Natural Resources for Human Health
eISSN: 2583-1194

Original Research

Received 12 May 2026
Revised 20 June 2026
Accepted 12 July 2026

Natural Resources for Human Health 2026, Vol. 6 (6s): 721–732

KEYWORDS:
Air Rifle Shooting; Cervical Strengthening; Balance Training; Postural Stability

Effect Of Cervical Strengthening Exercises and Lower Limb Balance Training on Craniocervical Flexion Endurance, Static and Dynamic Balance in Air Rifle Shooters

Shalini Solank[1], Tabish Fahim*[2]

[1]Shalini Solanki, PhD Scholar, GD Goenka University, Gurugram
[2]Dr Tabish Fahim, Associate Professor, GD Goenka University, Gurugram
Corresponding author: Dr Tabish Fahim, Associate Professor, GD Goenka University, Gurugram

ABSTRACT: Air rifle shooting places sustained postural demands on athletes, requiring precise neuromuscular control during prolonged standing positions. No prior study has examined whether combining cervical strengthening with lower limb balance training yields postural improvements or not. This randomised, three-group parallel trial enrolled 105 senior 10-metre air rifle shooters (mean age 20.86 ± 2.20 years) from Delhi National Capital Region (NCR) region. Group 1 received combined cervical strengthening and balance training, Group 2 underwent cervical strengthening alone, and Group 3 performed balance training alone, over six weeks. Craniocervical flexion endurance was assessed using the Craniocervical Flexion Test (CCFT), static balance using the Balance Error Scoring System (BESS), and dynamic balance using the modified Star Excursion Balance Test (mSEBT) at baseline, three weeks, and six weeks. All three groups showed significant within-group improvements over time ($p < 0.001$). Group 2 recorded the greatest absolute gain in CCFT (32.77 points; 38.26 to 71.03), followed closely by Group 1 (30.40 points; 38.69 to 69.09). Group 1 showed the greatest gains in balance outcomes, with BESS errors reducing by 9.28 points and mSEBT composite scores increasing by 9.66 points. At six weeks, Group 1 was significantly superior to both Group 2 and Group 3 on BESS ($F = 54.89$, $p < 0.001$) and mSEBT ($F = 11.71$, $p < 0.001$). These findings indicate that combining cervical proprioceptive training with lower limb balance training produces postural adaptations that surpass those achieved by either modality alone, supporting their integrated use in air rifle shooting conditioning programmes.

INTRODUCTION

Shooting performance in air rifle events depends considerably on the athlete's ability to minimise body movement between shots. The standing position is especially challenging: the shooter must support the rifle's asymmetric load while keeping the trunk nearly stationary for extended periods. Even minor muzzle oscillation during the release phase can result in a measurable scoring deficit (1,2). Under these conditions, the neuromuscular systems responsible for postural stability become a direct determinant of competitive outcome.

Maintaining postural equilibrium requires the continuous integration of visual, vestibular, and somatosensory inputs at the level of the brainstem and cerebellum (3). Among somatosensory contributors, the cervical region plays a particularly important role. The deep suboccipital and longus capitis muscles contain one of the highest muscle spindle densities in the human body, providing a continuous stream of head-position and movement-velocity information to the vestibular nuclei via primary and secondary afferent fibres (4,5). This cervicogenic input is further reinforced by the vestibulocollic reflex that activates cervical musculature in response to head perturbations and helps maintain gaze stability during dynamic tasks (6,7).

Sustained isometric loading or prolonged asymmetric head positioning, as commonly encountered in shooting, can lead to cervical muscle fatigue through both peripheral and central mechanisms. Peripherally, the accumulation of metabolic by-products such as inorganic phosphate and hydrogen ions reduces force output and impairs intrafusal stretch sensitivity, degrading spindle afferent discharge quality (8,9). Centrally, Group III and IV afferents activated by local acidosis inhibit motor unit firing through spinal and supraspinal pathways is a phenomenon broadly referred to as central fatigue (10). The combined effect distorts head-position signalling, increases centre-of-pressure sway velocity, and slows postural correction responses (11–13). In shooting, this problem is further compounded by the attentional demands of aiming, which reduce the athlete's capacity to rely on visual compensation when cervical sensory input is degraded (14,15).

Wobble board training has been widely used to improve neuromuscular postural control in athletic populations (16,17). Repeated exposure to surface perturbations refines motor unit recruitment patterns, shortens stretch-reflex latencies, and modifies how the central nervous system (CNS) weights competing sensory inputs (18,19). Physical fatigue degrades the data your brain receives from your senses and weakens your muscles' ability to react, forcing the body into less efficient backup strategies to stay upright (20). However, these adaptations primarily address the lower limb and core components of the postural chain. The cervical sensory-motor system equally critical in shooting remains largely unaddressed by balance training alone.

The literature currently lacks evidence on whether integrating cervical strengthening with wobble board balance training offers greater postural benefits than either intervention in isolation among competitive air rifle shooters. This study was designed to address that gap. Using a six-week randomised design, we compared the effects of combined training against each individual intervention, using the Craniocervical Flexion Test (CCFT), Balance Error Scoring System (BESS), and modified Star Excursion Balance Test (mSEBT) as primary outcome measures of craniocervical flexion endurance, static postural stability, and dynamic postural stability, respectively.

