RESEARCH ARTICLE

Biomechanical analysis of police shooting technique optimization and stability enhancement in training

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Police shooting as a key skill in law enforcement imposes extremely high requirements on shooting accuracy and movement stability. However, in high-pressure situations, limited by traditional training methods, police officers often experience problems such as unstable gun-holding movements and rapid muscle fatigue, which affect shooting performance. Based on biomechanics, this study aimed to improve the accuracy of police shooting and the stability of shooting movements. The study used electromyography to monitor changes in muscle contribution rates and muscle amplitudes of major muscle groups under different shooting postures. Moreover, the study combined a high-precision impact point tracking system to evaluate shooting accuracy and compared traditional and optimized training programs. Traditional training focused on basic physical fitness including lung capacity, standing long jump, sprinting, pull-ups, and shoulder flexibility, while optimized training added the center axis relock (CAR) shooting system training, scapular stability exercises, suspension training, and psychological training to improve stability and precision. The results showed that the posterior deltoid was the main stabilizing muscle in shooting, and its contribution rate in traditional straight-arm shooting was 43.7% with poor shoulder stability. After scapular stability training, the contribution rate increased to 47.5%, while suspension training further improved to 50.1%. The CAR shooting system training increased to 51.2%, and the comprehensive optimized training achieved the best result with a contribution rate of 54.8%. Concerning muscle amplitude, the CAR shooting system reduced the posterior deltoid amplitude by 97.1 µV. Comprehensive optimized training further lowered the amplitude by 145.3 µV, significantly enhancing shooting stability and precision. Overall, comprehensive optimized training maximized firearm stability, reduced muscle amplitude, and improved shooting accuracy. This study provided a scientific biomechanical basis for optimizing police shooting training, optimized the training system, and improved police officers' shooting performance and combat ability under high-pressure conditions.

Keywords: shooting; training; biomechanical analysis; cloud model; electromyogram.

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Introduction

Police shooting refers to shooting training and actual combat operations conducted by law enforcement personnel, especially police officers, during their duty execution. Its purpose is to maintain accurate shooting ability in critical moments, ensure the smooth completion of tasks, and protect the safety of themselves and others [1, 2]. Police shooting not only requires shooting accuracy but also stability and reaction speed in high-pressure environments [3]. Traditional training programs aim to provide a solid physical foundation for police shooting by improving basic physical fitness. These programs emphasize enhancing strength, endurance, flexibility, and stability required for shooting, thereby improving shooting accuracy and stability [4]. With the diversification and complication of law enforcement scenarios, traditional police shooting training models face many challenges, especially putting forward higher requirements for shooters' body control, muscle coordination, and psychological quality in dynamic environments [5].

In recent years, with the development of biomechanics and sports science, more studies have begun to explore how to improve the stability and accuracy of shooting movements through scientific training methods, especially, these studies focus on the precise analysis and training of muscle groups during shooting [6]. Worldwide studies have focused on the mechanical characteristics of shooting movements, the stability of gun-holding postures, and muscle control mechanisms. O'Donovan *et al*. compared the posture differences between professional and novice shooters in weighted shooting using inertial measurement units and found that expert shooters were significantly superior to novices in task stability and target switching efficiency [7]. Kasović *et al*. explored the relationship between plantar pressure distribution patterns and pistol shooting efficiency and indicated that, when standing, higher rear foot pressure was associated with poorer shooting performance, while higher forefoot pressure was related to better shooting performance [8]. Sundaram *et al*. summarized four factors affecting shooting performance based on literature analysis, which included gun-holding stability, aiming accuracy, trigger control, and target retention time, emphasizing that posture stability was the key to achieving excellent results [9]. With the deepening of biomechanical research, the key role of the control ability of core muscles, upper limb muscles, and scapulae in shooting movements has become increasingly prominent. Biomechanics, as a discipline studying the mechanical principles in the movement of organisms, especially the human body, integrate mechanics and biology to reveal the functions and influences of muscles, bones, joints, and other tissues during movement by analyzing the movement patterns of various parts of the human body, force transmission, and their interrelationships [10]. Laaksonen *et al*. pointed out that biomechanical factors could remarkably improve shooting accuracy and stability by optimizing movement coordination, reducing fatigue, lowering joint damage, and improving comfort. Meanwhile, these factors could enhance muscle coordination and shooting precision, thus improving body stability and accuracy [11]. Feng *et al*. and Öztürk *et al*. believed that, by monitoring changes in muscle amplitude and contribution rates, combined with movement stability analysis, the biomechanical mechanisms of shooting movements could be more comprehensively revealed. Thus, it provided scientific theoretical support and optimization paths for police shooting training [12, 13]. Ibrahim and Abdelgawad argued that muscle fatigue and the use of muscle groups directly affected shooting stability, while fatigue could lead to uncoordinated muscle activity, thereby reducing shooting accuracy. High-level shooters could cope with fatigue by adjusting muscle groups and techniques to maintain high shooting stability [14]. Shi *et al*. found that the biological relationships in pistol shooting involved multiple physiological and neural mechanisms including vision, hearing, muscle control, and brain activity. Under low light and noise interference conditions, shooters' electroencephalogram activity and shooting performance were negatively affected [15]. Sinka *et al*. believed that enhancing shoulder joint strength and dynamic stability could effectively improve shooting performance and reduce the risk of injury [16]. Existing studies have focused on the optimization of police shooting technical movements and shooting stability, covering multiple dimensions such as sports biomechanics, electromyographic analysis, visual-motor coordination ability, and psychological training. Meanwhile, studies have pointed out that factors such as muscle control, posture adjustment, training methods, and psychological state jointly affect shooting stability. Moreover, optimized training helps improve gun-holding stability and accuracy. However, there are still certain research gaps and deficiencies.

