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RESEARCH

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Inspiratory muscle training enhances jumping power and shooting performance in elite air pistol athletes

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Abstract

Background Inspiratory muscle training (IMT) has been shown to enhance respiratory efficiency, postural stabilization, and neuromuscular coordination in athletic populations. However, its effects in precision sports such as air pistol shooting remain insufficiently explored. This study investigated the impact of a 4-week IMT program on respiratory muscle strength, explosive lower-limb performance, reaction time, and shooting accuracy in competitive air pistol athletes.

Methods Twenty trained male air pistol athletes (age 18–35 years) were randomly assigned to an IMT group ($n=10$) or a control group ($n=10$). The IMT group performed supervised inspiratory muscle training twice daily (30 breaths/session), six days per week, for four weeks, using a threshold-loading device set initially at 40% of maximal inspiratory pressure (MIP), with progressive overload applied weekly. Both groups maintained their regular shooting training routines. Pre- and post-intervention assessments included countermovement jump (CMJ) and squat jump (SJ) performance (OptoJump), visual and auditory reaction time (Cognitech), and shooting performance evaluated via the SCATT system. A two-way repeated-measures ANOVA (group × time) was used for statistical analysis.

Results Significant group × time interactions were observed for CMJ height ($p<0.001$, $\eta^2p=0.618$), CMJ power ($p=0.007$, $\eta^2p=0.345$), SJ height ($p=0.050$, $\eta^2p=0.184$), and SJ power ($p=0.050$, $\eta^2p=0.181$), indicating meaningful improvements in explosive performance in the IMT group. Shooting accuracy demonstrated a large and statistically significant interaction effect ($p<0.001$, $\eta^2p=0.532$), with substantial improvement observed only in the IMT group. Reaction time variables showed favourable but non-significant trends ($p>0.05$).

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Conclusion A short-term IMT intervention significantly enhanced lower-limb explosive performance and shooting accuracy in competitive air pistol athletes without altering overall training load. These findings suggest that IMT may represent an effective, low-cost adjunct strategy to improve neuromuscular stability and fine-motor precision in precision-sport athletes.

Trial registration This trial was registered at ClinicalTrials.gov under the title " Inspiratory Muscle Training Enhances Jumping Power and Shooting Performance in Elite Air Pistol Athletes" (ClinicalTrials.govNCT07406451 registration date 06 February 2026 retrospectively registered).

Keywords Inspiratory Muscle Training, Jump performance, Shooting performance, SCATT, Reaction Time

Introduction

Air pistol shooting is a precision sport that requires the integration of physiological control, neuromuscular coordination, and psychological stability. Optimal performance depends on maintaining a steady posture, fine motor coordination, and controlled breathing during the aiming and triggering phases [1, 2]. Even minor disturbances in body sway, muscle activation, or respiratory rhythm can affect aim stability and shot precision. Consequently, the efficiency of the respiratory and neuromuscular systems plays a crucial role in sustaining accuracy and consistency during competition.

The respiratory system contributes not only to ventilation but also to postural stability. The diaphragm and accessory inspiratory muscles help regulate intra-abdominal pressure and provide a stable foundation for distal limb movement [3]. This mechanism supports trunk stability and balance, two essential elements of shooting performance. Improved respiratory function can enhance oxygen delivery, reduce fatigue, and support fine motor control, all of which are critical for precision tasks [4].

Inspiratory muscle training (IMT) is a specific resistance-breathing method designed to strengthen the inspiratory muscles. Regular IMT improves maximal inspiratory pressure (MIP), increases respiratory endurance, and delays the onset of fatigue in both respiratory and locomotor muscles [4, 5]. Enhanced inspiratory muscle strength also contributes to improved core stability and intra-abdominal pressure regulation, potentially facilitating better postural control and steadiness during aiming tasks [6, 7]. Breathing control is known to influence psychophysiological regulation, including heart rate variability, attentional focus, and motor synchronization [8, 9]. Elite shooters exhibit slower, more controlled breathing patterns that synchronize with aiming and trigger actions, suggesting a functional link between respiratory control and performance stability [10, 11]. Strengthening the inspiratory muscles may enhance these mechanisms by reducing respiratory effort and stabilizing the trunk, thereby improving shot consistency and accuracy.

Although IMT has been extensively studied in endurance and strength-based sports, limited evidence exists regarding its potential benefits in precision disciplines such as shooting. Air pistol shooting provides a unique opportunity to explore how respiratory muscle strengthening might influence both fine-motor control and neuromuscular efficiency. Improved inspiratory function could decrease tremor amplitude, enhance oxygenation, and reduce psychophysiological strain, factors that collectively promote more stable and accurate performance [12]. Emerging evidence also indicates that respiratory muscle training can induce cross-system adaptations, enhancing limb strength and explosive power through shared neuromuscular pathways [6]. These effects may benefit performance measures beyond respiration, such as lower-limb power, balance, and reaction time.

