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Article

Upper Limb Strength Balance and Shooting Performance in Elite Air Pistol Athletes

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Abstract

Background: Upper limb strength characteristics are considered important determinants of shooting stability in precision sports; however, the specific relationships between upper limb strength variables and shooting performance in elite air pistol athletes remain insufficiently understood. Therefore, this study aimed to investigate the associations between upper limb specific strength characteristics and shooting performance in elite air pistol shooters. **Methods:** A prospective observational cohort study was conducted using a purposive total population sample from an elite training camp. Isometric peak force and rate of force development of nine upper limb muscle actions, including handgrip, elbow flexion and extension, and shoulder joint movements, were assessed using a Vald Dynamo handheld dynamometer. Official scores from an international selection competition were used as indicators of shooting performance. Ridge regression analysis was applied to examine the relationships between strength variables and shooting performance while addressing multicollinearity among predictors. **Results:** Twenty four elite air pistol athletes at national master level or above were recruited. Shooting performance demonstrated significant positive associations with handgrip peak force, handgrip rate of force development, elbow flexion peak force, elbow extension peak force, shoulder abduction peak force, shoulder internal rotation peak force, and elbow extension rate of force development. Significant negative associations were observed between shooting performance and shoulder flexion peak force, shoulder adduction peak force, shoulder external rotation peak force, shoulder extension rate of force development, shoulder adduction rate of force development, and shoulder internal rotation rate of force development. **Conclusions:** These findings indicate that a coordinated balance of upper limb specific strength is a key factor influencing shooting performance in elite air pistol athletes. Appropriate development of task specific muscle strength may enhance gun holding stability and trigger control, whereas excessive activation of antagonistic muscle groups may adversely affect shooting accuracy.

Keywords: air pistol; shooting athletes; shooting performance

1. Introduction

Precision pistol shooting is one of the most technically demanding Olympic sports, requiring athletes to maintain exceptional postural control, fine motor stability, and psychological regulation while executing movements within extremely narrow margins of error [1,2]. Performance depends

on the ability to stabilise the pistol, minimise involuntary movement, and coordinate neuromuscular and perceptual processes during the aiming and triggering phases [3]. Because of these constraints, even small variations in upper-limb strength, motor control, or fatigue can meaningfully influence shot dispersion and competitive outcomes [4,5].

China has been particularly successful in Olympic shooting, and since 1984 the national team has frequently secured the first gold medal of the Games. Across eleven Olympic appearances, Chinese shooters have won the first gold medal on eight occasions, including five times as the first gold medal of the entire Olympics. At the 2024 Paris Games, the team achieved its best historical performance with five gold, two silver, and three bronze medals. Olympic shooting awards fifteen gold medals across rifle, pistol, and shotgun disciplines, with five events in each category [6]. Traditional perspectives have regarded psychological stability and technical proficiency as the primary determinants of shooting performance. Consequently, a substantial body of research on pistol shooting has focused on psychological and technical factors. Psychological studies have examined the effects of emotional arousal, attentional regulation, electroencephalographic activity, and central fatigue on shooting stability and performance. Neurophysiological evidence suggests that elite shooters demonstrate superior attentional control and reduced cortical noise during aiming and triggering phases compared with lower level performers, highlighting the importance of neural efficiency and behavioral regulation in precision sports [7,8].

Technical analyses of air pistol shooting have shown that the shooting process consists of multiple phases, including pistol raising, preliminary aiming, fine aiming, holding, triggering, and recovery. Key technical variables such as aiming duration, pistol holding stability, aiming accuracy, trigger stability, and trigger time have been reported to explain approximately seventy five to eighty percent of the variance in shooting performance [9,10]. In rifle shooting, the presence of a longer aiming baseline and additional stability provided by shooting suits reduces the physical demands placed on the upper limb. As a result, no significant sex differences have been observed in rifle shooting performance or aiming technique [11]. In contrast, Olympic pistol shooting rules require athletes to shoot in a standing position without any external support while holding the pistol with one hand.

During competition, air pistol athletes are required to aim at a target with a diameter of 11.5 millimeters from a distance of 10 meters, corresponding to an angular error tolerance of approximately 0.09 degrees according to International Shooting Sport Federation regulations. Under such highly constrained conditions, sufficient upper limb specific strength is required to stabilize the pistol and reduce lateral movement, thereby improving shooting accuracy [4]. Unlike rifle shooting, pistol shooting lacks the stabilizing assistance of shooting suits and does not benefit from a large target area as in shotgun events. The single handed shooting posture places substantial physical demands on the upper limb of the shooting side.