This study aimed to explore the impact of different training modes on the stability and accuracy of police shooting movements, particularly focusing on the optimization path of muscle control mechanisms using biomechanical analysis methods to monitor changes in muscle contribution rates and muscle amplitudes of key muscle groups under different shooting postures through electromyography (EMG). Meanwhile, the study combined a high-precision impact point tracking system and cloud model method to quantitatively evaluate shooting accuracy. Further, the study compared traditional training program with comprehensive optimized training program that included scapular stability, suspension, psychological, and center axis relock (CAR) shooting system training. This research systematically compared the impact of different training methods on the stability of shooting movements from a biomechanical perspective and constructed a systematic training optimization strategy based on electromyographic parameters. The results provided theoretical support for the scientization and refinement of the police shooting training system, offered important practical guidance for improving the shooting performance and emergency response capabilities of police officers in actual combat environments.

Materials and methods

Data collection and grouping

This study selected 20 students from the Beijing Police College (Beijing, China) including 10 males and 10 females, aged from 19 to 21 years old. All participants were right-handed shooters and right-eyed aiming eyes with at least 1 year of pistol shooting experience. The participants had no visual impairment and no major past medical history such as fractures or other conditions affecting motor ability in the upper and lower limbs. The participants were randomly divided into two groups. As a basic training stage, traditional training was applied to both groups before they received different forms of optimal training interventions, respectively. Specifically, after completing traditional training, participants in group 1 adopted individual optimal training through one-by-one format with each training lasting 30 minutes per day for one week, while participants in group 2 adopted collective optimal training with each training lasting 30 minutes per day for a total of 4 weeks. All procedures of this research were approved by the Ethical Committee of Hebei Vocational College of Public Security Police (Shijiazhuang, Hebei, China).

Traditional training program

Traditional training consisted of five main items including lung capacity training, 50-meter sprint, standing long jump, pull-up, and shoulder flexibility training, which aimed to comprehensively improve the physical fitness foundation required for police shooting. The training would enhance cardiopulmonary function through abdominal breathing and interval running. The sprint and long jump training improved lower limb explosive power and core stability. The pull-ups strengthened upper limb muscle endurance, while shoulder flexibility training improved joint mobility and gun-holding control ability, thereby providing physical support for stability and accuracy during shooting. The traditional training cycle lasted 8 weeks with 5 training sessions per week and 60 minutes per training session. The training time for each item was controlled between 10 and 20 minutes. After the 8-week training, shooting tests in different postures including straight-arm and bent-arm were conducted. EMG signals from key muscles including deltoid, biceps, triceps, and extensor carpi radialis were recorded using

Noraxon Myo 1200 Wireless EMG Telemetry System (Noraxon, Scottsdale, AZ, USA) to assess the impact of training on muscle contribution rates and amplitude changes. The scores of bullet impact points and shooting accuracy were tracked using Scatt WS1 Smart Wireless Electronic Laser Shooting Training Tester (Scatt Shooting Trainers, Bucuresti, Romania). Matlab (https://www.mathworks.com/products/matlab.html) was used for EMG signal processing and constructing the cloud model of bullet impact points.