Importantly, air pistol athletes must maintain prolonged, static postural alignment while minimizing involuntary sway, and even low levels of respiratory fatigue can destabilize this delicate balance. This makes inspiratory muscle strength particularly relevant for sustaining fine-motor precision under competitive conditions.

Given these findings, inspiratory muscle training may offer multidimensional advantages by improving respiratory efficiency, postural control, and neuromuscular coordination. However, the evidence in precision sports remains scarce. Taken together, these physiological and neuromechanical mechanisms reinforce the rationale that IMT could enhance both gross motor capacities and the fine-motor precision required in shooting performance. No previous studies have examined the effects of IMT on shooting performance in air pistol athletes. The combined effects of IMT on both neuromuscular (e.g., jumping performance) and precision-based outcomes (e.g., shooting accuracy) have not been simultaneously investigated. Furthermore, the underlying mechanisms linking respiratory muscle function to performance in precision sports remain unclear.

The primary aim of this study was to examine the effects of a four-week IMT on shooting accuracy and reaction time in elite air pistol athletes. Secondary outcome included lower-limb explosive performance. It was hypothesized that IMT would enhance respiratory muscle strength and neuromuscular coordination, resulting in improved explosive power and shooting precision.

Materials and methods

Research design

This study was designed as a 4-week parallel-group randomized controlled trial with pre– and post–assessments. The primary aim of this study was to examine the effects of a four-week IMT on shooting accuracy and reaction time in elite air pistol athletes. Secondary outcome included lower-limb explosive performance. These performance components are widely recognized as essential contributors to success in precision sports that rely on postural stability, attentional control, and neuromuscular coordination [13, 14]. Their inclusion was based on existing literature and expert consultation to ensure a comprehensive and sport-specific evaluation framework. Reaction time were selected as indicator of rapid sensorimotor responsiveness, while jumping performance reflected joint mobility, muscular function, and explosive strength capacity [15]. After baseline testing, athletes were randomly allocated to an IMT group or a control group, after which the IMT group completed a 4-week training protocol in addition to their regular practice, whereas the control group maintained standard training routines. All outcome measures were collected at identical pre- and post-intervention time points to determine short-term adaptation to IMT. The primary outcome measures were shooting performance (SCATT) and reaction time. Secondary outcomes included lower-limb explosive performance (CMJ, SJ). The overall experimental procedure is illustrated in Fig. 1. No adverse events were reported during the training or testing procedures.

Participants

Twenty male volunteer air-pistol athletes from various regions of Turkey participated in the study. All participants were registered athletes competing at the national level and were ranked within the top 20 in their respective categories. Additionally, 95% of the sample had experience representing the national team. The required sample size was estimated using G*Power 3.1.9.7 (University of Düsseldorf, Germany) for a repeated-measures ANOVA (within–between interaction), assuming a medium effect size (f = 0.30) based on previous SCATT performance research [16], an alpha level of 0.05, and a statistical power of 0.80. The minimum required sample size was 18; therefore, 20 athletes were recruited to