METHODOLOGY

Experimental Design

A prospective, three-arm randomised controlled trial was conducted between April 2025 and January 2026. Outcome measures were collected at baseline (Week 0), mid-intervention (Week 3), and post-intervention (Week 6). Ethical approval was obtained from the Waves Women Empowerment Trust Independent Ethics Committee (Reference: F.1/IEC/WWE/(06)/04/2024/No. 14), and the trial was registered with the Clinical Trials Registry India (CTRI/2025/02/080648, registered 17 February 2025). Written informed consent was obtained from all participants prior to enrolment. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki.

Participants

A priori power analysis was conducted using G*Power version 3.1.9.7 to determine the minimum required sample size for a repeated-measures ANOVA with between-subjects factors. The analysis assumed a medium effect size (Cohen’s $f = 0.25$), a significance level of $\alpha = 0.05$, and a desired statistical power of 0.80. The study design included three groups and three repeated measurements, with an assumed correlation of 0.50 among repeated measures. The analysis indicated that a minimum total sample size of 108 participants (36 participants per group) would be required. Participants were recruited from Tapasya Shooting Academy and Royal Rifle Academy, Delhi NCR. However, three participants were lost to follow-up, resulting in a final sample of 105 participants included in the analysis (35 per group). Senior-level 10-metre air rifle shooters competing within the Delhi NCR region were recruited from the Tapasya Shooting Academy and Royal Rifle Academy. Eligibility required active competitive participation. Shooters were excluded if they had any musculoskeletal, neurological, visual, or orthopaedic condition in the preceding three months that could affect balance testing or exercise tolerance, or if cervical radiculopathy, significant neck disability, or neural provocation signs were present (21). The enrolled cohort comprised 105 shooters with a mean age of 20.86 ± 2.20 years.

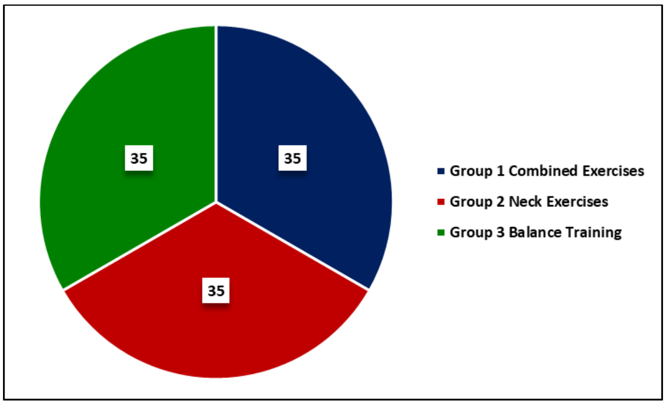

Figure 1 — Distribution of participants across intervention groups

Intervention Protocol

Group 1: Combined Training

Participants completed both cervical strengthening and wobble board balance training sessions, each conducted three times per week for six weeks. The cervical theraband progressive overload protocol was implemented in accordance with the original colour-coded elastic band progression system described by Page et al. (22). Sessions began with a warm-up of all cervical movements held for six seconds with three repetitions, followed by the primary circuit: neck shrugs, cervical flexion, extension, lateral flexion, rotation, and chin-tuck, performed for 10-25 repetitions across two to three sets with five-second inter-set rest intervals. Resistance commenced at yellow-band level and advanced sequentially through red, green, and blue as each participant achieved three sets of 25 repetitions, whereupon repetitions were reset to three sets of ten at the higher resistance level (23). Each cervical session was preceded and followed by five minutes of neck and shoulder stretching.

Balance training sessions of 15-30 minutes were conducted on the same days. Sessions opened with a five-minute warm-up comprising tip-toe walking, sagittal and frontal plane leg swings, walking knee pull-ups, walking lunges with hip rotation, and bilateral quadriceps stretching (two sets of ten repetitions per limb). The training circuit included single-leg stance, single-leg squats (30-45° knee flexion), and single-leg stance combined with a bilateral catching task, performed on both stable and unstable surfaces with eyes open and closed. Weeks one and two were performed on flat unstable surfaces; from week three onward, all balance exercises were transferred to the wobble board. Work-to-rest ratios of 20-30 seconds active to 20-30 seconds passive were maintained throughout (24,25).

Group 2: Cervical Strengthening Only

Participants in Group 2 followed the same cervical exercise protocol as Group 1, including the TheraBand progression, warm-up, and cool-down stretching, conducted three sessions per week for six weeks (22,23). No balance training was incorporated.

Group 3: Balance Training Only

Participants in Group 3 completed the same progressive balance training programme as described for Group 1, including the warm-up routine, progressive surface and volume increments, and three sessions of 15-30 minutes per week over six weeks (24,25). No cervical strengthening was included. The programme was structured in five progressive phases:

Phase 1 (Days 1-7): All exercises were performed on a firm floor surface with eyes open. Participants completed one set of eight repetitions per leg, incorporating single-leg stance, single-leg squats at 30-45° knee flexion, and single-leg stance combined with a functional catching activity.

Phase 2 (Days 8-14): The floor surface was maintained but eyes-closed conditions were introduced to increase proprioceptive demand. Volume progressed to two sets of ten repetitions per leg, retaining the same three exercises.

Phase 3 (Days 15-21): Participants were transitioned to a wobble board surface with eyes open. Exercise volume increased to two sets of 12 repetitions per leg, and the repertoire was modified to include single-leg stance, single-leg squats at 30 - 45°, and double-leg stance with active rotation of the unstable surface.

eISSN: 2583-1194

Phase 4 (Days 22-28): A dual visual condition was introduced within the same session. Single-leg stance was performed with eyes closed for two sets of 15 repetitions per leg, while single-leg squats and single-leg stance with surface rotation were performed with eyes open at the same volume, all on the wobble board.

