Effect of a Neuromuscular Training Program on the Recurrence Rate of Ankle Injuries among Handball Players

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Introduction

Ankle injuries represent one of the most frequent musculoskeletal disorders encountered in sports that involve running, jumping, and rapid changes of direction. Among these, handball is considered a high-risk sport for ankle sprains due to its dynamic, contact-oriented nature that requires sudden acceleration, deceleration, and pivoting movements under physical pressure from opponents. Epidemiological data suggest that ankle sprains account for approximately 30% to 40% of all reported injuries in handball, surpassing those observed in basketball and volleyball (Bahr & Bahr, 2020; Fousekis et al., 2012). Lateral ankle sprains, in particular, are the most prevalent form of ankle injury, often resulting from excessive inversion and plantarflexion mechanisms during landing or sudden directional shifts.

While many athletes recover from their first ankle sprain within weeks, a large proportion experience recurrent sprains and chronic symptoms that persist long after initial recovery. Studies indicate that up to 50% of athletes who sustain a first-time ankle sprain are likely to suffer another within 6 to 12 months (McKeon & Mattacola, 2008). These recurrent injuries contribute to chronic ankle instability (CAI) , a condition characterized by mechanical laxity, proprioceptive deficits, muscle weakness, and functional instability, leading to impaired balance, altered movement patterns, and decreased performance (Delahunt et al., 2018). In handball players, such impairments may not only increase the risk of further injury but also compromise essential technical skills such as jumping, landing, and quick transitions—key determinants of competitive success.

Traditional rehabilitation programs following ankle injuries have emphasized muscle strengthening, joint mobilization, and proprioceptive exercises. However, these conventional methods often fail to fully restore neuromuscular control, particularly the coordination between the central

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nervous system and the muscles surrounding the ankle joint (Verhagen & Bay, 2010). This limitation underscores the need for more integrative and functionally oriented approaches that target both motor control and sensorimotor feedback mechanisms.

Neuromuscular training (NMT) has emerged as one of the most effective and comprehensive approaches in recent years for preventing lower-limb injuries and enhancing joint stability. NMT integrates a variety of exercises—such as balance, plyometrics, coordination, agility, and movement re-education—to stimulate proprioceptive pathways and improve the timing and strength of muscular activation around the joints (Emery et al., 2021). Through repeated exposure to controlled instability and dynamic tasks, NMT aims to improve the body’s automatic responses to perturbations, thereby reducing the risk of injury recurrence (Herman et al., 2018).

Several studies have documented the efficacy of neuromuscular training in reducing ankle injury incidence in sports such as soccer, volleyball, and basketball. For example, Owoeye et al. (2020) reported a significant reduction in ankle sprains following an eight-week neuromuscular training program among soccer players. Similarly, Petersen et al. (2011) demonstrated that implementing structured balance and agility exercises during pre-season training reduced lower-limb injury rates by up to 35%. Despite these encouraging findings, limited research has specifically focused on handball players , whose sport-specific demands—such as frequent jumping, landing, and multidirectional movements—create unique mechanical and neuromuscular stress on the ankle joint.

Furthermore, most existing studies have emphasized primary prevention , targeting athletes with no prior history of ankle injury. In contrast, fewer investigations have addressed secondary prevention , which aims to minimize the recurrence of injuries in athletes who have already sustained ankle sprains. Given that recurrent injuries often result in chronic instability, ligamentous laxity, and long-term functional impairment, the development of secondary prevention protocols tailored to the handball population is of paramount importance. Addressing this gap could not only reduce medical costs and time loss from training but also prolong athletic careers and enhance overall performance.

Another important aspect to consider is that neuromuscular training programs are not uniform; their effectiveness depends on specific parameters such as training duration, intensity, exercise progression, and the inclusion of sport-specific tasks. Previous studies have recommended intervention durations ranging from 6 to 12 weeks, with sessions incorporating progressive balance, perturbation, and plyometric exercises. However, the optimal design of such programs for handball players—who face distinct biomechanical challenges during play—remains insufficiently defined in the literature.

Therefore, the present study aims to evaluate the effect of a structured neuromuscular training program on the recurrence rate of ankle injuries among handball players . Specifically, this research seeks to determine whether an eight-week NMT intervention can effectively reduce the frequency of recurrent ankle sprains and improve measures of balance, proprioception, and dynamic stability when compared with traditional training methods. It is hypothesized that athletes participating in the neuromuscular training program will demonstrate a significant reduction in injury recurrence and superior functional outcomes, thereby supporting the integration of NMT as a standard preventive component in handball training regimens.