Optimized training program

The optimized training proposed in this study built on traditional training by incorporating biomechanical analysis, which focused on specialized training for shooting stability, movement coordination, and psychological stress control. The optimized training program consisted of four main parts including scapular stability training, suspension training, psychological training, and CAR shooting system training. The scapular stability training began with scapular retraction and relaxation exercises. Trainees stood against a wall with their shoulders touching the wall and performed slow scapular retraction and protraction movements to enhance shoulder stability. Prone Y-T-W-L exercises, a multi-angle training method for scapular stability and posture control, employed dumbbells or resistance bands to train shoulder muscles at different angles, improving scapular coordination and support, which selectively activated key muscle groups such as the trapezius, rhomboid, infraspinatus, and teres minor through different arm postures, thus improving common posture problems. The Y referred to the Y movement by raising both arms to form a Y shape, which effectively activated the lower trapezius and enhanced the upward rotation and stability of the scapula. T was the T movement that raised the arms horizontally to form a T shape and focused on activating the middle trapezius and rhomboid muscles, improving the control ability during shoulder abduction. W movement contracted the scapula backward with elbows flexed to form a W shape to strengthen the adduction and stability of the scapula. L movement flexed the elbows at 90 degrees and performed shoulder external rotation to form an L shape to activate the infraspinatus and teres minor in the rotator cuff muscles. Thus, the rotational control ability of the shoulder joint could be enhanced. This training combination could significantly improve shoulder control ability and upper limb stability, providing reliable muscle support for tasks requiring fine motor control. The barbell shoulder press combined with isometric static holds strengthened shoulder pressing power and improved scapular static stability, thus enhancing shoulder control during firearm handling. These exercises improved shoulder stability and control during shooting [17-19]. The suspension training module included one-arm rows, one-leg squats, and core training. The one-arm row primarily strengthened the back muscles and improved the endurance of the shooting arm. The one-leg squat focused on lower limb strength and stability, aiding trainees in maintaining optimal balance while in single-leg shooting positions. The core training enhanced the stability of the core muscles through side planks and static firearm-holding exercises, which ensured superior control during prolonged firearm holding and mitigated muscle fatigue. These exercises markedly enhanced overall stability and muscle coordination, thus elevating shooting accuracy [20-23]. The psychological training was based on breathing regulation using the 4-4-8 breathing technique, which was a breathing skill commonly used in psychological regulation and relaxation training. It specifically referred to inhaling for 4 seconds, holding breath for 4 seconds, and exhaling slowly for 8 seconds. This method effectively stimulated the parasympathetic nervous system by extending the exhalation time, helping to reduce heart rate, relax muscles, and stabilize emotions. Therefore, it could alleviate anxiety and tension and improve psychological control and concentration in high-pressure environments. Meditation and mindfulness training facilitated trainees staying calm under high-pressure conditions, enhancing their ability to focus, and reducing firearm shaking caused by nervousness or anxiety. These psychological exercises helped trainees maintain better concentration and decision-making abilities during actual shooting, improving shooting accuracy and stability [24, 25]. The CAR shooting system training included CAR firearm-holding posture, multi-angle shooting, and rapid aiming and shooting rhythm training. In firearm-holding posture training, trainees optimized the force distribution in the shoulders, elbows, and wrists to ensure stability when shooting at close range. Multi-angle shooting training improved adaptability in changing environments by varying shooting positions and angles. Rapid aiming and shooting rhythm training enhanced reaction speed, helping trainees quickly lock onto targets and shoot accurately under pressure. These exercises improved tactical shooting skills and enhanced reaction speed and accuracy [26, 27].

Characteristics of shooting projectile landing point based on cloud model method

The cloud model was a mathematical model that combined fuzzy mathematics and probability theory, which could handle problems involving uncertainty, ambiguity, and randomness. Using the cloud model method, effective feature extraction and analysis of bullet impact points could be conducted, thereby evaluating shooting accuracy and stability [28]. In the analysis of shooting impact point characteristics based on the cloud model method, key calculation equations mainly involved expected value, entropy value, and hyper-entropy value with specific calculations as follows [29, 30].

$$E_x = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (1)$$

$$E_y = \frac{1}{n}\sum_{i=1}^{n} y_i \quad (2)$$

$$E_n = \frac{1}{n}\sum_{i=1}^{n} \sqrt{(x_i - E_x)^2 + (y_i - E_y)^2} \quad (3)$$

$$H_e = E_n^2 \quad (4)$$

where x_i and y_i were coordinate points. n was the number of shots. E_x and E_y were the expected values of the horizontal and vertical coordinates of the shooting point, respectively. E_n was the entropy value, reflecting the degree of discretion of the shooting point. H_e was the superentropy value, which was used to measure the stability of the entropy value.