Phase 5 (Days 29-42): The most demanding phase, maintaining the wobble board surface throughout. Volume was increased to three sets of 15 repetitions per leg for all exercises. Single-leg stance was performed with eyes closed, while single-leg squats and single-leg stance with unstable surface rotation were performed with eyes open, consolidating the neuromuscular adaptations developed across the preceding phases.

Outcome Measures

Craniocervical Flexion Test (CCFT) - The CCFT assesses the neuromuscular control, activation, and endurance of the deep cervical flexor muscles, as well as their co-ordination with the superficial flexors (26). The participant lies supine in crook lying with the cervical spine in a neutral position and no pillow. An uninflated pressure biofeedback unit is placed behind the neck, in contact with the occiput, and inflated to a baseline of 20 mmHg that is sufficient to fill the natural cervical lordosis without inducing excessive extension. The participant then gently nods the head in a cranio-cervical flexion movement, as if indicating 'yes.' Beginning at 20 mmHg, the participant attempts to reach five target pressure levels in 2 mmHg increments up to a maximum of 30 mmHg. At each level, the contraction is held isometrically for 10 seconds across 10 repetitions. Performance is recorded as the highest pressure level achieved (activation score), and a performance index is calculated based on the number of successful 10-second holds completed at that level (26).

Balance Error Scoring System (BESS) - Static postural stability was assessed using the BESS, a validated clinical balance tool (27). Participants performed six 20-second stances on double-leg, single-leg, and tandem, on both firm and foam surfaces with eyes closed and hands placed on the iliac crests. Errors were recorded for any deviation from the test position. The cumulative error score across all six stances was retained; a lower score indicates superior static balance.

Modified Star Excursion Balance Test (mSEBT) - Dynamic postural control was assessed using the mSEBT (28). Participants balanced on one limb and reached maximally with the contralateral foot in three directions: anterior, posteromedial, and posterolateral. Reach distances were normalised to leg length and averaged to produce a composite score; a higher composite score reflects superior dynamic balance.

Figure 2 — Eyes Closed Tandem Stance, Firm Surface **Figure 3** — Eyes Open Single Leg, Foam Surface

Natural Resources for Human Health
eISSN: 2583-1194

Figure 4 — Modified Star Excursion Balance Test (mSEBT). (A) and (B) show the anterior and posteromedial reach directions, respectively.

Statistical Analysis

Data are presented as mean ± SD. Within-group changes across the three time points were examined using repeated measures ANOVA (RM ANOVA); Bonferroni's post hoc test identified significant pairwise intervals. Between-group comparisons at each time point used one-way ANOVA followed by Tukey's Honestly Significant Difference (HSD) test. Statistical significance was set at $\alpha = 0.05$.

RESULTS

Cervical Muscle Endurance — Craniocervical Flexion Test (CCFT)

Baseline CCFT scores were comparable across groups (Group 1: 38.69 ± 13.66; Group 2: 38.26 ± 9.32; Group 3: 34.11 ± 8.61; $F = 1.93$, $p = 0.151$). All three groups showed statistically significant within-group improvements over six weeks ($p < 0.001$). Group 2 recorded the greatest absolute gain (32.77 points; 38.26 to 71.03), followed closely by Group 1 (30.40 points; 38.69 to 69.09). Group 3 demonstrated markedly smaller improvement (6.29 points; 34.11 to 40.40), consistent with the limited direct stimulus that balance training alone provides for deep cervical flexor endurance.

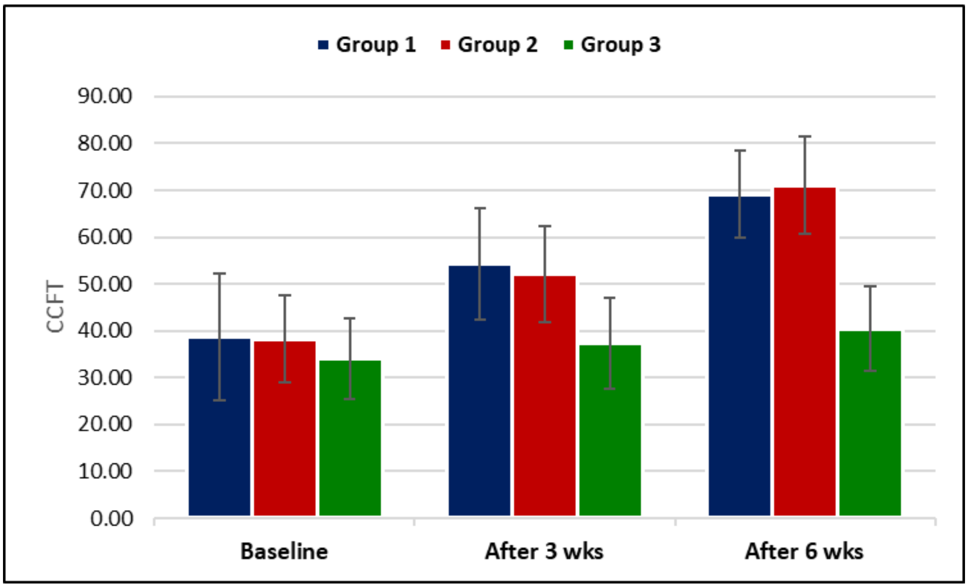

Figure 5 — Intergroup and intragroup comparison of CCFT Score

Intergroup differences were non-significant at baseline but became highly significant at three weeks (F = 25.91, p < 0.001) and six weeks (F = 111.4, p < 0.001). Tukey's post hoc analysis confirmed that both Group 1 and Group 2 were significantly superior to Group 3 at six weeks (mean differences: 28.69 and 30.63, respectively; both p < 0.001), while no significant difference was observed between Group 1 and Group 2 at any time point (p = 0.676 at six weeks). Bonferroni's analysis confirmed significant incremental gains at each interval across all groups, with Groups 1 and 2 demonstrating substantially greater progression than Group 3 throughout (Figure 5).