By addressing these objectives, this study seeks to contribute to the growing body of literature on evidence-based injury prevention and to provide practical recommendations for coaches, physiotherapists, and sports medicine practitioners. Ultimately, the findings may guide the implementation of structured neuromuscular protocols within handball clubs and federations to reduce the burden of ankle injuries and enhance player longevity and performance.

Methodology

Research Design

The present study adopted a quasi-experimental design (one-group pre–post test) to investigate the effect of a 12-week neuromuscular preventive program aimed at reducing recurrent ankle injuries among handball players. The study incorporated systematic assessments before and after the intervention to evaluate changes in ankle stability, balance, and functional performance.

Participants

The study sample included 12 male handball players aged 15–18 years, recruited from Tama Sports Club (Sohag Governorate, Arab Republic of Egypt). All players were registered participants in the club's youth handball program and had a documented history of recurrent ankle sprain. Each participant was medically cleared for full physical activity prior to program initiation.

Inclusion Criteria

* Age between 15–18 years.
* History of at least two ankle sprains in the same joint within the past 12 months.
* Regular participation in organized handball training (≥3 sessions/week).
* Medical clearance from a sports physician to resume training.

Exclusion Criteria

* Lower limb fractures, surgery, or major ligament injuries within the past year.
* Neurological or balance disorders affecting postural control.
* Absence from more than 10% of the intervention sessions.

All participants and their guardians provided written informed consent .

Data Collection Instruments

To ensure comprehensive assessment of outcomes, **multiple validated tools** were employed:

1. **Star Excursion Balance Test (SEBT):**

- Evaluates dynamic balance in eight directions.
- High reliability (ICC = 0.88–0.96).
- Scores standardized relative to leg length.

2. **Foot and Ankle Ability Measure (FAAM):**
- Self-report questionnaire assessing ankle function in daily and sports activities.
- 29 items (ADL and Sports subscales).
- Arabic-validated version used for comprehension and accuracy.

3- Isometric Strength Assessment:
- Measured using a hand-held dynamometer for ankle evertors and invertors.
- Peak torque values (N·m) recorded for both limbs.

4- Landing Error Scoring System (LESS):
- Video-based analysis to evaluate landing biomechanics.
- Assesses knee valgus, trunk alignment, and foot stability during jump-landing.

3- Injury Surveillance Log:
- Weekly log maintained by physiotherapist.
- Records new or recurrent ankle sprains (date, mechanism, severity, absence days).

4- Observation Checklist:
- Used by coach and physiotherapist during sessions.
- Tracks exercise performance, adherence, and neuromuscular control quality.

All instruments were validated by a panel of **three experts in sports rehabilitation**, and inter-rater reliability

Identification of Recurrent Ankle Injuries

Recurrent ankle injuries were identified through:

1. Medical History Review: Each participant completed a detailed injury history form validated by the team physiotherapist, specifying the number, type, and mechanism of previous ankle sprains.
2. Clinical Examination: Conducted by a certified sports medicine specialist to assess ligament integrity (anterior drawer test, talar tilt test) and detect signs of chronic instability.
3. Functional Assessment: Players showing reduced balance, instability during single-leg stance, or recurrent pain/swelling during activity were classified as having recurrent ankle sprain .

Causes of Recurrent Ankle Injuries

The analysis of the players' medical records and clinical observations revealed that the most common causes of recurrent ankle sprain included:

* Insufficient rehabilitation following the first injury.
* Weakness of peroneal and tibialis anterior muscles.
* Deficits in proprioception and balance control.
* Premature return to play without neuromuscular re-education.
* Improper footwear or unstable landing mechanics.
* Fatigue-induced decline in neuromuscular control.

These causes guided the design principles of the preventive program to target both neuromuscular and biomechanical deficits.

General Objectives of the Preventive Program

1. To reduce the recurrence rate of ankle sprains among handball players.
2. To improve dynamic and static balance and postural stability.
3. To enhance proprioceptive awareness and neuromuscular control of the ankle joint.
4. To strengthen stabilizing muscles around the ankle and lower limb.
5. To improve movement mechanics during jumping, landing, and directional changes.

Principles of Program Design

The program was structured according to the following principles:

* Gradual progression in intensity and complexity from basic to advanced motor tasks.
* Specificity to the demands of handball (jumping, landing, pivoting).
* Integration of proprioceptive, strength, and coordination exercises.
* Controlled fatigue exposure to simulate game conditions.
* Individualization based on each athlete's level of stability and recovery rate.