Several studies have indicated that pistol shooters may enhance shooting performance through scientifically designed physical training programs that improve muscular strength and control during the shooting task [12]. Moreover, multiple investigations have reported significant associations between pistol shooting performance and upper limb strength variables, particularly handgrip strength and arm strength [1,13]. However, pistol shooting requires the coordinated involvement of multiple upper limb muscle groups during pistol holding and triggering. Previous studies have primarily focused on agonist muscles such as the forearm flexors and shoulder abductors, while largely neglecting the role of antagonistic and stabilizing muscles around the upper limb joints.

In summary, existing research on upper limb strength in pistol shooters has typically examined a limited number of muscle groups and has not comprehensively accounted for the major agonist and antagonist muscles involved in the shooting action. Therefore, the purpose of the present study was to analyze the influence of upper limb specific strength on competitive performance in elite Chinese air pistol athletes. The findings may provide a theoretical basis for the design of targeted

physical training programs and contribute to the scientific development of strength training strategies for pistol shooters.

2. Materials and Methods

Study Design

A prospective observational cohort study was undertaken for a period of four weeks in February 2025, Ningbo, China. Ethical approval was obtained from the Ethics Committee of Beijing Sport University (ref: 2025125H). The methods are reported according to the STROBE checklist for cohort studies.

Data collection occurred during a scheduled national air pistol shooting training camp. Upper limb specific strength assessments were performed over two consecutive days in the second week of the camp, using the strength and conditioning laboratory at the Ningbo training facility. Shooting performance data were derived from official results of the 2025 international selection competition, which took place one week after the strength assessments at the Guangxi Santang Sports Training Base, Nanning, China.

Setting

The study was conducted within the context of a four-week national training camp for elite air pistol athletes, held in Ningbo, China. The camp provided a controlled, high-level training environment with standardised daily schedules, coaching, nutrition, and recovery protocols for all participants.

Participant recruitment occurred during the first week of the camp, with eligible athletes approached during routine team meeting. Strength testing took place in a dedicated laboratory setting within the camp facility, under consistent environmental conditions (temperature-controlled room, standardised equipment setup). There was no defined exposure period, as the study was observational and examined naturally occurring upper limb strength characteristics in elite athletes.

Shooting performance data were collected under official competition conditions at the Guangxi Santang Sports Training Base one week following the strength assessments. The competition utilised a SIUS laser electronic scoring system in a regulated indoor shooting range, ensuring identical environmental and procedural conditions for all participants.

Participants

Participants were eligible for inclusion if they were enrolled in the 2025 national air pistol shooting training camp, which comprised elite athletes, including those selected for the Olympic team. There were no restrictions based on age or gender. Individuals were excluded if they had sustained a recent injury or were currently undergoing rehabilitation. A total of 24 elite air pistol athletes (14 males and 10 females) were recruited and completed the study, with no attrition or post-recruitment exclusions. The participant flow is illustrated in Figure 1. All participants held national master or international master qualifications, representing the highest competitive level in the discipline. Demographic and training characteristics are summarised in Table 1.

Table 1. Basic Information of Research Subjects.

Participants	n	Age (year)	Height (cm)	Training experience (year)
Male athletes	14	23.7±3.5	177.9±3.6	10.3±3.3
Female athletes	10	21.6±2.3	163.7±5.1	10.0±2.5