Table 1. Intergroup and intragroup comparison of CCFT Score

CCFT	Baseline Mean ± SD	3 Weeks Mean ± SD	6 Weeks Mean ± SD	RM ANOVA F-value	p-value
Group 1	38.69 ± 13.66	54.34 ± 11.88	69.09 ± 9.32	108.80	**<0.001**
Group 2	38.26 ± 9.32	52.11 ± 10.31	71.03 ± 10.40	176.40	**<0.001**
Group 3	34.11 ± 8.61	37.43 ± 9.68	40.40 ± 9.07	24.80	**<0.001**
Significance	F=1.93, p=0.151	F=25.91, p<0.001	F=111.4, p<0.001	—	—

Static Balance — Balance Error Scoring System (BESS)

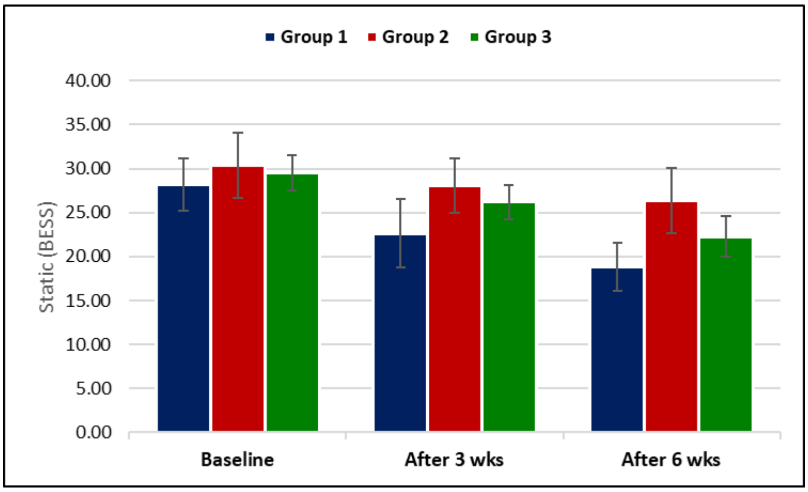

Figure 6 — Intragroup and intergroup comparison of static balance (BESS)

BESS error scores declined significantly within all three groups over six weeks (all p < 0.001). Group 1 improved from 28.14 ± 2.98 errors at baseline to 18.86 ± 2.75 at six weeks, a reduction of 9.28 errors (F = 136.10). Group 3 improved from 29.51 ± 2.03 to 22.29 ± 2.31 (reduction: 7.22 errors; F = 294.90), and Group 2 improved from 30.37 ± 3.66 to 26.34 ± 3.74 (reduction: 4.03 errors; F = 70.90). Intergroup differences were present at baseline (F = 5.02, p = 0.008) and grew substantially by three weeks (F = 27.84, p < 0.001) and six weeks (F = 54.89, p < 0.001). At six weeks, Group 1 outperformed Group 2 (mean difference: −7.49, p < 0.001) and Group 3 (mean difference: −3.43, p < 0.001). Group 3 also surpassed Group 2 (mean difference: 4.06, p < 0.001) (Figure 6).

Table 2. Intragroup and intergroup comparison of static balance (BESS)

BESS	Baseline Mean ± SD	3 Weeks Mean ± SD	6 Weeks Mean ± SD	RM ANOVA F	p
Group 1	28.14 ± 2.98	22.63 ± 3.91	18.86 ± 2.75	136.10	**<0.001**
Group 2	30.37 ± 3.66	28.06 ± 3.11	26.34 ± 3.74	70.90	**<0.001**
Group 3	29.51 ± 2.03	26.23 ± 1.94	22.29 ± 2.31	294.90	**<0.001**

BESS	Baseline Mean ± SD	3 Weeks Mean ± SD	6 Weeks Mean ± SD	RM ANOVA F	p
Significance	F=5.02, p=0.008	F=27.84, p<0.001	F=54.89, p<0.001	—	—

Dynamic Balance — Modified Star Excursion Balance Test (mSEBT)