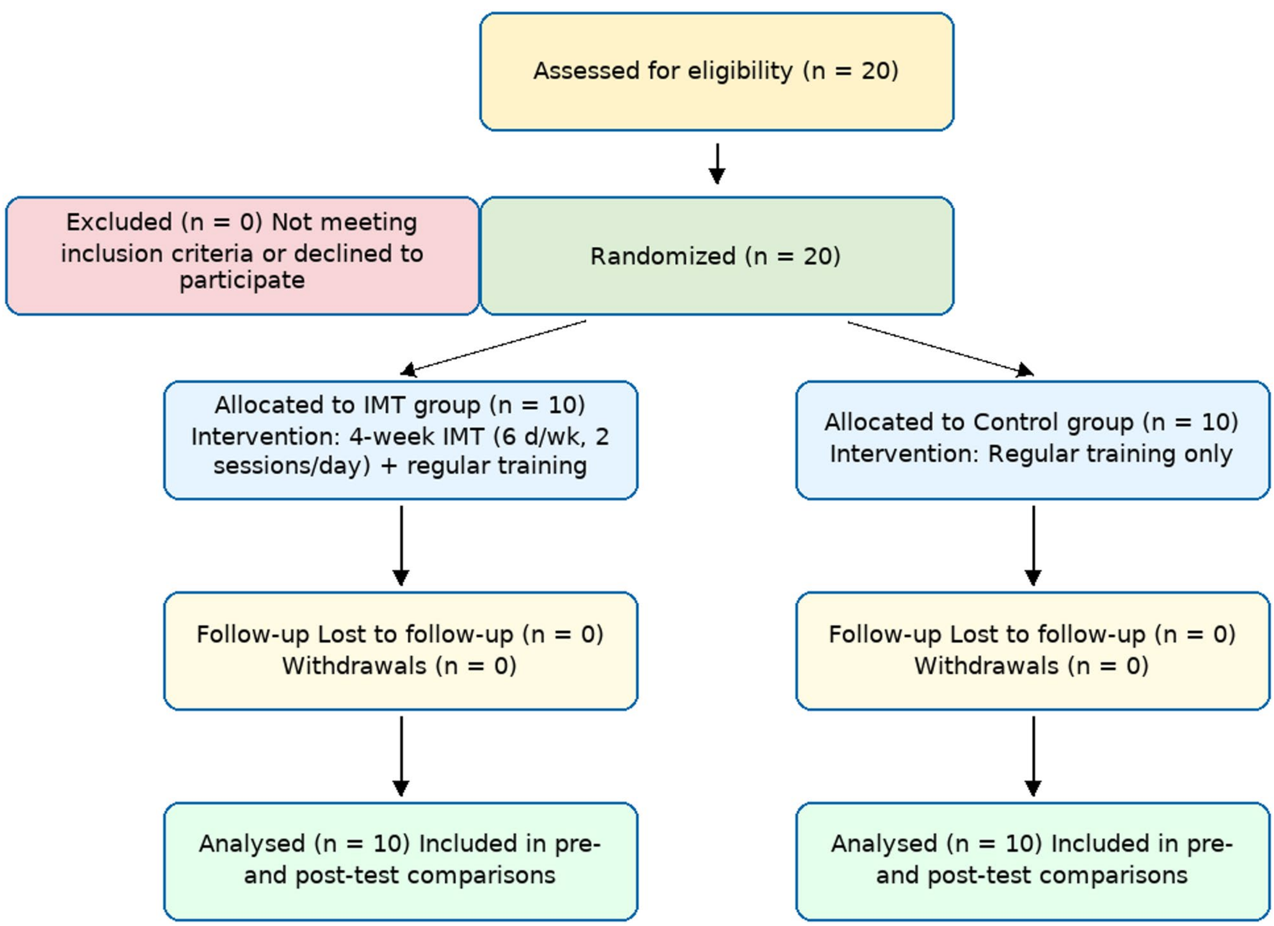

Fig. 1 Experimental design

ensure adequate power while accounting for potential dropouts. Randomization followed a two-stage procedure. First, 20 numbers were generated, placed in sealed envelopes, and drawn by the participants. Second, athletes were allocated to the IMT group or control group using a computerized randomization tool (https://www.randomizer.org/). Each group included ten participants. Inclusion criteria were as follows: (i) male athletes aged 18–35 years; (ii) no diagnosed musculoskeletal, respiratory, or chronic disease; (iii) engagement in continuous physical training for at least six months; (iv) possession of a valid federation license and active participation in national-level competitions; (v) a minimum of 5 years of competitive experience, and ranking within the top 20 at the national level All participants completed a comprehensive medical screening prior to enrolment and provided medical clearance to participate. Efforts were made to ensure comparability between groups regarding demographic and training-related characteristics, thus allowing performance outcomes to be interpreted independent of confounding factors [17]. Participants were instructed to maintain their usual diet and sleep patterns during the study period to minimize potential confounding effects. The study was approved by the Çankırı Karatekin University Health Sciences Ethics Committee and conducted in accordance with the Declaration of Helsinki (Meeting No: 19; Decision No: 10-04-2025). All athletes provided written informed consent prior to participation. This trial was retrospectively registered at ClinicalTrials.gov (NCT07406451; registration date: 06 February 2026, retrospectively registered).

Training protocol

Inspiratory muscle training (IMT)

IMT was performed using a POWERbreathe® Classic device (IMT Technologies Ltd., Birmingham, UK). The program consisted of two daily sessions (morning and evening) performed six days per week for four weeks. Each session included 30 resisted breaths, resulting in a total of 60 breaths per day [18]. The protocol followed previously validated IMT methods shown to be effective in healthy and athletic populations [19]. Training resistance was initially set at 40% of each participant's maximal inspiratory pressure (MIP) and was increased weekly by approximately 10 cmH_2O, in line with established recommendations [20]. All IMT sessions were supervised by a sports science specialist to ensure correct technique and training adherence. To minimise observer bias, the supervisor was not involved in data collection, outcome assessment, or statistical analysis. Performance testing was conducted by an independent evaluator blinded to group allocation. Participants were blinded to the expected effects of the IMT to reduce performance bias. Athletes in the IMT group performed the program in addition to their regular training, while the control group continued their usual training routines without IMT. Compliance with the IMT program was high (mean adherence: 96%), with most athletes completing 22–24 supervised sessions during the intervention period. Adherence logs were recorded daily.

Measurement procedures

All performance assessments were conducted under standardized laboratory and sports hall conditions by experienced sports scientists, physiotherapists, and certified coaches. Before each testing session, participants completed a 10-minute standardized warm-up, widely employed in performance-testing protocols. The warm-up included dynamic stretching (e.g., leg swings, arm circles), light jogging or brisk walking, and joint-mobilization exercises designed to increase muscle temperature, enhance neuromuscular activation, and improve the viscoelastic properties of the muscle–tendon unit [21]. Following the warm-up, evaluators confirmed that athletes had reached an adequate physiological state for safe and valid performance testing. Minor adjustments to warm-up intensity or duration were made individually to ensure optimal readiness and to minimize any potential influence of fatigue or under-activation.