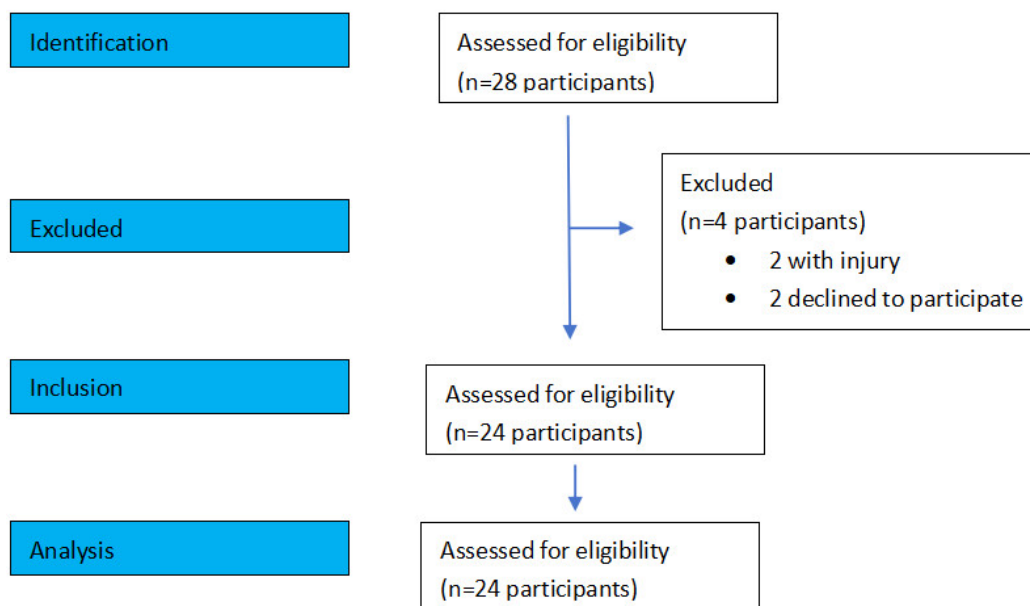


Figure 1. A Strobe flow diagram illustrating recruitment.

Testing Procedures

The testing protocol consisted of two components, including upper limb specific strength assessment and specialized shooting performance assessment using a laser electronic target system.

Upper Limb Specific Strength Assessment

Upper limb specific strength was assessed using a Vald Dynamo handheld dynamometer. The device is equipped with a nine axis inertial measurement unit accelerometer and operates at a sampling frequency of 1000 Hz.

Based on the functional demands of air pistol shooting, nine upper limb muscle actions relevant to shooting performance were selected for testing. These included handgrip strength, elbow flexion and extension, shoulder flexion and extension, shoulder abduction and adduction, and shoulder internal and external rotation. For each muscle action, isometric peak force and rate of force development were measured.

Each muscle action was tested three times, and the highest value was recorded for subsequent analysis. A rest interval of two minutes was provided between tests of different muscle groups to minimize fatigue effects. All strength assessments were performed while athletes maintained a shooting specific support posture in order to simulate postural control conditions during actual shooting. The testing equipment and testing postures are illustrated in Figure 2.



Figure 2. Vald Dynamo Handheld Force Measuring Sensor.

Specialized Shooting Performance Assessment Using a Laser Electronic Target

Shooting performance data were obtained from the 2025 international competition selection event. The competition was held at the Guangxi Santang Sports Training Base in China, and the shooting competition took place one week after the completion of the upper limb specific strength assessments. A SIUS laser electronic target system manufactured in Switzerland was used during the competition, as shown in Figure 3.

Competition results were used as analytical data because all athletes competed under identical testing conditions, including the same shooting range and environmental settings. In addition, competition settings are more likely to elicit maximal competitive motivation from athletes compared with simulated testing conditions, thereby providing a more accurate reflection of athletes' true competitive performance.



Figure 3. SIUS Laser Electronic Target.

Sampling and sample size

A total population purposive sampling approach was undertaken.

Attempts to reduce bias

Several considerations were made to reduce bias this included using a standardized training schedule, outside of a competitive time with coaching and support staff who had been with athletes across a consistent period of time. No identified outbreaks of illness or environmental distribution (closing of shooting) range were identified. Scoring systems technology and environmental conditions were kept consistent across the study and all coaches were provided with the same standard of training.

Statistical Analysis

All statistical analyses were performed using SPSS AU software (version 25.0, China). Data were initially screened for outliers and distribution characteristics. Descriptive statistics are reported as mean \pm standard deviation (SD). There were no missing data, as all 24 participants completed both the strength assessments and the competition from which shooting performance scores were derived; thus, no imputation or exclusion procedures were required. To examine bivariate relationships between individual strength variables and shooting performance, Pearson product-moment correlation coefficients were calculated. Multicollinearity among the 18 predictor variables (9 peak force and 9 rate of force development measures) was assessed using variance inflation factors (VIF) and condition indices. VIF values exceeding 10 and condition indices >30 in the ordinary least squares (OLS) regression model indicated substantial multicollinearity, confirming the need for a biased estimation approach.