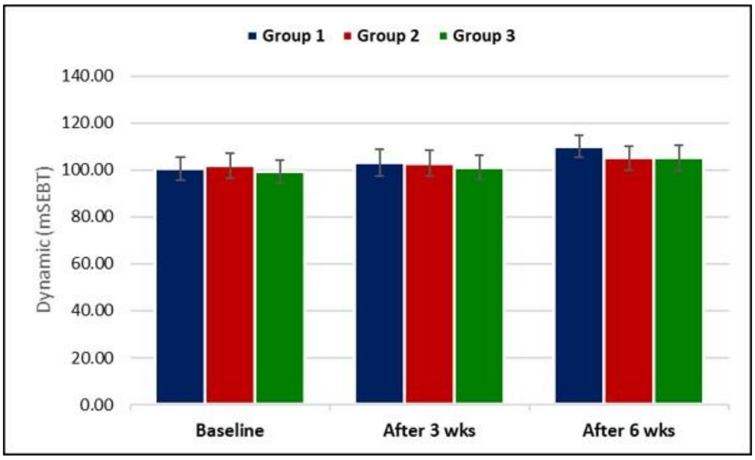

Figure 7 — Intragroup and intergroup comparison of dynamic balance (mSEBT)

mSEBT composite scores improved significantly within all groups (all p < 0.001). Group 1 progressed from 100.48 ± 4.97 at baseline to 110.14 ± 4.58 at six weeks (gain: 9.66 points; F = 81.80). Group 3 improved from 99.18 ± 4.84 to 105.06 ± 5.37 (gain: 5.88 points; F = 347.40), and Group 2 from 101.86 ± 5.33 to 105.09 ± 5.18 (gain: 3.23 points; F = 215.50). Groups were comparable at baseline (p = 0.090) and three weeks (p = 0.065). By six weeks, between-group differences were highly significant (F = 11.71, p < 0.001); Group 1 exceeded Group 2 (mean difference: 5.05, p < 0.001) and Group 3 (mean difference: 5.08, p < 0.001), while Groups 2 and 3 were indistinguishable from each other (p = 0.999) (Figure 7).

Table 3. Intragroup and intergroup comparison of dynamic balance (mSEBT) across assessment points

mSEBT	Baseline Mean ± SD	3 Weeks Mean ± SD	6 Weeks Mean ± SD	RM ANOVA F	p
Group 1	100.48 ± 4.97	103.10 ± 5.71	110.14 ± 4.58	81.80	**<0.001**
Group 2	101.86 ± 5.33	102.85 ± 5.53	105.09 ± 5.18	215.50	**<0.001**
Group 3	99.18 ± 4.84	101.14 ± 5.04	105.06 ± 5.37	347.40	**<0.001**
Significance	F=2.47, p=0.090	F=1.35, p=0.065	F=11.71, p<0.001	—	—

Table 4. Intergroup comparison of parameter changes from baseline to six weeks

Parameter Change	Group 1 Mean ± SD	Group 2 Mean ± SD	Group 3 Mean ± SD	ANOVA F	p
CCFT	30.40 ± 12.87	32.77 ± 12.68	6.29 ± 5.82	62.60	**<0.001**
BESS (static)	−9.29 ± 2.11	−4.03 ± 2.18	−7.23 ± 2.03	55.40	**<0.001**
mSEBT (dynamic)	9.66 ± 5.14	3.23 ± 1.03	5.88 ± 1.74	35.89	**<0.001**

DISCUSSION

This study examined the effects of a six-week combined cervical strengthening and wobble board balance training programme on craniocervical flexion endurance (CCFT), static postural stability (BESS), and dynamic postural stability (mSEBT) in competitive air rifle shooters, relative to each intervention administered alone. The principal finding was that the combined programme produced significantly greater improvements in both balance outcomes than either single-modality programme, with intergroup differences emerging progressively and reaching statistical significance by six weeks. These results support the premise that simultaneously targeting cervical proprioceptive pathways and lower-limb neuromuscular control generates postural adaptations that neither approach can achieve independently.

Cervical strengthening directly loads the deep neck flexors and extensors, which house the highest concentration of muscle spindles in the axial skeleton (4). Progressive TheraBand resistance training increases the fatigue resistance of these muscles and helps sustain spindle afferent sensitivity throughout prolonged training sessions. Group 2 recorded the greatest absolute gain in CCFT (32.77 points), followed closely by Group 1 (30.40 points), reflecting the direct stimulus that targeted cervical loading provides to the deep cervical flexors. Functionally, an adequately conditioned cervical musculature supports the cervico-oculomotor pathway, which coordinates eye position with head movement and underpins the vestibulo-ocular reflex, a mechanism critical for gaze stabilisation during shooting (5,6).

When cervical fatigue degrades proprioceptive signal quality, the CNS compensates by increasing its reliance on visual and vestibular inputs (19,20). In the shooting context, however, this compensatory shift is limited: sustained visual attention on the target consumes attentional resources that would otherwise support visual postural stabilisation (15,16). The result is an unresolved sensory conflict that amplifies postural sway and introduces inconsistency into the aiming process. Cervical strengthening addresses this vulnerability directly by preserving the quality of proprioceptive afference under fatigue and reducing the extent to which the CNS must fall back on less available sensory channels.

Wobble board training places multidirectional mechanical demands on the foot-board interface, challenging the entire postural control hierarchy from the ankle plantarflexors and dorsiflexors to the hip abductors and spinal extensors. The controlled instability demands ongoing co-contraction and rapid reactive responses, which over time sensitise joint mechanoreceptors, reinforce Golgi tendon organ regulatory loops, and shorten stretch-reflex latencies in the lower limb (17,18). Group 3's BESS and mSEBT improvements confirm that these adaptations are functionally meaningful. However, wobble board training alone does not address the upper sensory-motor chain. Improved lower-limb stability cannot fully compensate for the head-positioning errors that arise when the cervical musculature fatigues during the extended standing demands of competitive shooting.