Reaction time tests

Visual and auditory reaction times were assessed using a high-precision Reaction Time Tester (Cognitech Ltd., UK). Reaction time is a key cognitive–motor component in shooting performance, reflecting the ability to respond rapidly and accurately to external stimuli [12]. Participants were exposed to two stimulus types: (i) visual (sudden light signals) and (ii) auditory (brief sound cues). Three trials were executed for each stimulus type. Each trial lasted 5 s, yielding a total of nine measurements.

Testing was conducted in a quiet, distraction-free laboratory to ensure internal validity [22]. The device recorded the latency between stimulus onset and motor response in milliseconds. The mean value of the trials was used for analysis. Reaction time is regarded as a multidimensional neuromotor indicator related to cognitive processing, neural conduction velocity, and motor execution [14].

The device was calibrated before each session in accordance with manufacturer guidelines. Tests were administered by trained sports scientists and physiotherapists, ensuring strict adherence to protocol. Rest intervals of 2–3 min were provided between trials to minimize fatigue effects [23]. All recorded data were securely transferred to a digital database for subsequent statistical analysis.

The jump performance test

Explosive lower-limb performance was evaluated using the OptoJump Next optoelectronic measurement system (Microgate S.r.l., Italy), which provides high-precision measurements of jump height, flight time, and contact dynamics [21]. Participants performed two vertical jump tests: the countermovement jump (CMJ) and the squat jump (SJ). The CMJ assessed elastic–reactive strength through a rapid stretch–shortening cycle, while the SJ evaluated concentric force production from a static semi-squat position [24, 25]. Each athlete performed three attempts per test, and the highest jump height and associated power output were used for analysis. Reliability was confirmed through intraclass correlation coefficients (ICC): CMJ = 0.819 and SJ = 0.871. Rest intervals of 2–3 min were provided to avoid fatigue. The OptoJump system uses infrared light barriers to record take-off and landing times with millisecond precision. Flight time was used to determine jump height, and take-off power was estimated using established biomechanical formulas. These variables provide objective indicators of explosive strength, neuromuscular coordination, and lower-limb power output [21, 25].

SCATT performance measurement

Shooting performance was assessed using the SCATT simulation system, a widely validated tool for evaluating technical precision in shooting sports. SCATT quantifies aiming stability, trigger execution, and barrel movement immediately before and during shot release using laser-based tracking technology. The system records micro-movements, involuntary oscillations, and shot dispersion with high temporal and spatial resolution. The SCATT system provides a quantitative measure of shooting accuracy and stability, reflecting factors such as aiming precision, shot dispersion, and hold stability.

All assessments were conducted under controlled laboratory conditions by an experienced shooting coach and a sports scientist. Each athlete performed the standardized number of shots prescribed by the test protocol, and measurements were repeated three times to ensure reproducibility. Reliability analysis yielded an intraclass correlation coefficient (ICC) of 0.883 for SCATT performance. This method provided objective insight into athletes' technical steadiness and aiming control, supporting performance evaluation based on scientifically validated criteria [26].

Maximum inspiratory pressure (MIP) measurement

Maximum inspiratory pressure (MIP) was assessed using a portable respiratory pressure meter (MicroRPM, CareFusion Micro Medical, Kent, UK), following the standards of the American Thoracic Society and the European Respiratory Society [20]. Participants performed maximal inspiratory efforts from residual volume while standing, breathing through a mouthpiece equipped with a 1 mm aperture to prevent glottic closure and minimize buccal muscle involvement. A nasal clip was used to eliminate nasal airflow. Three maximal attempts were performed, and values were recorded in cmH_2O; the mean of the trials was used. Measurement reliability demonstrated an ICC of 0.871. This assessment was used solely to determine IMT resistance settings and was not included as an outcome variable.

Data collection process

Data collection was conducted over three standardized laboratory visits. First, participants were familiarized with all testing procedures to minimize learning effects and ensure consistent performance. One week later, baseline (pre-intervention) measurements were obtained during the second visit, establishing a reference point for subsequent comparisons. Finally, post-intervention measurements were collected during the third visit, following the 4-week training period, allowing for the evaluation of short-term adaptations to the IMT protocol. To ensure measurement accuracy, all equipment was calibrated according to manufacturer specifications before each session, and calibration was verified again at the end of each session. Whenever irregular or technically invalid data were detected, measurements were immediately repeated, maintaining data reliability. Once collected, the data were carefully managed. All measurements were securely transferred to a pre-designed digital database with encryption and restricted-access protocols. Participant information was anonymized in accordance with ethical standards. To minimize potential confounding factors, routine checks were performed to ensure that participants adhered to study guidelines regarding diet, sleep, and additional physical activity. To prepare the dataset for analysis, routine backups and audit logs were maintained throughout the study. The dataset was systematically organized and verified, ensuring methodological consistency and readiness for statistical evaluation.