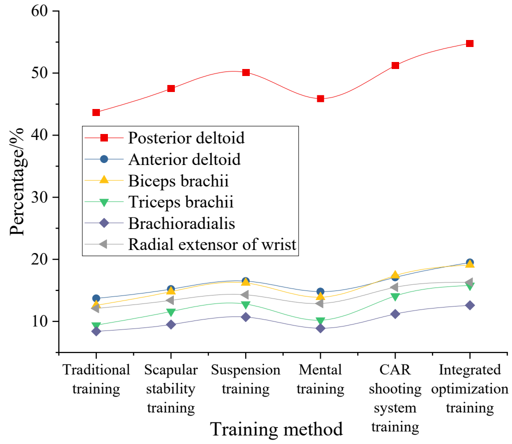
Statistical analysis

SPSS 26.0 software (IBM, Armonk, New York, USA) was employed in this research. Independent samples t-tests and one-way analysis of variance (ANOVA) were used to statistically analyze performance differences between groups on shooting accuracy, electromyographic activity, and psychological indicators. All data underwent a normality test before analysis. When the data conformed to normal distribution and the homogeneity of variance assumption holds, parametric tests were used, otherwise, non-parametric test such as Mann-Whitney U test was selected. The significance level was set at α = 0.05.

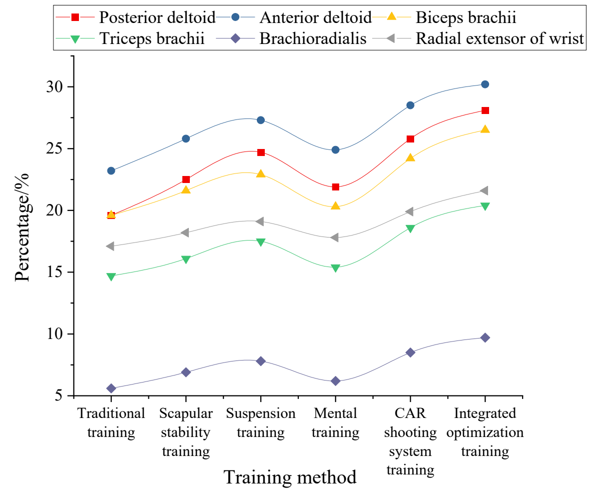
Results and discussion

Muscle contribution comparison

The comparison results of the muscle contribution rate of various shooting techniques across different training conditions showed that, during straight-arm shooting, the posterior deltoid exhibited a 43.7% contribution rate in traditional training, making it the primary stabilizing muscle group. However, the anterior deltoid contributed relatively little at 13.7%, indicating insufficient coordination between the anterior and posterior shoulder muscles. Scapular stability training increased the contribution rates of both the anterior and posterior deltoids while enhancing the stability of the arm muscles. Suspension training further strengthened shoulder and core control, boosting the posterior deltoid's contribution rate to 50.1%. Psychological training exerted a more modest impact, mainly improving muscle coordination. The CAR shooting system optimized arm coordination with the posterior deltoid's contribution rate reaching 51.2%.



(a) Straight arm shooting muscle contribution



(b) Flexed arm shooting muscle contribution

Figure 1. Comparative results of the muscle contribution rate of different shooting techniques under different training conditions.

Comprehensive optimized training integrated multiple methods, significantly increasing the contribution rates of all muscle groups. The posterior deltoid's contribution rate peaked at 54.8%, enhancing firearm stability and shooting accuracy (Figure 1a). During bent-arm shooting, the anterior deltoid had a higher contribution rate of 23.2% in traditional training, signifying the important role of anterior shoulder muscles in shooting. Nevertheless, there remained room for improvement in the stability of the arm muscles. Scapular stability training elevated the contribution rates of the anterior deltoid, biceps, and triceps, improving firearm stability. Suspension training further enhanced the stability of these muscles, especially increasing the biceps' contribution rate. Psychological training had a minor effect on muscle contribution rates but helped shooters allocate muscle strength more effectively. The CAR shooting system improved control over the shoulder and upper arm with the anterior deltoid's contribution rate reaching 28.5% and significant increase in the contributions of the biceps and triceps. Comprehensive optimized training optimized the contribution rates of all muscle groups, particularly in the anterior deltoid (30.2%) and biceps (26.5%), significantly enhancing shooting stability and accuracy (Figure 1b). Different training methods demonstrated a remarkable impact on muscle contribution rates, which was consistent with the conclusions in existing literatures regarding the influence of muscle coordination and core stability on shooting performance. As reported by previous studies, scapular stability training distinctly increased the contribution of the posterior and anterior deltoid muscles, enhancing upper limb control, while suspension training was particularly effective in improving shoulder and core control. The CAR shooting system and comprehensive optimized training further strengthened the synergy of muscle groups, notably improving the stability and accuracy of straight-arm and bent-arm shooting. In addition, bent-arm shooting showed higher muscle contribution rates under multiple training methods, especially in the biceps brachii and anterior deltoid muscles, which was better than straight-arm shooting. This finding further verified the advantages of the bent-arm posture in terms of control and accuracy. The comprehensive training method demonstrated the optimal effect, reflecting the significant gain of multi-factor collaborative training.