The superiority of the combined programme in both BESS and mSEBT is best understood through the framework of sensory reweighting proposed by Peterka (19) and elaborated by Paillard (20). The CNS continuously adjusts the relative contribution of proprioceptive, vestibular, and visual inputs according to their reliability and task demands. When cervical strengthening improves the fidelity of upper-body proprioceptive signals while wobble board training simultaneously improves somatosensory input quality from the lower limb, the CNS receives a richer and more consistent multi-source representation of body position. This improved sensory environment reduces the computational load of postural stabilisation, enabling faster and more accurate corrective motor outputs and fewer balance errors in challenging stance conditions. The advantage seen in Group 1, therefore, reflects not a simple summation of two training effects but an integrative adaptation at the level of the sensorimotor system, which neither single modality can independently induce.

The mSEBT composite gain of 9.66 points in Group 1 reflects improvements across all three reach directions, each of which engages a distinct neuromuscular subsystem. Anterior reach is primarily dependent on ankle dorsiflexion range and tibialis anterior eccentric control, while posteromedial and posterolateral reach place greater demands on hip abductor and external rotator strength, and on pelvis-on-femur stability (28). The Group 1 protocol challenged these direction-specific stabilisers on unstable surfaces from week one and on the wobble board from week three, likely improving participants' capacity to manage multi-planar perturbations under conditions of accumulated fatigue, conditions directly analogous to those encountered during extended shooting sessions. Concurrent cervical conditioning added a further dimension to this adaptation by preserving the head-righting reflexes and gaze stabilisation mechanisms that underpin accurate postural responses, which are ordinarily the first to degrade when cervical muscles fatigue under sustained shooting load. This finding extends the observation of Kounalakis et al. (29) of improved shooting performance following balance training under load, by demonstrating that adding cervical strengthening produces a further statistically significant increment in dynamic postural control.

All three groups showed improved BESS scores, and the relative pattern of improvement is consistent with what each intervention would mechanistically be expected to produce. Gosselin et al. (15) demonstrated that cervical extensor fatigue elevates postural sway in healthy individuals, and Schieppati et al. (13) showed that neck muscle fatigue disrupts proprioceptive transmission to the CNS in a manner that persists well beyond the period of active loading. Group 2 has a reduction in BESS errors by 4.03 ± 2.18 points fits this evidence: progressive TheraBand loading improved the fatigue resistance of the deep cervical flexors, maintained spindle afferent quality for longer during each training session, and thereby attenuated the postural sway that degraded cervical signalling would otherwise have produced. The findings of Abdelkader et al. (14) and Vuillerme and Pinsault (30), who both observed meaningful balance deterioration when cervical muscles were experimentally loaded or subjected to pain, lend additional support to the view that cervical conditioning carries genuine postural significance. Additionally, Vuillerme et al. (31) demonstrate that individuals with neck fatigue face a significantly elevated risk of balance loss when navigating low-light or uneven environments, underscoring the need for multi-sensory strategies in rehabilitation.

Group 3 outperformed Group 2 in BESS reduction (7.23 ± 2.03 vs 4.03 ± 2.18 errors), a finding consistent with the established literature on balance training efficacy. Zech et al. (17,18), in two systematic reviews, reported that proprioceptive training on unstable surfaces yields broad neuromuscular gains in athletes, including faster stretch-reflex responses, more precise motor unit recruitment, and better centre-of-pressure control, all of which translate into fewer BESS errors. The additional advantage of wobble board training over cervical strengthening alone for static balance likely reflects the specificity of the perturbation stimulus: the BESS directly loads the lower-limb and trunk stabilisers that wobble board training targets most directly.

The mSEBT findings offer the clearest demonstration of the combined programme's advantage. Group 1 gained 9.66 ± 5.14 points, which was nearly twice that of Group 3 (5.88 ± 1.74) and approximately three times that of Group 2 (3.23 ± 1.03), with intergroup ANOVA at six weeks yielding $F = 35.89$ ($p < 0.001$). What balance training alone could not address was the feed-forward dimension of postural control identified by Mousavi-Khatir et al. (32): sustained cervical loading impairs not only reactive balance but also the anticipatory postural adjustments that precede voluntary movement. In shooting, these adjustments counteract the predictable forces imposed by the rifle; when they are degraded, stance consistency is lost. Gardas et al. (33) reported reductions in dynamic reaching distances following cervical muscle fatigue, attributing these losses to impaired proprioceptive afference rather than lower-limb weakness. Hung et al. (34) reported that complex functional strength training incorporating unstable surfaces significantly improved rifle stability and shooting scores over six weeks. Group 1 is superior mSEBT performance over Group 3 is consistent with this interpretation: cervical strengthening preserved the afferent signal quality whose degradation Gardas et al. (33) identified as the proximate mechanism of reduced reaching. Group 1 is superior in mSEBT was not apparent at three weeks but was clearly established by six weeks. This time course is physiologically expected. Sensorimotor integration adaptations are not rapidly acquired; they require sustained, repeated co-activation across multiple proprioceptive input channels before the CNS settles into a reorganised, higher-performing reweighting state (19). The three-week assessment captured early neuromuscular gains that were broadly distributed across all groups. However, only at six weeks had the combined group accumulated sufficient dual-channel training stimulus to drive the integrative adaptation that neither single-modality group could independently replicate.