Data analyses

All statistical analyses were performed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA). Data distribution was evaluated using the Shapiro–Wilk test, complemented by visual inspections of histograms, Q–Q plots, and skewness–kurtosis values. Normally distributed variables are reported as mean ± standard deviation (SD). Between-group differences at baseline were examined using independent-samples t-tests. Intervention effects were analysed using a two-way repeated-measures ANOVA (group × time), followed by Bonferroni-adjusted post-hoc comparisons where appropriate. Effect sizes for ANOVA outcomes were calculated using partial

Table 1 Comparison of participants' defining characteristics according to their participation status in the final

Variable	Group	*n*	Mean	SD	t	*p*
Weight(kg)	IMT	10	72.51	13.92	1.079	0.295
	Control	10	66.83	9.14		
Height (cm)	IMT	10	173.1	6.06	0.254	0.803
	Control	10	172.5	4.38		
BMI (kg/m^2)	IMT	10	23.07	5.25	0.308	0.763
	Control	10	22.49	2.83		
BFP (%)	IMT	10	18.92	10.55	0.561	0.582
	Control	10	16.45	9.08		
Experience (year)	IMT	10	7.1	1.05	0.550	0.593
	Control	10	6.5	2.67		

Values are presented as mean ± standard deviation (SD). Independent-samples t-tests were used to compare baseline characteristics between groups. No significant differences were observed at baseline ($p > 0.05$)

Abbreviations: *BMI* Body Mass Index, *BFP* Body Fat Percentage, *SD* Standard Deviation

Table 2 Comparison of participants' jumping performance based on their qualification status for the final

Variable	Group	Pre-test Mean ± SD	Post-test Mean ± SD	95% Confidence Interval		Group x Time Interaction		
				Lower	Upper	F	p	η^2_p
Countermovement Jump (cm)	IMT	26.56 ± 8.55	32.68 ± 8.67↑	22.10	30.71	29.076	$p < 0.001$	0.618
	Control	26.25 ± 9.73	28.72 ± 9.60↑	26.40	34.99			
Countermovement Jump (W)	IMT	767.92 ± 134.5	853.41 ± 115.72↑	695.96	821.75	9.460	0.007	0.345
	Control	749.78 ± 133.28	787.87 ± 126.07↑	763.79	877.48			
Squat Jump (cm)	IMT	25.96 ± 8.48	29.37 ± 9.77↑	20.81	28.95	4.054	0.05	0.184
	Control	23.8 ± 8.86	25.5 ± 8.99↑	23.03	31.85			
Squat Jump (W)	IMT	756.45 ± 127.58	800.84 ± 131.10↑	675	795.29	3.978	0.05	0.181
	Control	713.84 ± 128.47	734.53 ± 133.33↑	705.57	829.80			

Values are presented as mean ± SD. A two-way repeated-measures ANOVA was used to examine group × time interaction effects. ↑ indicates improvement from pre- to post-test. $p < 0.05$ denotes significant time or interaction effects. Effect size is reported as partial eta-squared (ηp^2): small ≥ 0.01, medium ≥ 0.06, large ≥ 0.14

eta-squared (η^2p), interpreted as small (≥ 0.01), medium (≥ 0.06), or large (≥ 0.14) effects [27]. Measurement reliability across repeated trials was assessed using the intraclass correlation coefficient (ICC), interpreted as moderate (0.50–0.75), good (0.75–0.90), or excellent (> 0.90) reliability [28]. Statistical significance was set at $p < 0.05$.

Results

Table 1 presents a comparison of participants' baseline characteristics according to their final participation status. No statistically significant differences were observed between the IMT and control groups in any of the descriptive variables, including weight, height, BMI, body fat percentage, or experience (all $p > 0.05$). This indicates that the two groups were comparable at baseline.

Table 2 shows the effects of training conditions on jumping performance. Two-way repeated measures ANOVA revealed significant group × time interactions for all jumping variables: CMJ height ($F(1,18) = 29.08$, $p < 0.001$, $\eta^2p = 0.618$), CMJ power ($F(1,18) = 9.46$, $p = 0.007$, $\eta^2p = 0.345$), SJ height ($F(1,18) = 4.05$, $p = 0.05$, $\eta^2p = 0.184$), and SJ power ($F(1,18) = 3.98$, $p = 0.05$, $\eta^2p = 0.181$). Post-hoc Bonferroni tests indicated significant pre-to-post improvements in the IMT group across all measures ($p < 0.05$), with medium-to-large effect sizes (Cohen's d = 0.38–0.70). In contrast, the control group showed only small, non-significant changes. These results suggest that IMT had a meaningful impact on lower-limb explosive performance.