Ridge regression was therefore employed to stabilise coefficient estimates and address multicollinearity while retaining all predictors in the model. The ridge parameter (k) was determined by examining the ridge trace plot and selecting the smallest value at which coefficients stabilised and

VIF values fell below 10 ($k = 0.02$). To evaluate the robustness of this choice, a sensitivity analysis was conducted by testing a range of k values (0.01–0.10 in increments of 0.01). Results showed minimal changes in the direction and relative magnitude of significant coefficients across this range, supporting the stability of the selected model.

When multicollinearity was identified among peak force and rate of force development variables, ridge regression analysis was applied to further examine the relationships between upper limb specific strength variables and shooting performance. To comprehensively examine the relationships between upper limb specific strength variables and shooting performance, male and female athletes were analyzed as a single group rather than being separated by sex. Above approach ensured a robust examination of the relationships between upper limb strength characteristics and shooting performance while appropriately handling the inherent multicollinearity in the dataset.

3. Results

Model Validation Results

Descriptive statistics for the upper limb specific strength variables are presented in Table 2. Ordinary least squares multiple linear regression analysis was first conducted using these variables, and the regression results are shown in Table 3. The adjusted R squared value of the model was 0.868, and the F test value was 10.251. The overall regression model was highly significant with a p value of less than 0.001, indicating good model fit.

Table 2. Descriptive Statistical Results of Special Strength Test Indicators.

Joint region	Movement pattern	Force(N)	RFD(N/s)
Wrist	Grip strength	432.67±133.45	1819.93±932.45
	Flexion	172.58±68.02	814.33±627.63
	Extension	150.92±77.27	755.33±541.79
Elbow	Anterior flexion	80.08±25.94	421.17±257.55
	Posterior extension	138.33±63.09	647.83±534.81
Shoulder	Abduction	86.17±31.62	406.67±265.61
	Adduction	113.67±46.10	572.17±420.71
	Internal rotation	141.75±73.51	588.00±349.43
	External rotation	108.17±61.90	448.92±3319.19

Table 3. Regression Results of Ordinary Least Squares Method.

Variable	Unstandardized Coefficients		Standardized Coefficient	T	P	Collinearity Diagnostics	
	B	SE	Beat			VIF	Tolerance
Constant	579.696	0.946	-	612.503	0.000**	-	-
Grip strength (Wrist) F1	0.025	0.006	1.422	3.923	0.002**	64.916	0.015
Elbow flexion F2	0.061	0.023	1.752	2.651	0.019*	215.85	0.005
Elbow extension F3	0.039	0.005	1.258	7.072	0.000**	15.646	0.064
Shoulder anterior flexion F4	-0.314	0.07	-3.429	-4.507	0.000**	286.114	0.003
Shoulder posterior extension F5	-0.023	0.034	-0.615	-0.687	0.503	396.035	0.003
Shoulder abduction F6	0.292	0.058	3.886	5.030	0.000**	295.046	0.003

Variable	Unstandardized Coefficients		Standardized Coefficient	T	P	Collinearity Diagnostics	
	B	SE	Beta			VIF	Tolerance
Shoulder adduction F7	-0.166	0.042	-3.222	-3.990	0.001**	322.446	0.003
Shoulder internal rotation F8	0.042	0.008	1.289	5.121	0.000**	31.344	0.032
Shoulder external rotation F9	-0.073	0.02	-1.895	-3.560	0.003**	140.056	0.007
Grip strength (Wrist) RFD1	0.006	0.001	2.314	5.813	0.000**	16.834	0.059
Elbow flexion RFD2	0.005	0.002	1.315	2.143	0.05	39.969	0.025
Elbow extension RFD3	0.009	0.003	2.041	2.647	0.019*	63.215	0.016
Shoulder anterior flexion RFD4	0.009	0.006	0.974	1.547	0.144	42.12	0.024
Shoulder posterior extension RFD5	-0.021	0.007	-4.632	-3.155	0.007**	228.955	0.004
Shoulder abduction RFD6	0.033	0.017	3.721	2.013	0.064	363.099	0.003
Shoulder adduction RFD7	-0.019	0.006	-3.295	-3.353	0.005**	102.582	0.01
Shoulder internal rotation RFD8	-0.013	0.005	-1.846	-2.717	0.017*	49.043	0.02
Shoulder external rotation RFD9	-0.002	0.002	-0.297	-1.447	0.170	4.65	0.224

Note: *p < 0.05, **p < 0.01. R² = 0.868, F statistic = 10.251, Sig. (F statistic) = 0.000.