LIMITATIONS

Recruitment from two regional academies limits generalisability across competitive levels and geographical settings. The six-week duration was sufficient to detect between-group divergence but does not address whether adaptations are retained post-detraining or what maintenance volume is needed. The CCFT, BESS, and mSEBT are well-validated balance measures but do not capture kinematics or segmental joint displacement directly.

Implications and Future Directions

A three-session-per-week combined programme of progressive TheraBand cervical work and wobble board balance training is realistic within a standard weekly shooting schedule and produces clinically meaningful postural improvements within six weeks. Future trials should include larger multi-centre samples, longer follow-up phases, force-plate sway metrics, and direct muzzle displacement measures. Systematic variation of TheraBand progression rate, board instability level, and dual-task conditions would help define optimal dosing parameters across competitive levels.

CONCLUSION

Six weeks of combined cervical strengthening and wobble board balance training produced significantly greater improvements in craniocervical flexion endurance (CCFT), static postural stability (BESS), and dynamic postural stability (mSEBT) in competitive air rifle shooters than either intervention alone. The superiority of the combined programme is grounded in the concurrent optimisation of cervical proprioceptive signalling and lower-limb neuromuscular reactivity, with two components of the postural system that each modality addresses in isolation but only their integration targets together. It is worth noting that the core musculature, while not specifically trained in isolation in this study, was engaged through the wobble board protocol and represents a third stabilising layer: whereas the cervical system calibrates the sensory map and the lower limb provides reactive and anticipatory mechanical adjustment, the core transmits force between segments and anchors the rifle-bearing structure against trunk oscillation. A future programme incorporating discrete core stabilisation alongside the present two modalities may yield further performance gains. These findings support the routine incorporation of both cervical and balance training into precision sport conditioning and establish a basis for further mechanistic and dose-response research.

ACKNOWLEDGEMENT

The authors thank the athletes and coaching staff of Tapasya Shooting Academy and Royal Rifle Academy, Delhi NCR, for their participation and cooperation throughout the study.

FUNDING

No external funding was received for this research.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DECLARATION OF ARTIFICIAL INTELLIGENCE (AI) ASSISTANCE PROCESS

No artificial intelligence tools were used to generate, analyse, or interpret the study data, or to draft the scientific content of this manuscript. AI-based language assistance was used only for grammar and language polishing during manuscript revision; the authors reviewed and take full responsibility for the final content.

AUTHOR CONTRIBUTIONS

All authors contributed to study conception and design, data collection, analysis and interpretation of results, and drafting and critical revision of the manuscript. All authors read and approved the final version of the manuscript.

ETHICS APPROVAL

Ethical approval was obtained from the Waves Women Empowerment Trust Independent Ethics Committee (Reference: F.1/IEC/WWE/(06)/04/2024/No. 14). The trial was registered with the Clinical Trials Registry India (CTRI/2025/02/080648, registered 17 February 2025). Written informed consent was obtained from all participants prior to enrolment. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki.

DATA AVAILABILITY

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

ABBREVIATION

CCFT: Craniocervical Flexion Test; BESS: Balance Error Scoring System; mSEBT: modified Star Excursion Balance Test; CNS: central nervous system; RM ANOVA: repeated measures analysis of variance; HSD: Honestly Significant Difference; SD: standard deviation.

REFERENCES

[1] Rogers MW, Mille ML. Lateral stability and falls in older people. Exerc Sport Sci Rev. 2003;31(4):182–187. doi: 10.1097/00003677-200310000-00005

[2] Shumway-Cook A, Woollacott MH. Motor Control: Translating Research into Clinical Practice. 2nd ed. Philadelphia: Lippincott Williams and Wilkins; 2000.

[3] Proske U, Gandevia SC. The proprioceptive senses: their roles in signalling body shape, body position and movement, and muscle force. Physiol Rev. 2012;92(4):1651–1697. doi: 10.1152/physrev.00048.2011

[4] Kulkarni V, Chandy MJ, Babu KS. Quantitative study of muscle spindles in suboccipital muscles of human foetuses. Neurol India. 2001;49(4):355–359.

[5] Pettorossi VE, Schieppati M. Neck proprioception shapes body orientation and perception of motion. Front Hum Neurosci. 2014;8:895. doi: 10.3389/fnhum.2014.00895

[6] Peng B, Yang L, Li Y, Liu T, Liu Y. Cervical proprioception impairment in neck pain - pathophysiology, clinical evaluation, and management: a narrative review. Pain Ther. 2021;10(1):143–164. doi: 10.1007/s40122-020-00230-z

[7] Uchino Y. Role of cross-striolar and commissural inhibition in the vestibulocollic reflex. Prog Brain Res. 2004;143:403–409. doi: 10.1016/S0079-6123(03)43038-0

[8] Goldberg JM, Cullen KE. Vestibular control of the head: possible functions of the vestibulocollic reflex. Exp Brain Res. 2011;210(3–4):331–345. doi: 10.1007/s00221-011-2611-5

[9] Allen TJ, Proske U. Effect of muscle fatigue on the sense of limb position and movement. Exp Brain Res. 2006;170(1):30–38. doi: 10.1007/s00221-005-0174-z

[10] Pinsault N, Vuillerme N. Degradation of cervical joint position sense following muscular fatigue in humans. Spine. 2010;35(3):294–297. doi: 10.1097/BRS.0b013e3181b0c889

[11] Kim JY, Kwag KI. Clinical effects of deep cervical flexor muscle activation in patients with chronic neck pain. J Phys Ther Sci. 2016;28(1):269–273. doi: 10.1589/jpts.28.269

[12] Liang Z, Clark R, Bryant A, Quek J, Pua YH. Neck musculature fatigue affects specific frequency bands of postural dynamics during quiet standing. Gait Posture. 2014;39(1):397–403. doi: 10.1016/j.gaitpost.2013.08.007

[13] Schieppati M, Nardone A, Schmid M. Neck muscle fatigue affects postural control in man. Neuroscience. 2003;121(2):277–285. doi: 10.1016/s0306-4522(03)00439-1

[14] Abdelkader NA, Mahmoud AY, Fayaz NA, Mahmoud LSED. Decreased neck proprioception and postural stability after induced cervical flexor muscles fatigue. J Musculoskelet Neuronal Interact. 2020;20(3):421–428.