Muscle amplitude comparison

The comparative results of muscle amplitude changes in different shooting techniques under various training conditions showed that, in straight-arm shooting with traditional training, the amplitude of all muscle groups was the highest. The results indicated that traditional training failed to effectively reduce unnecessary muscle activity, leading to unstable muscle control during shooting. With scapular stability training, the amplitude decreased moderately with the posterior deltoid and biceps being decreased by 31.8 μV and 8.3 μV, respectively. The results suggested improved scapular stability, which enhanced upper limb muscle coordination and stabilized shooting movements. Suspension training further lowered the amplitude, especially in the posterior deltoid and triceps, reflecting significant improvement in upper limb stability. Such a decrease in amplitude signified enhanced muscle coordination and control, minimizing extraneous muscle activity during shooting. Psychological training exerted a minimal impact on amplitude but slightly reduced the amplitude of the extensor carpi radialis, which illustrated its ability to alleviate shooting-related nervousness and improve muscle stability, albeit to a lesser extent than other training methods. After training with the CAR shooting system, the amplitude of all muscle groups dropped significantly with notable decreases in the posterior deltoid and triceps as 97.1 μV and 30.4 μV, respectively. The results demonstrated that this training method effectively improved shooting accuracy by reducing unnecessary muscle activity and boosting movement stability. Comprehensive optimized training induced a significant reduction in the amplitude of all muscles with particularly notable decreases in the posterior deltoid and biceps, which was the most effective training method, maximizing shooting stability by reducing excessive muscle activation and demonstrating the strongest training effect. In bent-arm shooting, traditional training led to higher muscle amplitudes, prominently in the posterior deltoid (330.7 μV) and anterior deltoid (306.4 μV), indicating more intense muscle activity and less stable shooting movements. With scapular stability training, the amplitude decreased slightly with the posterior deltoid, anterior deltoid, and biceps amplitudes at 320.4 μV, 290.3 μV, and 259.2 μV, respectively, which suggested that scapular stability training helped reduce excessive muscle activity and improved muscle coordination. In suspension training, the amplitude of the posterior deltoid, anterior deltoid, and biceps decreased most significantly. Psychological training exerted an insignificant overall effect on amplitude changes but elicited relatively larger decreases in specific muscles like the posterior deltoid, biceps, and extensor carpi radialis, which indicated that psychological training helped reduce stress and improve shooting stability, although its effect was relatively mild. Under the CAR shooting system training, amplitudes dropped markedly, showing that this method effectively reduced muscle tension and enhanced movement accuracy and stability. Comprehensive optimized training had the most notable impact on amplitude, especially in the posterior deltoid and triceps, which demonstrated that this training method effectively reduced muscle activity fluctuations, maximized shooting stability and accuracy, and demonstrated the best training effect. Comparison of the standard deviation of muscle amplitude showed that traditional training generally had larger standard deviations in all muscle groups. Particularly, it had the posterior deltoid at 64.8 μV during straight-arm shooting and the anterior deltoid at 48.1 μV during bent-arm shooting. The results illustrated that traditional training resulted in greater fluctuations in muscle activity during shooting, leading to poorer movement stability and relatively lower shooting accuracy. In contrast, optimized training methods such as the CAR shooting system, scapular stability, suspension, and psychological training showed smaller standard deviations, which suggested that these optimized training methods mitigated muscle activity fluctuations and improved shooting stability. Especially in comprehensive optimized training, the posterior deltoids in straight-arm and bent-arm shooting (45.1 μV and 11.7 μV)