However, examination of variance inflation factors revealed that all explanatory variables in the regression model exhibited VIF values greater than 10, indicating a high degree of multicollinearity among the predictors and strong linear dependence between variables. To address the issue of multicollinearity, ridge regression was selected as the estimation method in the present study. Ridge regression has been shown to provide more stable and reliable parameter estimates in the presence of multicollinearity and allows for improved interpretation of the relationships and interactions among correlated predictors. This approach provides an effective analytical framework for examining the influence of upper limb specific strength characteristics on shooting performance.

Results of the Ridge Regression Model

Ridge regression analysis was performed using peak force and rate of force development values obtained from different joint actions as independent variables, with total shooting score from the selection competition as the dependent variable. The resulting ridge trace plot is presented in Figure 4. After comprehensively considering variance inflation factors and the appropriate range of the regularization parameter K, a value of K = 0.02 was selected.

The ridge regression model at K = 0.02 was subsequently evaluated, and the results are shown in Table 4. The coefficient of determination was R² = 0.958, indicating that more than 95.8 percent of the variance in shooting performance was explained by the independent variables, demonstrating strong explanatory power. In addition, variance analysis of the ridge regression model is presented

in Table 5. The F statistic was 6.297 with a corresponding p value of 0.026, indicating that the regression model passed the significance test at the predefined significance level. At this point, the ridge regression equation for total shooting score was obtained as follows:

$$\text{Total score} = 0.000 - 0.386F1 - 0.005F2 + 0.425F3 - 0.025F4 - 0.455F5 + 0.384F6 - 0.585F7 + 1.224F8 + 0.303F9 + 0.825RFD1 + 0.003RFD2 + 0.307RFD3 - 0.155RFD4 - 0.240RFD5 - 0.419RFD6 - 0.466RFD7 - 0.193RFD8 - 0.009RFD9.$$

Further analysis of the ridge regression coefficients indicated that, for peak force variables, handgrip strength, elbow flexion strength, elbow extension strength, shoulder abduction strength, and shoulder internal rotation strength were positively associated with total shooting score. In contrast, shoulder flexion strength, shoulder adduction strength, and shoulder external rotation strength showed negative associations with shooting performance.

For rate of force development variables, handgrip rate of force development and elbow extension rate of force development were positively associated with total shooting score, whereas shoulder extension rate of force development, shoulder adduction rate of force development, and shoulder internal rotation rate of force development were negatively associated with shooting performance.

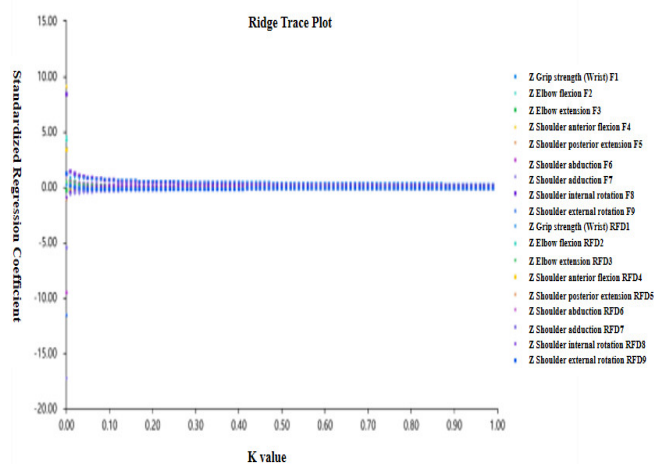


Figure 4. Ridge Trace Diagram of Each Explanatory Variable.

Table 4. Ridge Regression Results when K = 0.02.

Variable	Unstandardized Coefficients		Standardized Coefficient	T	P	Collinearity Diagnostics	
	B	SE	Beta			VIF	Tolerance
Constant	579.696	0.946	-	612.503	0.000**	-	-
Grip strength (Wrist) F1	0.025	0.006	1.422	3.923	0.002**	64.916	0.015
Elbow flexion F2	0.061	0.023	1.752	2.651	0.019*	215.85	0.005
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Elbow flexion RFD2	0.005	0.002	1.315	2.143	0.05	39.969	0.025
Elbow extension RFD3	0.009	0.003	2.041	2.647	0.019*	63.215	0.016
Shoulder anterior flexion RFD4	0.009	0.006	0.974	1.547	0.144	42.12	0.024
Shoulder posterior extension RFD5	-0.021	0.007	-4.632	-3.155	0.007**	228.955	0.004
Shoulder abduction RFD6	0.033	0.017	3.721	2.013	0.064	363.099	0.003
Shoulder adduction RFD7	-0.019	0.006	-3.295	-3.353	0.005**	102.582	0.01
Shoulder internal rotation RFD8	-0.013	0.005	-1.846	-2.717	0.017*	49.043	0.02
Shoulder external rotation RFD9	-0.002	0.002	-0.297	-1.447	0.170	4.65	0.224

Note: $R^2 = 0.958$, F statistic = 6.297, Sig. (F statistic) = 0.026.