Program Duration and Structure

The total duration of the program was 12 weeks , divided into three progressive phases , each lasting 4 weeks .

Training sessions were conducted three times per week , each lasting 60 minutes , supervised by a qualified physiotherapist and the head coach.

Phase 1: Foundation and Stability Phase (Weeks 1–4)

Objectives:

* Restore joint alignment and static stability.
* Develop proprioception and basic muscle strength.
* Improve confidence in single-leg support.

Content:

* Dynamic warm-up (10 min): low-intensity jogging, ankle mobility drills, dynamic stretching.
* Balance training (15 min): single-leg stance on flat surface → foam pad → wobble board.
* Strength training (15 min): theraband exercises for eversion/inversion, calf raises, toe curls.
* Coordination drills (10 min): side steps, ladder footwork, mirror movement tasks.
* Cool-down (10 min): static stretching, deep breathing.

Method of Execution:

* 3 sets per exercise, 12–15 repetitions, moderate intensity.
* Visual and verbal feedback to correct alignment.

Phase 2: Dynamic Control and Agility Phase (Weeks 5–8)

Objectives:

* Enhance dynamic balance and reactive control.
* Develop agility and plyometric capacity.
* Improve joint stiffness regulation and landing technique.

Content:

* Dynamic warm-up (10 min): multi-directional runs, skipping, lateral shuffles.
* Balance on unstable surfaces (15 min): single-leg stance with perturbation, balance board throws.
* Strength and power (20 min): single-leg squats, step-downs, lateral jumps, mini-hurdle hops.

* Agility and reaction (10 min): T-drill, cone zig-zag with visual cues.
* Cool-down (5 min): foam rolling, static stretching.

Execution:
* 3–4 sets, 10–12 reps; focus on control and accuracy.
* Progressive overload through surface instability and speed.

Phase 3: Functional and Sport-Specific Phase (Weeks 9–12)

Objectives:
* Transfer neuromuscular control to handball-specific tasks.
* Improve quick reactive balance under fatigue.
* Prepare players for full match-intensity participation.

Content:
* Warm-up (10 min): dynamic mobility + sprint drills.
* Functional drills (20 min): jump-landing with directional change, single-leg hops onto BOSU, reactive cutting maneuvers.
* Strength and plyometric circuit (20 min): bounding, resisted sprints, eccentric heel drops.
* Handball-specific tasks (5–10 min): defensive sliding, pivot with sudden stop, shooting under pressure.
* Cool-down (5 min): stretching and recovery breathing.

Execution:
* Emphasis on movement quality , core engagement , and fatigue tolerance .
* 4 sets × 8–10 repetitions, moderate-to-high intensity.

Training Session Structure (60 minutes)

Component	Duration	Content Summary
Warm-up	10 min	Dynamic mobility and activation
Balance/Proprioception	15 min	Static → dynamic balance tasks
Strength/Coordination	15 min	Theraband + bodyweight exercises
Agility/Plyometrics	15 min	Jump, landing, cutting drills
Cool-down	5 min	Stretching, breathing exercises

Evaluation and Assessment Methods

Assessment occurred before the program , midway (after 6 weeks) , and after 12 weeks , using standardized tools:

1. Star Excursion Balance Test (SEBT) – to assess dynamic balance.
2. Foot and Ankle Ability Measure (FAAM) – for self-reported functional performance.
3. Isometric Strength Test – of evertor/invertor muscles using a dynamometer.
4. Injury Surveillance Log – to record recurrence and severity of ankle sprains.
5. Video Analysis – to observe changes in landing and pivoting mechanics.

Data Analysis

Data were processed using SPSS v26 .

Descriptive statistics (mean ± SD) were calculated.

Comparisons between pre-, mid-, and post-tests were analyzed using repeated measures ANOVA , with

Bonferroni correction for post-hoc comparisons.

Significance level set at $p < 0.05$, and effect size (η^2) computed to determine intervention magnitude.

Results

1. Descriptive Statistics

All twelve participants completed the 12-week neuromuscular preventive training program with an attendance rate exceeding 92% , and no injuries or adverse events were reported during the intervention period. Table 1 presents the pre-, mid-, and post-test mean values and standard deviations for the primary study variables: dynamic balance (SEBT composite score), ankle muscle strength (evertors/invertors), and functional performance (FAAM-Sports score).

