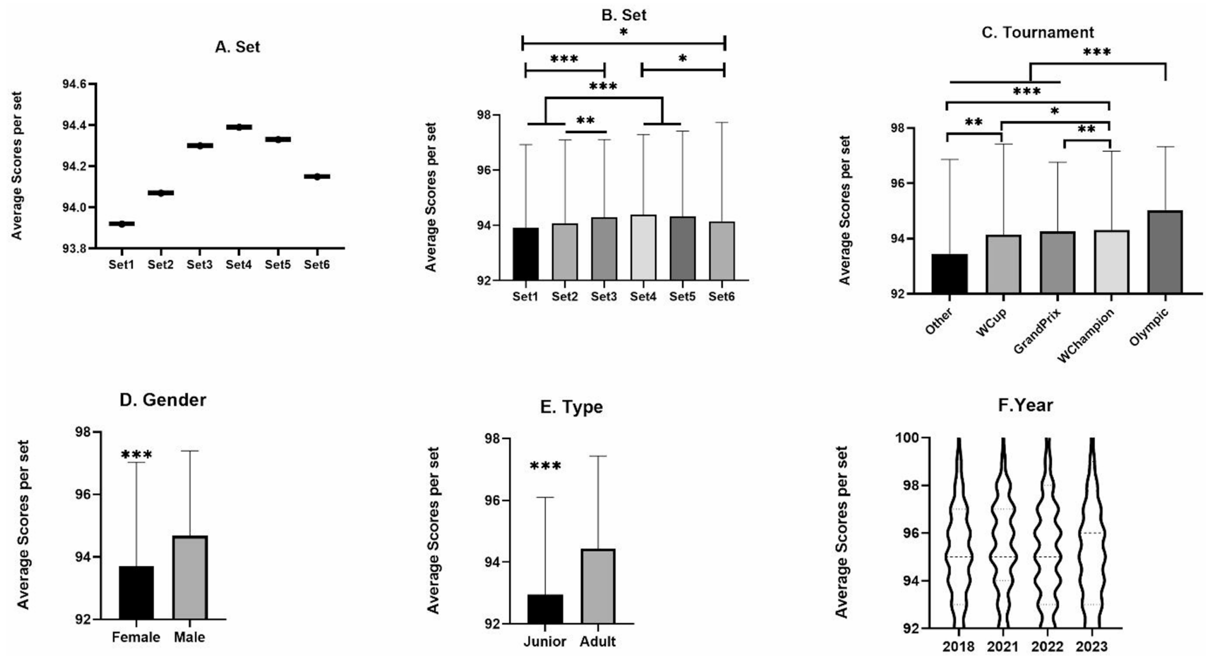

Fig. 3. Graphical plots for pistol. (**A**) The scores per set versus Set. (**B**) The scores per set versus Set(statistics). (**C**) The scores per set versus Tournament. (**D**) The scores per set versus Gender. (**E**) The scores per set versus Type. (**F**) The scores per set versus Year.

Parameters	β (95% CI)	Stand Error	Wald
Intercept	− 91.221(− 236.016,53.573)	73.87	1.525
Set: Set 1#			
Set: Set 2	0.155(0.035,0.275)	0.061	6.425*
Set: Set 3	0.38(0.258,0.502)	0.062	37.419***
Set: Set 4	0.472(0.351,0.593)	0.062	58.646***
Set: Set 5	0.417(0.292,0.542)	0.064	42.897***
Set: Set 6	0.239(0.092,0.386)	0.075	10.182**
Gender (Male vs Female)	0.956(0.781,1.132)	0.09	113.792***
Tournament: Grand Prix#			
Tournament: Olympic	1.012(0.649,1.375)	0.185	29.901***
Tournament: Others	− 0.658(− 1.168, − 0.148)	0.26	6.395*
Tournament: Championship	0.596(0.292,0.9)	0.155	14.745***
Tournament: World Cup	0.211(− 0.02, 0.442)	0.118	3.197
Type (Junior vs Adult)	− 1.659(− 1.91, − 1.407)	0.128	166.843***
Year	0.091(0.02,0.163)	0.037	6.253*
Pseudo-R^2	0.069		

Table 4. Significant Parameters from the GEE Analysis for pistol (N = 14,088). Notes: ***, **, and * denote statistical significance at the 0.1%, 1%, and 5% levels, respectively. β denotes estimated coefficients. # denotes Reference categories.

This also accords with our earlier observations, which showed that the results in the last set were obviously worse than those in the third, fourth, and fifth sets. Our findings support the inverted U relationship between arousal and performance, as predicted by Arent and Landers[39]. At the start of the game, a low arousal level may result in slower reaction times or reduced concentration levels. Alternatively, too much arousal could lead to a decline in aiming ability due to quicker reflexes and movements[39,40]. This could reduce the time available for gathering target-specific information and may introduce a trade-off between the speed and precision of the task.

It should be mentioned that prior studies have noted the multi-dimension of arousal[41], and arousal can be divided into physiological reactivity, affect (feelings), and cognitions (thoughts). As mentioned in the literature, there is no solid theoretical foundation for establishing a connection between cognitive anxiety and physiological arousal[42]. Several reports suggest that performance is related to somatic anxiety but not cognitive anxiety or self-confidence in a curvilinear manner (inverted-U). Thus, we suggest an inverted U relation between physiological arousal and performance.