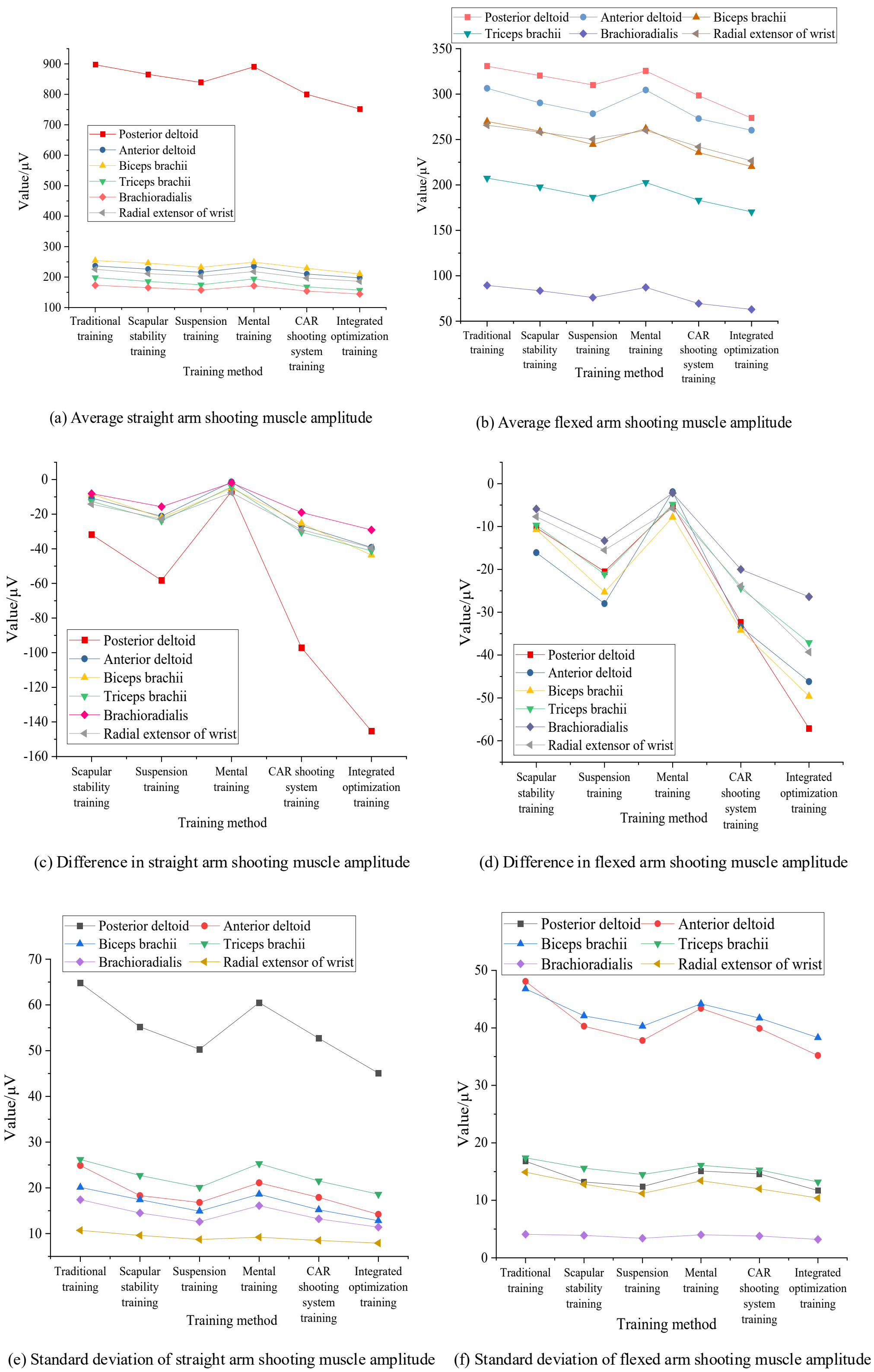


Figure 2. Comparative results of muscle amplitude changes of different shooting techniques under different training conditions.