Table (1)

Descriptive statistics and changes across the intervention (n = 12)

Variable	Pre-test (Mean ± SD)	Mid-test (Mean ± SD)	Post-test (Mean ± SD)	% Improvement	p-value
Star Excursion Balance Test (cm)	71.4 ± 4.6	78.9 ± 3.8	86.2 ± 3.2	+20.7%	< 0.001
Evertor Strength (N·m)	23.8 ± 2.5	26.5 ± 2.1	30.4 ± 2.3	+27.7%	< 0.001
Invertor Strength (N·m)	21.9 ± 2.1	25.0 ± 2.0	28.2 ± 1.9	+28.8%	< 0.001
FAAM-Sports (%)	68.1 ± 6.4	78.3 ± 5.9	88.7 ± 4.8	+30.3%	< 0.001
Landing Error Score (LESS)	7.8 ± 1.1	6.1 ± 1.0	4.9 ± 0.8	–37.2%	< 0.001

2. Statistical Analysis

Results from repeated-measures ANOVA revealed statistically significant improvements across all study variables between pre-, mid-, and post-testing sessions (*p* < 0.001).

Effect sizes were large (η^2 = 0.67–0.81), indicating a strong positive impact of the neuromuscular training program on ankle function, balance, and injury prevention capacity.

Post-hoc analysis (Bonferroni correction) showed:

* Significant improvement between pre- and mid-tests , reflecting early adaptation to proprioceptive and balance training.

* Further significant gains between mid- and post-tests , indicating continued neuromuscular development through the sport-specific phase.

No new ankle injuries occurred during the 12-week intervention or within the subsequent four-week follow-up period, confirming the preventive efficacy of the program.

Discussion

The current study aimed to investigate the effect of a 12-week neuromuscular preventive training program on reducing the recurrence rate of ankle injuries and improving ankle functional performance among handball players at Tama Sports Club, Sohag Governorate, Arab Republic of Egypt . The discussion interprets the obtained results in light of previous literature, physiological principles, and sport-specific demands.

A key finding of this study was the significant enhancement in dynamic balance performance as measured by the *Star Excursion Balance Test (SEBT)*, showing an average improvement of 20.7% between pre- and post-testing. This result indicates that the neuromuscular program effectively improved proprioceptive sensitivity, postural control, and neuromuscular coordination around the ankle joint.

According to McKeon and Mattacola (2008) , proprioceptive deficits are among the primary consequences of recurrent ankle sprains, leading to decreased afferent input from joint mechanoreceptors and delayed neuromuscular response. The present study's progressive proprioceptive training—starting with stable single-leg tasks and advancing to dynamic and unstable-surface exercises—appears to have retrained sensory feedback mechanisms and improved central motor control.

These findings are consistent with Wikstrom et al. (2010) , who reported significant gains in dynamic postural control after a 6-week balance and coordination training program among athletes with chronic ankle instability. Furthermore, Hupperets et al. (2009) emphasized that structured balance exercises significantly reduce the incidence of ankle sprains in team sports by improving both anticipatory and reactive postural adjustments.
Therefore, the current study supports the hypothesis that neuromuscular re-education through progressive proprioceptive tasks enhances the efficiency of sensory-motor loops and contributes directly to the prevention of re-injury .

The findings revealed a 27–29% increase in evertor and invertor muscle strength , indicating substantial adaptation in the dynamic stabilizers of the ankle joint. Strengthening these muscle groups is particularly vital in preventing lateral ankle sprains , which are the most common type among handball players due to frequent jumping, landing, and pivoting (Gribble et al., 2016).

The results align with the findings of Donovan et al. (2016) , who observed that resistance-band and eccentric heel drop exercises significantly increased peroneal muscle activation and strength, enhancing joint stiffness and resilience during rapid inversion movements. Similarly, Kwon et al. (2019) demonstrated that neuromuscular training integrating isometric and dynamic contractions effectively reduces mechanical instability by increasing muscle-tendon responsiveness.

In the present program, progressive strengthening was introduced through phased loading strategies :

* Phase 1 emphasized *theraband resistance* and *controlled concentric contractions*.
* Phase 2 incorporated *eccentric control* and *body-weight exercises*.
* Phase 3 advanced to *plyometric and reactive drills*.

This structured progression facilitated both morphological adaptation (strength gain) and neuromuscular activation efficiency , contributing to the enhanced functional stability of the ankle joint and reduced injury risk.

Functional recovery was evident in the 30.3% improvement in the FAAM-Sports score , reflecting enhanced subjective and objective performance in handball-specific movements. This outcome suggests that the neuromuscular program not only restored physiological balance and strength but also translated these improvements into sport-relevant actions .

According to Hall et al. (2015) , neuromuscular interventions that incorporate sport-specific movement patterns—such as cutting, pivoting, and jump-landing—result in more effective transfer of training gains to real performance. The inclusion of these elements during the third phase of the present program (functional and sport-specific integration) likely accounted for the observed improvements.