Stress is a dynamic condition in which an individual is confronted with an opportunity for having what (s)he desires and for which the resolution of is perceived to have uncertainty but which will lead to important outcomes. We assume the demand for shooters to perform well is further heightened by the fact that the decisiveness of the final outcome of the game increases as the number of sets increases. So the different set number is assumed to measure stress. On this basis, we can reasonably infer that there is inverted-U stress-performance relationship. Consistent with the previous studies[5,43,44], our finding suggests that some stress is necessary to motivate optimal job performance. Graphically, this optimal stress level is depicted by the center of the inverted-U curve where stress, along the X axis, is moderate, and performance, along the Y axis, is at its peak.

The current investigation found that the average score from the second to the sixth set forms an asymmetric inverted U-shaped curve. In accordance with the present results, previous studies have demonstrated that the commonly accepted symmetric shape of the inverted-U curve is inaccurate[45]. In rifle, the average shooting score of the set experienced a statistically significant decrease from the fifth to the sixth set. Performance declines abruptly rather than gradually. However, the decline was far less dramatic than the catastrophe model predicted[46], because the average shooting score of the sixth set (103.594) is better than that of the second set (103.546) and is approximately equal to the mean scores per set (103.590). The results for the pistol were similar to those for the rifle, with one difference being that the sixth set score was not significantly lower than the fifth set score, but the sixth set score was significantly lower than the fourth set score. Thus, athletes make ironic performance errors when told not to do specific actions not because of physical, physiological, or technical limitations, but because they are unable to effectively regulate unwanted thoughts, especially when their attentional resources are under cognitive strain[47]. The above findings confirmed for the first time that the inverted U shape is realistic for a competitive sports situation.

Limitations and practical implications

One major weakness of this study was the absence of specific physiological measures such as a stethoscope measurement of heart rate or Palmar Sweat Index, or a global paper–pencil measure of arousal such as STAI or SCAT. As the study lacked a direct measure of physiological stress or psychological arousal, this may be the reason why the study did not find arousal as a modulating factor that affects shooting performance. Based on the study's methods, developing biofeedback or other cognitive-behavioral strategies could be difficult. And we assumed that set number is a valid measure of stress or arousal in the present study. Such assumption that stress or arousal will increase as the game progresses is entirely reasonable speculation without any objective measurement to verify it.

However, we investigate how decisiveness affects and inferred stress or arousal response has certain practical significance. This implies that it is essential to maintain an optimal level of arousal or stress to achieve peak performance and avoid the adverse effects of both low and high arousal or stress. Understanding the reasons behind performance declines is a crucial and fascinating research area for academics and practitioners. These findings could impact the training of professionals such as police, military personnel, astronauts, divers, bomb disposal experts, and athletes.

Conclusion

For a long time, researchers have implicitly assumed that the relationships between stress and performance are nonlinear. This assumption has been challenged conceptually and empirically, but results to date have been inconclusive. The current research based on two independent shooting tasks provided credible evidence for the curvilinear relationships between various phases of the contest and shooting performance dimensions such that maximal shooting performance was observed at middle sets in shooting competitions. Overall, current findings have important theoretical and practical implications. Theoretically, the findings help clarify the relationships between stress and performance. As such, this contributes to the broader understanding of stress in determining behaviors.

Supplement

In rifle, the magnitude of the tournament's impact is significant (Table 2). Regarding shooters' average scores per set, the Olympic Games are significantly higher than the Grand Prix games ($\beta = 0.256$ [95% CI: 0.035–0.478], $p = 0.023$). Shooters' performance in the Olympics and Grand Prix is considerably better than in the World Cup and World Championship games (Fig. 2C). There is also a significant type effect for youth shooters, showing they perform significantly worse than adult shooters ($\beta = -0.579$ [95% CI: −0.77–-0.388], $p < 0.0001$, Fig. 2E). And a significant Year effect indicates a year-to-year incremental trend in average shooting scores in recent years ($\beta = 0.11$ [95% CI: 0.051–0.169], $p < 0.0001$, Fig. 2F). Finally, there is no significant effect for the gender variable ($\beta = -0.104$ [95% CI: −0.217–0.009], $p = 0.07$, Fig. 2D).

In pistol, the results indicate significant differences between the different types of tournaments. The average scores per set of qualification rounds in the Olympics games (95.03 ± 2.30) were considerably higher ($p < 0.0001$) than that of the World Cup games (94.14 ± 3.28), GrandPrix games (94.27 ± 2.49) and other games (93.43 ± 3.43). And in Fig. 3C, the corresponding shooting performance in the World Championships is also significantly higher than in World Cup games ($p < 0.01$), Grand Prix games ($p < 0.05$), and other games ($p < 0.0001$).

The p-value for the comparison between the male and female groups of shooters is less than 0.0001 (Table 4), indicating that the male shooters' pistol shooting performance is significantly higher compared to the shooting performance of females (Fig. 3D). Furthermore, there is also a significant type effect for youth shooters, showing they perform significantly worse than adult shooters ($\beta = -1.659$ [95% CI: −1.91 − −1.407], $p < 0.0001$, Fig. 3E).

Finally, a significant Year effect indicates a year-to-year incremental trend in average shooting scores in recent years ($\beta = 0.091$ [95% CI: 0.02–0.163], $p = 0.012$, Fig. 3F).

Data availability

All data are available at https://osf.io/gswkq/?view_only=6e1e9688af854b698fc309bc01f9349b.

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Declarations

Competing interests

The authors declare no competing interests.

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