Table 5. Analysis of Variance (ANOVA) Results of Ridge Regression.

	Sum of Squares	df	Mean Square	F	p
Regression	21.062	18	1.170	6.297	0.026
Residual	0.929	5	0.186		
Total	21.991	23			

4. Discussion

Influence of Coordinated Upper Limb Specific Strength on Shooting Performance

Identifying the role of upper limb specific strength and rate of force development provides an important extension to existing performance models, particularly in precision sports such as air pistol shooting. Previous studies examining the relationship between strength characteristics and shooting performance have predominantly relied on simple linear correlation or regression approaches [1,10]. Although these methods offer initial insights, they frequently overlook the substantial multicollinearity that exists among strength related variables, which is inherent to coordinated motor tasks [15].

To address this limitation, ridge regression was employed in the present study. The results revealed pronounced multicollinearity among upper limb strength indicators in elite air pistol athletes. When multicollinearity is present, ordinary least squares estimation can yield unstable coefficients and reduce model reliability. Ridge regression mitigates this issue by introducing a regularization parameter, allowing for a small bias while substantially reducing variance inflation [16]. With the regularization parameter set to 0.02, the present model demonstrated improved stability and interpretability, thereby providing a more robust analytical framework for examining the influence of specific strength variables on shooting performance.

The findings indicate that upper limb specific strength plays a significant role in shooting performance, which aligns with the biomechanical characteristics of air pistol shooting that require highly coordinated neuromuscular control. During pistol aiming and triggering, muscle groups responsible for handgrip, elbow stabilization, and shoulder positioning operate in a tightly coupled manner under central nervous system regulation [17,18]. Efficient pistol raising and aiming are

characterized by rapid yet controlled movements, which enhance postural stability and improve shooting accuracy [4].

The present study showed that handgrip peak force and rate of force development, elbow flexion and extension peak force, and shoulder abduction and internal rotation peak force were positively associated with shooting performance. These results suggest that adequate strength in these muscle groups contributes to improved stability during aiming and more consistent trigger execution. Rate of force development, in particular, reflects the capacity of the neuromuscular system to generate force rapidly and has been shown to play a critical role in tasks requiring postural control and movement precision [19,20]. Higher rate of force development may reduce force onset delay and allow athletes to better counteract perturbations during the triggering phase.

In contrast, shoulder flexion, adduction, and external rotation peak force, as well as shoulder extension, adduction, and internal rotation rate of force development, were negatively associated with shooting performance [21]. This finding indicates that shooting specific strength is not universally beneficial when increased indiscriminately. Excessive or overly rapid activation of certain muscle groups may disrupt postural balance and interfere with fine motor coordination. Previous research has shown that excessive force production can impair movement accuracy in precision tasks by increasing neuromuscular noise and physiological tremor [22]. Given the relatively small mass and moment of inertia involved in single handed pistol shooting, such disturbances may have a disproportionate effect on weapon stability and aiming precision.

Synergistic Effects of Psychological, Technical, and Physical Factors on Shooting Performance

Shooting performance emerges from the synergistic interaction of psychological stability, technical execution, and physical capacity. Advantages in any single dimension are insufficient to sustain elite level performance. Instead, the dynamic balance and mutual reinforcement among these factors enable athletes to maintain high accuracy under competitive pressure [17].

Neurophysiological studies have demonstrated that elite shooters exhibit increased alpha band activity in the prefrontal cortex during shooting tasks, which is associated with enhanced attentional control and emotional regulation [23]. Elite athletes also show reduced visual dependency when performing under stress, reflecting more efficient sensorimotor integration [7]. Conversely, elevated psychological stress and anxiety can increase sympathetic nervous system activation, leading to heightened physiological tremor and reduced postural stability, which negatively affect pistol control and aiming accuracy [24].