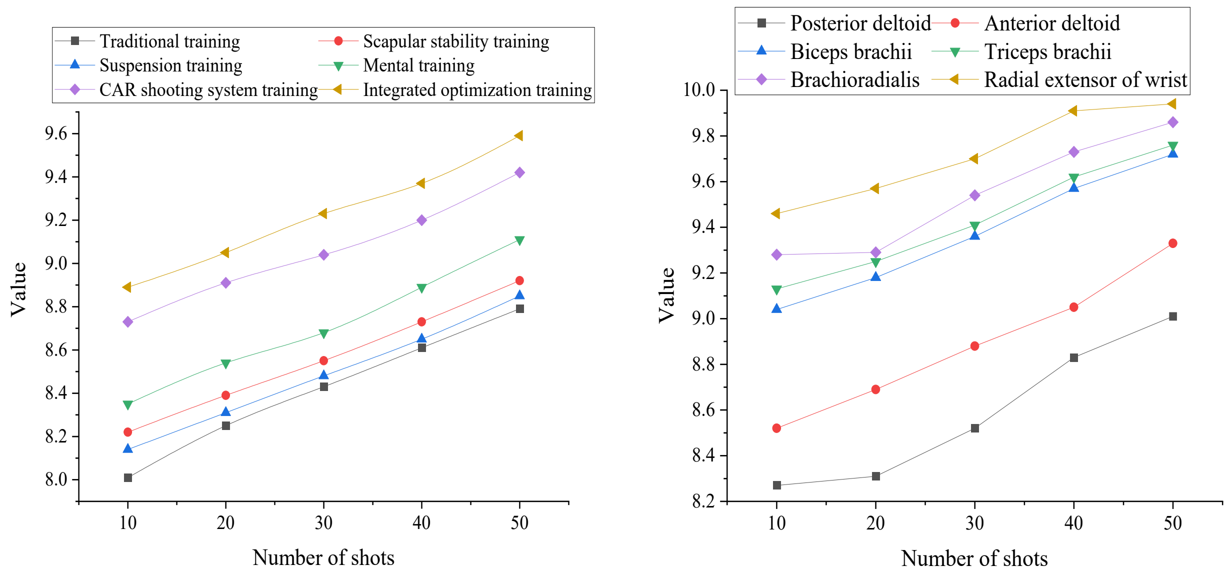
showed significantly smaller standard deviations (Figure 2). The results indicated that this training method best stabilized muscle activity, reduced unnecessary fluctuations, enhanced muscle control, and improved shooting stability and accuracy. The optimized training, especially the CAR shooting system and comprehensive training, could markedly reduce muscle amplitude. Meanwhile, it could reduce fluctuations and redundant activities during action execution, thus improving the stability of shooting movements. The reduction in amplitude standard deviation also indicated that the stability of movements and the consistency of muscle control were improved. These results again confirmed that scientific and systematic training design helped improve the stability and repeatability of sports performance, which was consistent with previous research results on the effectiveness of neuromuscular control training.

Shooting score comparison

The number of rings of shooting impact points for different shooting technical movements under diverse training methods showed that different training methods produced obvious differences in the performance improvement of straight-arm shooting and bent-arm shooting. In straight-arm shooting, traditional training showed a gradual improvement, but the range was small. The effects of scapular stability training, suspension training, and psychological training gradually appeared with psychological training showing a significant effect on performance improvement, reflecting the positive impact of psychological quality on shooting accuracy. The CAR shooting system training and comprehensive optimized training brought prominent improvements. Comprehensive optimized training achieved the best effect with the straight-arm shooting score reaching 9.59 rings, reflecting the synergistic effect of multiple factors. In contrast, bent-arm shooting exhibited an overall better performance than straight-arm shooting with generally higher scores under various training methods and a greater range of improvement. Comprehensive optimized training made the bent-arm shooting score close to full marks, reaching 9.94 rings, showing its advantages in accuracy and stability (Figure 3). Overall, the comprehensive optimized training that integrated multiple training methods was the most significant, helping to improve shooting precision and stability. This was consistent with the views on the impact of shooting postures in some existing studies and further proved that the advantages of bent-arm shooting could be maximized through optimized training.