Table 3 summarizes changes in visual and auditory reaction times and shooting performance. Neither visual nor auditory reaction time showed statistically significant group × time interactions, although moderate effect sizes were observed (visual: $F = 2.861$, $p = 0.108$, $\eta^2p = 0.137$; auditory: $F = 3.708$, $p = 0.071$, $\eta^2p = 0.179$). The IMT group showed minimal improvements, while the control group slightly worsened. In contrast, shooting performance measured via SCATT demonstrated a very large and statistically significant group × time interaction ($F = 20.452$, $p < 0.001$, $\eta^2p = 0.532$). Post-hoc tests confirmed substantial improvement in the IMT group (Δ=+15.50 ± ~6.8 points, Cohen's d ≈ 1.10), whereas the control group showed only a small, non-significant increase (Δ=+5.40 points). These findings indicate that IMT selectively enhanced both explosive lower-limb performance and shooting accuracy.

Table 3 Comparison of visual and auditory reaction performance based on participation in the final

Variable	Group	Pre-test Mean ± SD	Post-test Mean ± SD	95% Confidence Interval		Group x Time Interaction		
				Lower	Upper	F	p	η^2_p
Visual Reaction	IMT	0.49 ± 0.06	0.47 ± 0.04↓	0.484	0.561	2.861	0.108	0.137
	Control	0.55 ± 0.10	0.59 ± 0.12	0.490	0.571			
Auditory Reaction	IMT	0.49 ± 0.05	0.47 ± 0.04↓	0.508	0.581	3.708	0.071	0.179
	Control	0.59 ± 0.10	0.63 ± 0.10	0.511	0.583			
SCATT	IMT	548.50 ± 8.58	564 ± 6.78↑	548.33	564.17	20.452	$p < 0.001$	0.532
	Control	538 ± 15.14	543.4 ± 15.62↑	532.78	5.48.62			

Values are presented as mean ± SD. Group × time interaction effects were analysed using repeated-measures ANOVA. ↑ indicates improvement; ↓ indicates deterioration of performance. $p < 0.05$ denotes a statistically significant interaction effect. Partial eta-squared (η^2_p) reflects effect magnitude: small ≥ 0.01, medium ≥ 0.06, large ≥ 0.14

Discussion

The primary aim of this study was to examine the short-term effects of a four-week inspiratory muscle training (IMT) protocol on multidimensional performance variables, including jumping ability, reaction time, and shooting accuracy, in competitive air pistol athletes. The principal findings revealed that IMT produced significant improvements in explosive lower-limb performance and shooting accuracy, while reaction-time parameters demonstrated non-significant yet favourable tendencies. These findings highlight the multifactorial influence of respiratory muscle conditioning on both biomechanical and fine-motor components of precision sports. These findings are consistent with previous literature suggesting that inspiratory muscle training may influence trunk stability and neuromuscular coordination; however, such mechanisms remain speculative in the context of the present data.

The significant improvements in CMJ and SJ height and corresponding power outputs in the IMT group are consistent with mechanistic models describing the role of the diaphragm and accessory inspiratory muscles in trunk stiffness, intra-abdominal pressure regulation, and kinetic chain efficiency. The diaphragm serves not only as a respiratory muscle but as a fundamental component of postural stabilization, enhancing spinal rigidity and facilitating optimal force transmission during explosive movements [29]. Reinforced inspiratory musculature yields greater control of thoraco-abdominal pressure, enabling more efficient hip-trunk coupling, which is critical for jump mechanics. Although jumping is not a direct performance factor in shooting, improvements in lower-limb power may indirectly contribute to a more stable stance, especially during long shooting sessions where postural fatigue can accumulate.

Previous evidence supports the cross-transfer effects of IMT on locomotor performance. Illi et al. (2012) and McConnell & Lomax (2006) demonstrated that reducing respiratory muscle fatigue lowers sympathetic drive and delays peripheral fatigue in limb muscles, thereby enhancing power production [4, 6]. The moderate-to-large effect sizes observed in the present study ($\eta^2 p \approx$ 0.18–0.62) mirror those reported in systematic reviews showing that IMT improves explosive performance indices in trained populations [30, 31]. Taken together, the evidence suggests that IMT may not act through a single pathway but through a network of physiological adjustments that support more efficient and coordinated movement.

All these findings in the literature, taken collectively, demonstrate that IMT not only provides increased strength in respiratory muscles but also leads to neuromechanical adaptations that improve posture control, kinetic efficiency, and coordinated muscle activation patterns [4, 6, 30, 31]. For athletes in precision sports, these fine adjustments may have a disproportionate effect, as even small reductions in wobble or micro-imbalance can affect the final shot placement. This is particularly important for air pistol athletes whose static shot posture requires precise trunk stabilization. It is important to acknowledge that the absence of a sham IMT group in this study limits the ability to isolate the specific physiological effects of inspiratory loading. Non-specific factors such as increased attention, supervision, participant expectations, and placebo effects may have contributed to the observed improvements. The IMT group received additional structured intervention and close monitoring; this may have increased motivation and compliance and potentially influenced performance outcomes independently of respiratory adaptations.

Despite small improvements in the IMT group, neither visual nor auditory reaction time reached statistical significance. Reaction time is influenced predominantly by cortical processing, sensorimotor integration, and long-term perceptual-cognitive development rather than respiratory musculature function alone [32]. Therefore, the lack of significant change aligns with the known specificity of reaction-time adaptations to targeted neuromotor drills. Still, the slightly improved reaction times in the IMT group suggest that reducing respiratory effort may free cognitive resources, potentially facilitating faster information processing, a trend that may become meaningful with longer training periods.