Furthermore, improved self-reported ankle confidence and stability may have led to better kinematic control and psychological readiness , factors recognized by Ross and Guskiewicz (2011) as essential components of functional rehabilitation success.

The significant 37% reduction in Landing Error Score (LESS) demonstrates notable enhancement in motor coordination, lower-limb alignment, and impact absorption during dynamic activities. This improvement reflects the players' ability to maintain neutral ankle alignment and avoid excessive inversion during landings—key biomechanical factors in ankle injury prevention.

These findings are in agreement with DiStefano et al. (2010) , who found that neuromuscular training emphasizing jump-landing and core stabilization reduces the risk of non-contact ankle and knee injuries by improving movement quality. Similarly, Myer et al. (2011) emphasized that teaching athletes to land with proper knee and ankle flexion, rather than a stiff-legged posture, enhances energy dissipation and joint stability.

In the present study, the progressive transition from controlled single-leg balance to reactive plyometric tasks successfully improved neuromuscular timing, coordination, and eccentric control , explaining the reduction in landing errors and injury risk.

A remarkable outcome of this research was the absence of any new or recurrent ankle injuries during the 12-week intervention and the four-week follow-up period. This result strongly supports the preventive efficacy of neuromuscular training in athletes with a prior history of ankle sprain.

According to Verhagen and Bay (2010) , neuromuscular programs combining balance, strength, and coordination elements can reduce ankle injury incidence by up to 50% among team-sport players. The structured, progressive design of the current program—guided by evidence-based principles and implemented under professional supervision—appears to have effectively mitigated key biomechanical and neuromuscular risk factors associated with reinjury.

Moreover, adherence to the training protocol (attendance >92%) likely enhanced the intervention's success, echoing findings by McGuine et al. (2012) that program compliance is a critical determinant of injury-prevention effectiveness.

The observed improvements can be attributed to multiple neuromechanical adaptations , including:

* Enhanced proprioceptive acuity: due to increased mechanoreceptor sensitivity in ligaments and joint capsules.
* Improved feedforward neuromuscular control: leading to quicker muscle activation before potential inversion events.
* Greater co-contraction efficiency: between agonist and antagonist muscles, stabilizing the ankle during perturbations.
* Reorganization of motor patterns: through repeated exposure to unstable and sport-specific conditions, promoting automatic stability responses.

These adaptations collectively reduce mechanical laxity , improve joint stability , and prevent functional instability , which are primary causes of recurrent ankle sprains (Hertel, 2019).

The current results are consistent with a growing body of literature supporting the efficacy of neuromuscular training in injury prevention:

* Hupperets et al. (2009) reported a 47% reduction in ankle sprains in volleyball players following a similar 12-week balance-based program.
* Emery et al. (2015) found significant declines in lower-limb injury rates in adolescent athletes using neuromuscular warm-up routines.
* Mansournia et al. (2018) confirmed that proprioceptive and coordination training improved ankle control and reduced reinjury incidence in soccer players.

The consistency of findings across different sports reinforces the universal effectiveness of neuromuscular re-education as a preventive tool.

The results of this study have direct applications in sports medicine, physiotherapy, and handball coaching practice :

* Integrating neuromuscular training into warm-up routines can enhance injury resilience without extending session duration.
* Coaches should monitor players' balance and landing technique regularly as indicators of ankle stability.
* Sports rehabilitation specialists should emphasize multi-surface

balance training and eccentric muscle control during return-to-play programs.

* Implementing progressive, phase-based programs ensures both safety and long-term adaptation.

Such interventions could be integrated into the Egyptian Handball Federation's youth training protocols , particularly in regions with limited access to physiotherapy services, like Sohag.

While the findings are promising, certain limitations should be acknowledged:

* The small sample size (n = 12) limits generalizability.
* The absence of a control group restricts causal interpretation.
* Short-term follow-up prevents assessment of long-term sustainability.

Future research should include larger randomized controlled trials, gender comparisons, and biomechanical analysis using motion capture to further validate the neuromuscular adaptations observed.

The present study provides strong evidence that a structured, 12-week neuromuscular training program — implemented at *Tama Sports Club, Sohag, Egypt*—can significantly improve dynamic balance, muscle strength, functional performance, and movement quality , while effectively preventing recurrent ankle injuries among youth handball players.

These results reinforce the growing consensus that neuromuscular and proprioceptive interventions are essential components of modern injury-prevention strategies in high-intensity team sports.

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