[15] Gosselin G, Rassoulian H, Brown I. Effects of neck extensor muscle fatigue on balance. Clin Biomech. 2004;19(5):473–479. doi: 10.1016/j.clinbiomech.2004.02.001

[16] Gosselin G, Fagan MJ. The effects of cervical muscle fatigue on balance — a study with elite amateur rugby league players. J Sports Sci Med. 2014;13(2):329–335.

[17] Zech A, Hübscher M, Vogt L, Banzer W, Hänsel F, Pfeifer K. Balance training for neuromuscular control and performance enhancement: a systematic review. J Athl Train. 2010;45(4):392–403. doi: 10.4085/1062-6050-45.4.392

[18] Zech A, Hübscher M, Vogt L, Banzer W, Hänsel F, Pfeifer K. Neuromuscular training for rehabilitation of sports injuries: a systematic review. Med Sci Sports Exerc. 2009;41(10):1831–1841. doi: 10.1249/MSS.0b013e3181a3cf0d

[19] Peterka RJ. Sensory integration for human balance control. Handb Clin Neurol. 2018;159:27–42. doi: 10.1016/B978-0-444-63916-5.00002-1

[20] Paillard T. Effects of general and local fatigue on postural control: a review. Neurosci Biobehav Rev. 2012;36(1):162–176. doi: 10.1016/j.neubiorev.2011.05.009

[21] Yajima H, Nobe R, Takayama M, Takakura N. The mode of activity of cervical extensors and flexors in healthy adults: a cross-sectional study. Medicina. 2022;58(6):728. doi: 10.3390/medicina58060728

[22] Page PA, Lamberth J, Abadie B, Boling R, Collins R, Linton R. Posterior rotator cuff strengthening using Theraband® in a functional diagonal pattern in collegiate baseball pitchers. *J Athl Train.* 1993;28(4):346–354.

[23] Gao Y, Kristensen LA, Grøndberg TS, Søgaard K, et al. Electromyographic evaluation of specific elastic band exercises targeting neck and shoulder muscle activation. Appl Sci. 2020;10(3):756. doi: 10.3390/app10030756

[24] McGuine TA, Keene JS. The effect of a balance training program on the risk of ankle sprains in high school athletes. Am J Sports Med. 2006;34(7):1103–1111. doi: 10.1177/0363546505284191

[25] Panwar N, Kadyan G, Gupta AA, Narwal R. Effect of wobble board balance training program on static balance, dynamic balance and triple hop distance in male collegiate basketball athletes. Int J Physiother Res. 2014;2(4):657–662.

[26] Jull GA, O'Leary SP, Falla DL. Clinical assessment of the deep cervical flexor muscles: the craniocervical flexion test. J Manipulative Physiol Ther. 2008;31(7):525–533.

[27] Bell DR, Guskiewicz KM, Clark MA, Padua DA. Systematic review of the Balance Error Scoring System. Sports Health. 2011;3(3):287–295. doi: 10.1177/1941738111403122

[28] Bulow A, Anderson JE, Leiter JR, MacDonald PB, Peeler J. The modified star excursion balance and Y-balance test results differ when assessing physically active healthy adolescent females. Int J Sports Phys Ther. 2019;14(2):192–203.

[29] Kounalakis S, Karagiannis A, Kostoulas I. Balance training and shooting performance: the role of load and the unstable surface. J Funct Morphol Kinesiol. 2024;9(1):17. doi: 10.3390/jfmk9010017

[30] Vuillerme N, Pinsault N. Experimental neck muscle pain impairs standing balance in humans. Exp Brain Res. 2009;192(4):723–729. doi: 10.1007/s00221-008-1639-7

[31] Vuillerme N, Pinsault N, Vaillant J. Postural control during quiet standing following cervical muscular fatigue: effects of changes in sensory inputs. Neurosci Lett. 2005;378(3):135–139. doi: 10.1016/j.neulet.2004.12.024

[32] Mousavi-Khatir R, Talebian S, Toosizadeh N, Olyaei GR, Maroufi N. Disturbance of neck proprioception and feed-forward motor control following static neck flexion in healthy young adults. J Electromyogr Kinesiol. 2018;41:160–167. doi: 10.1016/j.jelekin.2018.04.013

[33] Gardas S, Nerurkar A, Yardi S. Effect of cervical muscle fatigue on postural stability. Int J Physiother Res. 2017;5(4):2289–2292. doi: 10.16965/ijpr.2017

[34] Hung MH, Lin KC, Wu CC, Juang JH, Lin YY, Chang CY. Effects of complex functional strength training on balance and shooting performance of rifle shooters. Appl Sci. 2021;11(13):6143. https://doi.org/10.3390/app11136143