However, the direction of the observed changes, improved RT in IMT athletes versus slightly worsened RT in controls, may represent an early neuromotor facilitation resulting from reduced respiratory effort, increased oxygenation, and diminished fatigue-related interference in central motor pathways [33]. Longer IMT durations may be necessary for significant changes in RT, as suggested by neurocognitive training literature.

The most robust finding of the study was the large effect of IMT on shooting accuracy ($\eta^2 p = 0.532$). This aligns with theoretical models linking respiration to sensorimotor stability and fine-motor precision. Improved diaphragm strength reduces breathing-induced sway, stabilizes the trunk, and minimizes micro-movements during the aiming phase. The observed improvements in shooting accuracy may be related to enhanced postural stability and trunk control, although these mechanisms were not directly assessed in the present study. The observed 15.5-point increase in SCATT score should be interpreted not only in terms of statistical significance but also in practical terms. The SCATT system reflects shooting precision and stability, and improvements in this score may indicate enhanced control over aiming and shot execution. In high-level shooting sports, even modest gains in accuracy can translate into meaningful competitive advantages. Therefore, the magnitude of change observed in this study can be considered practically relevant. From a practical perspective, a 15.5-point increase may indicate improved shot consistency and reduced aiming error, which are critical determinants of competitive shooting performance. In precision sports such as air pistol shooting, even small improvements in accuracy can influence ranking positions and competition outcomes. Although a minimal clinically important difference (MCID) for SCATT scores has not been firmly established, the magnitude of change observed may be considered practically meaningful based on performance context.

Previous studies have shown that elite shooters synchronise their breathing cycles with trigger release and use breath-holding phases to optimise postural immobility [34–36]. IMT reduces involuntary oscillations by decreasing fatigue in respiratory muscles. It improves weapon control by enhancing postural-respiratory synergy [7]. It supports the precision of fine motor skills by increasing corticospinal excitability [6]. It also stabilises the core muscles, which are directly related to aiming accuracy in precision sports [2], potentially enhancing all these mechanisms. In practical terms, this means that shooters may experience a calmer, more controlled aiming process, an advantage that becomes especially valuable under competitive pressure.

Considering that performance changes in the control group were minimal, the significant improvements in the IMT group indicate a direct physiological contribution rather than an effect of practice or learning. The observed improvements in shooting performance may be associated with enhanced postural stability and respiratory control; however, causal mechanisms cannot be definitively established due to the absence of a sham-controlled design. Overall, these results suggest that even a relatively short IMT intervention can produce meaningful, real-world performance benefits for precision athletes.

The observed improvements in shooting performance may be associated with enhanced postural stability and respiratory control; however, causal mechanisms cannot be definitively established due to the absence of a sham-controlled design. While several physiological and neuromechanical mechanisms may explain the observed performance improvements, including enhanced postural stability, intra-abdominal pressure regulation, and corticospinal excitability, these variables were not directly measured in the present study. Therefore, any mechanistic interpretation should be considered speculative. Future studies incorporating direct assessments such as electromyography, postural sway analysis, or neurophysiological measurements are needed to clarify the underlying pathways.

Limitations

This study has several limitations that should be acknowledged to properly contextualize the findings. First, the sample size was relatively small, which may have limited the statistical power to detect more subtle effects, especially for reaction-time variables. Considerable inter-individual variability was observed in response to the intervention. Therefore, the relatively large effect sizes observed in this study should be interpreted with caution, as small sample sizes can lead to an overestimation of true effects. Second, because the sample included only male athletes, the results cannot be readily generalized to female shooters or broader athlete populations. Third, all participants were recruited from a limited number of sports clubs in Turkey, which may restrict the cultural and geographical representativeness of the results. Another important limitation concerns the type of performance assessments used. Most of the measurements focused on general physical fitness rather than sport-specific neuromechanical indicators, which may reduce the ecological validity of the findings in real competition settings. Additionally, there is the absence of a sham control group. Without a placebo or low-load IMT condition, it is not possible to fully distinguish between the specific physiological effects of inspiratory muscle load and non-specific effects such as increased attention, control, or anticipatory effects. This limitation reduces the internal validity of causal inferences regarding the effectiveness of IMT. Furthermore, it means that while objective device-based measurements (OptoJump, SCATT, Cognitech) help reduce the possibility of measurement bias, effects related to anticipatory or attention cannot be completely ruled out.

Finally, the study did not include psychological variables such as attentional control, mental focus, or stress regulation factors known to meaningfully influence shooting performance. Incorporating these elements in future research would help clarify whether IMT contributes not only to physical improvements but also to cognitive and psychophysiological functioning during shooting tasks.