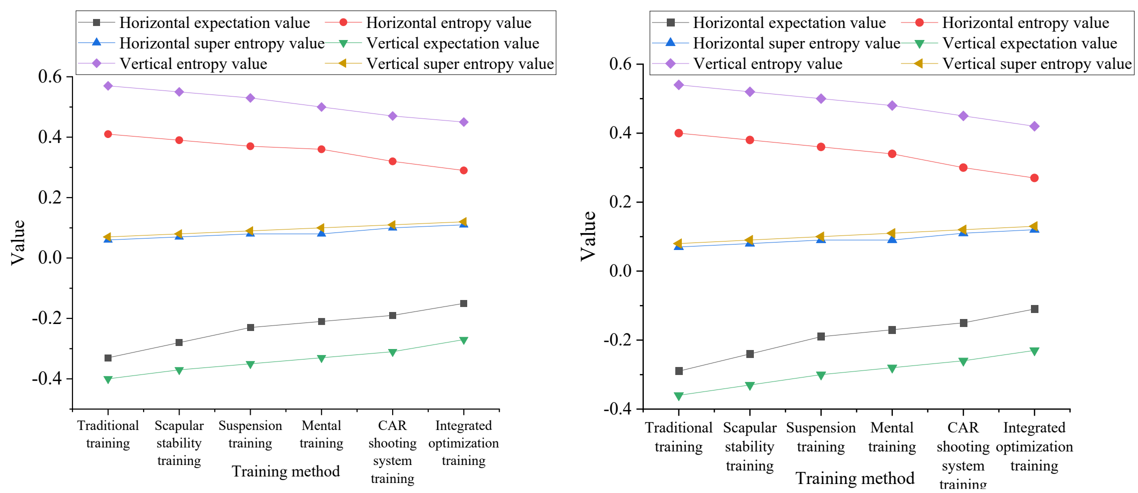
Cloud model analysis

The cloud model comparison results of different shooting techniques under different training demonstrated that, in bent-arm shooting, the expected values of horizontal and vertical coordinates were better than those in straight-arm shooting under all training methods, which indicated that the bullet impact points were more concentrated, and the shooting accuracy was higher in bent-arm shooting. Under comprehensive optimized training, the horizontal coordinate expected value for straight-arm shooting was -0.15, while it for bent-arm shooting improved to -0.11. The vertical coordinate's expected value increased from -0.27 to -0.23, showing better accuracy. In terms of entropy, the vertical coordinate entropy for bent-arm shooting was lower than that for straight-arm shooting, signifying a more stable distribution of bullet impacts and reduced shooting dispersion in bent-arm shooting. Under the CAR shooting system training, the vertical coordinate entropy for straight-arm shooting was 0.47, while it dropped to 0.45 for bent-arm shooting, which showed that bent-arm shooting could effectively reduce errors and improve shooting stability (Figure 4). Regarding super-entropy, bent-arm shooting yielded slightly higher than straight-arm shooting, which suggested that, while improving accuracy, bent-arm shooting maintained some adjustment capability, giving shooters better adaptability in complex tactical environments. Regarding the impact of different training methods, comprehensive optimized training and CAR shooting system training remarkably improved shooting accuracy and stability, bringing the



(a) Rings for straight arm shooting (b) Rings for flexed arm shooting

Figure 3. Number of rings of the shooting impact point under different training.



(a) Straight arm shooting (b) Flexed arm shooting

Figure 4. Comparative results of cloud models of different shooting techniques across diverse training methods.

performance of bent-arm shooting to the best level. Psychological training and suspension training also had good effects on enhancing shooting control and muscle stability. Traditional training and scapular stability training mainly improved shooting accuracy but had a limited impact on shooting stability. Bent-arm shooting was superior to straight-arm shooting in multiple dimensions including expected value and entropy value, indicating that it had stronger performance in terms of accuracy and stability. Especially under CAR and comprehensive training, its hit distribution was more concentrated, and the volatility was smaller. These data supported the theoretical hypothesis that the combination of shooting posture and training system could improve the precision strike ability. These data also provided optimization strategies with clear directions and a sufficient scientific basis for police practical shooting training.

Conclusion

This study analyzed the effects of different training methods on muscle contribution rates, muscle amplitude, and shooting accuracy and stability. The results showed that traditional training resulted in low muscle contribution rates and limited shooting stability. Scapular stability training and suspension training could improve the stability of the shoulders and upper limbs, but to a lesser extent than the CAR shooting system training. The CAR shooting system training exceled in muscle coordination and stability, especially in improving shooting accuracy. The optimized training was the most effective of all methods, significantly boosting firearm stability and making shooting movements more precise. In straight-arm shooting, comprehensive optimized training and CAR shooting system training were the most effective methods. They greatly reduced muscle amplitude, showing the strongest muscle control and stability, which helped improve accuracy. In bent-arm shooting, comprehensive optimized training stood out by minimizing excessive muscle amplitude, especially in the posterior deltoid and biceps, which indicated that this training method enhanced muscle coordination and movement stability during shooting. The combination of bent-arm shooting and optimized training yielded the most pronounced improvement in shooting performance. Psychological training and CAR shooting system training played key roles in enhancing stability and accuracy for different shooting methods. Compared to straight-arm shooting, bent-arm shooting performed better in accuracy, stability, and adaptability. With the support of the comprehensive optimized training and CAR shooting system training, it could achieve the best shooting results. Therefore, in practical training, adopting the bent-arm shooting posture combined with effective training methods was recommended to maximize shooting performance. The limitations of this study included a small sample size and a short training period. Future research could further verify the training effects by expanding the sample size and extending the training duration.

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