Elite shooters tend to display superior autonomic nervous system regulation, characterized by effective parasympathetic modulation and balanced sympathetic activation. This autonomic profile contributes to smaller heart rate fluctuations and greater physiological stability during competition [25,26]. Under stress conditions, rapid changes in autonomic activity can alter neuromuscular function. Athletes with higher rate of force development are better able to adapt to these changes, allowing muscles to respond quickly and maintain stability during critical moments of performance.

Technical execution in shooting is also deeply intertwined with physical capacity. Well designed physical training programs enhance specific strength, endurance, and neuromuscular control, thereby optimizing technical efficiency during aiming and triggering. A recent meta analysis identified gun holding stability, aiming accuracy, trigger control precision, aiming time, and postural balance as key determinants of shooting performance [27]. While sufficient upper limb strength contributes to improved weapon stability, excessive activation of hand and forearm muscles may impair fine motor control and reduce shooting accuracy [28].

These findings support the present results, which indicate that certain strength variables are negatively associated with shooting performance. This suggests that optimal shooting performance depends not on maximal force output, but on precise regulation of muscle activation. The coordination between muscle proprioception and technical execution is therefore critical. Training approaches that emphasize coordination and sensorimotor integration have been shown to improve movement consistency and precision in elite shooters [29]. Such adaptations are likely mediated by neuroplastic changes that enhance the precision of neural control over muscular activity [30].

In summary, elite shooting performance depends on the multidimensional synergy of psychological stability, technical execution, and physical capacity. Psychological regulation supports efficient neuromuscular functioning, while shooting specific strength contributes to technical stability when appropriately balanced. Together, these factors form a dynamic system that underpins high level competitive performance in air pistol shooting.

Limitations and Future Directions

Although the present study provides novel evidence regarding the influence of upper limb specific strength balance on shooting performance in elite air pistol athletes, several limitations must be acknowledged. First, the sample size was restricted to 24 participants due to the limited number of athletes available. This small sample reduces statistical power, increases the risk of Type II errors, and renders the ridge regression model potentially unstable, limiting the generalizability of the findings. Additionally, the sample comprised highly supported elite athletes with access to substantial resources, who may exhibit greater motivation and psychological resilience than non-elite or less-supported populations.

Second, as an observational study, causality cannot be inferred; the observed associations may be influenced by unmeasured confounding variables, including training volume, injury history, handedness, repeated exposure to testing procedures, psychological state on the day of assessment, sleep quality, and nutritional status. Third, although the Vald Dynamo handheld dynamometer has demonstrated acceptable reliability and validity in prior studies, potential measurement bias inherent to handheld dynamometry (e.g., examiner strength and positioning consistency) cannot be entirely ruled out.

Therefore, the study focused solely on associative relationships and did not examine the effects of targeted strength training interventions or the underlying physiological and neuromuscular mechanisms driving these associations. Future research should aim to recruit larger samples, incorporate additional variables (e.g., training load monitoring, handedness assessment, and objective measures of psychological and recovery states), and employ longitudinal or randomised controlled intervention designs to establish causal relationships. Such studies would enable the development of more robust and comprehensive models describing the interaction between upper limb strength characteristics, confounding factors, and shooting performance, ultimately informing evidence-based training prescriptions for air pistol athletes.

5. Conclusions

This study demonstrates that coordinated upper limb strength balance is a critical determinant of competitive performance in elite air pistol athletes. Using ridge regression to address multicollinearity, higher handgrip, elbow flexion/extension, shoulder abduction, and internal rotation peak force—along with handgrip and elbow extension rate of force development—were positively associated with shooting scores. In contrast, greater shoulder flexion, adduction, and external rotation peak force, as well as higher rates of force development in shoulder extension, adduction, and internal rotation, were negatively associated with performance.

These results indicate that optimal pistol stability and trigger control require task-specific agonist strength without excessive antagonistic activation, which may impair fine motor precision. Targeted strength training emphasizing agonist–antagonist balance could therefore enhance shooting outcomes. Ultimately, elite performance arises from the integrated interplay of physical, technical, and psychological factors, providing a foundation for evidence-based conditioning in precision shooting sports.

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Zhonghe Yang and Andrew Soundy; writing—review and editing, Wei Li, Andrew Soundy and Ling Pan. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Abbreviations

The following abbreviations are used in this manuscript:

SD	Standard Deviation
VIF	Variance Inflation Factor
OLS	Ordinary Least Squares
RFD	Rate of Force Development

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