Practical implications

The results of this study demonstrate that IMT is a practical, low-cost, and time-efficient method that can be systematically integrated into preparation programs for elite athletes. Significant benefits have been identified, including improvements in body stability and posture control, increased explosive force production, increased shooting accuracy without changing the training load, reduced respiratory effort during performance, and support for greater attention control, which may indirectly relate to performance-related factors such as concentration, although these were not directly assessed. These findings highlight the potential for IMT to become a standard component of technical-tactical and physical preparation for shooters. In addition, because the training requires minimal equipment and can be performed almost anywhere, coaches can incorporate IMT into warm-ups, recovery sessions, or individual training plans without disrupting existing routines. Overall, the practicality of IMT makes it highly suitable for precision sports, where small physiological advantages can translate into meaningful performance gains.

Future research

Future studies should aim to strengthen the evidential basis of IMT by employing larger and more diverse samples that include female athletes, youth competitors, and shooters from different cultural backgrounds. The use of sham-IMT protocols will be essential for isolating the true physiological effects of inspiratory loading from potential expectancy or supervision-related influences. Additionally, future research should incorporate comprehensive psychological and psychophysiological assessments, such as attentional control, mental focus, and stress-regulation indices, to provide a deeper understanding of how IMT influences cognitive-motor processes relevant to shooting performance. Although attention and cognitive control were not assessed in this study, future research may explore whether IMT has indirect effects on such variables. Advanced neuromechanical and neurophysiological measurement techniques (e.g., EMG, eye-tracking, electroencephalography, intra-abdominal pressure monitoring) should also be utilized to elucidate the mechanistic pathways through which IMT contributes to postural stability, movement coordination, and fine-motor precision. Longitudinal studies would also help determine whether the improvements observed in this short-term intervention translate into long-term competitive performance gains, retention of gains, and changes across an entire shooting season.

Conclusions

The present study investigated the effects of a four-week inspiratory muscle training (IMT) program on the physical and motor performance of air pistol shooters. The findings indicate that IMT significantly increased lower-extremity explosive strength, jump height, power output, and shooting accuracy, while reaction-time improvements did not reach statistical significance. However, variables such as attention, cognitive control, and psychological factors were not assessed and therefore should not be inferred from the present results. Future studies are warranted to examine these aspects. The moderate to large effect sizes observed despite the short intervention period highlight the potential of IMT to provide rapid and meaningful contributions to athletic performance. Importantly, these improvements were achieved without altering the athletes' normal training load, underscoring the efficiency of IMT as a supplemental method. IMT appears to be a promising adjunct training strategy; however, the findings should be interpreted with caution due to potential non-specific effects. Overall, IMT appears to be a safe, efficient, and practically applicable method that can be incorporated into the physical preparation practices of precision-sport athletes. IMT may contribute to improvements in performance, potentially through mechanisms related to neuromuscular coordination and stability. Given its accessibility and low time requirement, IMT may offer a valuable competitive edge for shooters seeking consistent improvements in stability and accuracy.

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

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Authors' contributions

Conceptualization, A.S.A., C.Y., T.A., M.S., G.G., V.T., Y.S., E.E., V.A.G. and R.Ç.; Methodology, A.S.A., C.Y., T.A., Y.S., M.S., and R.Ç.; Software, A.S.A., C.Y., Y.S., İ.K., T.C., T.A., E.E.; Validation, A.S.A., C.Y., M.S., G.G., V.T., T.A. and V.A.G.; Formal Analysis, C.Y., M.S., T.A., E.E. and I.K.; Investigation, A.S.A., C.Y., T.C., G.G., Y.S., and E.E.; Resources, C.Y. and T.A.; Data Curation, A.S.A., C.Y., T.A., M.S., and I.K.; Writing—Original Draft Preparation, A.S.A., C.Y., E.E., V.Y., T.C., T.A., V.T.; Writing—Review and Editing, C.Y., M.S., Y.S., T.C., D.G.B., and V.A.G.; Visualization, A.S.A., C.Y., and T.A.; Supervision, C.Y., D.G.B., R.Ç. and V.A.G.; Project Administration, C.Y., V.A.G. and D.G.B.; Funding Acquisition, D.G.B., R.Ç., Y.S., E.E., V.A.G., and C.Y. All authors have read and agreed to the published version of the manuscript.

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Data availability
The data that support the findings of this study are available on request from the corresponding author.

Declarations

Ethics approval and consent to participate
The study was approved by the Çankırı Karatekin University Health Sciences Ethics Committee (Meeting No: 19, Decision No: 10-04-2025) and conducted in accordance with the principles of the Declaration of Helsinki (World Medical Association, 2013). All participants provided written informed consent prior to participation. This trial was registered at ClinicalTrials.gov under the title "Inspiratory Muscle Training Enhances Jumping Power and Shooting Performance in Elite Air Pistol Athletes" (Registration ID: NCT07406451; registration date: 06 February 2026, Retroactively). This manuscript has been prepared in accordance with the CONSORT 2025 reporting guidelines for randomized controlled trials.

Consent for publication
Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the participants to publish this paper.

Competing interests
The authors declare no competing interests.

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