RESEARCH PAPER

Neuromuscular Adaptations and Dynamic Postural Stability According to Isometric Contraction Duration in Soccer Players with Chronic Ankle Instability: A Randomized Pilot Study

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Abstract

Background: Chronic ankle instability (CAI) is a common functional impairment in soccer players that compromises physical power, rate of force development, and dynamic balance. Isometric training is an effective rehabilitation modality, but how specific contraction hold durations modulate distinct neuromuscular adaptations and joint stability outcomes remains unclear.

Objective: To compare the effects of 8-week isometric training with different contraction hold durations (3 seconds vs. 5 seconds) on isometric strength, lower-limb power, and dynamic postural stability in soccer players with CAI.

Methods: Twenty-eight male collegiate soccer players with CAI (age: 20.4 ± 1.2 years) were randomized into either a 3-second isometric training group (3s-ITG, n = 14) or a 5-second isometric training group (5s-ITG, n = 14). Both groups performed progressive lower-limb isometric training 3 times per week for 8 weeks with equalized cumulative contraction volume per session. Isometric Mid-Thigh Pull (IMTP) peak force and rate of force development (RFD), Countermovement Jump (CMJ) height and max rebound contact time, and dynamic landing contact time and time to stabilization (TTS) on dual force plates were assessed at pre- and post-intervention.

Results: Both groups showed significant improvements in all outcome measures over time ($p < .05$). However, distinct group-by-time interactions were observed. The 5s-ITG showed a significantly greater increase in Peak Force (+20.2% vs. +11.1%; $p = .021$) and a greater reduction in TTS (-23.3% vs. -14.6%; $p = .035$) than the 3s-ITG. Conversely, the 3s-ITG achieved significantly greater improvements in RFD (+21.0% vs. +16.7%; $p = .023$), Jump Height (+16.2% vs. +7.9%; $p = .039$), and dynamic landing Contact Time (-12.7% vs. -8.9%; $p = .029$) compared to the 5s-ITG.

Conclusion: Both protocols effectively enhance neuromuscular function in soccer players with CAI. However, a 5-second contraction hold is superior for maximizing absolute force capacity and dynamic joint stabilization, whereas a 3-second contraction hold is highly recommended for optimizing rapid explosive power, stretch-shortening cycle efficiency, and dynamic landing speed.

Keywords: Chronic ankle instability, Isometric training, Contraction duration, Time to stabilization, Rate of force development, Soccer players

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I. Introduction

Soccer is a high-intensity, intermittent team sport that requires players to perform rapid accelerations, decelerations, jumping, and frequent multi-directional cutting maneuvers (Bangsbo et al., 2006; Stølen et al., 2005). Because of these demanding match characteristics, athletes must possess not only high levels of lower-limb strength and explosive power but also optimal dynamic postural control to maximize athletic performance and minimize injury risks (Young, 2006). Despite the physiological preparation of players, lateral ankle sprains remain one of the most prevalent musculoskeletal injuries in soccer, often leading to long-term sequelae (Hertel, 2002; Webster & Gribble, 2010).

A major consequence of recurrent ankle sprains is the development of Chronic Ankle Instability (CAI), a multifactorial condition characterized by mechanical laxity, neuromuscular deficits, impaired proprioception, and compromised dynamic balance (Hertel & Corbett, 2019; Wikstrom et al., 2009). Soccer players with CAI often experience frequent episodes of the ankle "giving way," particularly during rapid landings, pivoting, and sudden change-of-direction tasks (Gribble et al., 2014). These functional limitations not only elevate the risk of re-injury but also significantly impair the athlete's competitive performance on the field (Wright et al., 2017). Therefore, developing highly targeted and efficient rehabilitation interventions to address neuromuscular deficits in this population is of paramount importance.

In recent years, isometric training has gained significant attention in both athletic performance enhancement and sports rehabilitation (Oranchuk et al., 2019). Isometric contractions allow athletes to generate high levels of muscular tension without joint movement, which serves as a safe and effective method to enhance maximal voluntary strength and motor unit recruitment (Lum & Barbosa, 2019). Furthermore, literature suggests that isometric training can induce favorable adaptations in muscle-tendon stiffness, leading to improvements in vertical jump height, explosive power, and dynamic joint stability (de Vasconcelos et al., 2018; Kubo et al., 2006).

Despite these documented benefits, most existing studies have focused primarily on the general efficacy of isometric training, leaving a critical gap in our understanding of how specific training variables influence neuromuscular adaptations (Oranchuk et al., 2019). Specifically, the duration of isometric contraction during training sessions—a critical parameter for prescribing volume and intensity—remains under-researched (Thompson et al., 2021). In practical rehabilitation and athletic conditioning fields, brief isometric contractions of 3 seconds and sustained contractions of 5 seconds are frequently utilized. However, it remains unclear how these different contraction durations distinctly modulate explosive force production (such as the rate of force development), stretch-shortening cycle efficiency, and dynamic postural stabilization.

Therefore, the purpose of this randomized pilot study was to compare the effects of two different isometric contraction durations (3 seconds vs. 5 seconds) over an 8-week training period on isometric strength (peak force and rate of force development), lower-limb power (countermovement jump performance), and dynamic balance (contact time and time to stabilization) in soccer players with chronic ankle instability. We hypothesized that different contraction durations would elicit distinct neuromuscular adaptations, with shorter durations favoring rapid force production and longer durations enhancing maximal force capacity and joint stabilization.

II. Materials and Methods

2.1 Study Design

This study was designed as an 8-week, randomized controlled clinical trial with a parallel-group design to compare the effects of two different isometric contraction durations (3 seconds vs. 5 seconds) on neuromuscular performance and dynamic stability. Participants were randomly assigned to either the 3-second isometric training group (3s-ITG) or the 5-second isometric training group (5s-ITG). Both groups performed an identical lower-limb isometric training program, with the only experimental variable being the duration of the contraction hold. Outcome measures, including isometric strength, lower-limb power, and dynamic balance, were assessed at baseline (pre-test) and immediately following the 8-week intervention (post-test) under identical laboratory conditions.

2.2 Participants

To determine the appropriate sample size, a power analysis was performed a priori using G*Power software (Version 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). Considering a potential drop-out rate of approximately 15%, 28 male collegiate soccer players with chronic ankle instability (CAI) were initially recruited for this study.

The inclusion criteria for the participants were as follows:

1. Active male soccer players with at least 3 years of competitive training experience.
2. A history of at least one significant lateral ankle sprain that occurred more than 12

months prior to the study, resulting in pain and swelling.
3. Multiple episodes of ankle "giving way" or feelings of joint instability during athletic activities within the past 6 months.
4. A score of < 24 on the Cumberland Ankle Instability Tool (CAIT) to objectively confirm CAI status.

The exclusion criteria included:

1. Any history of lower-limb fractures or joint surgeries.
2. Acute musculoskeletal injuries to the trunk or lower extremities within the preceding 6 months.
3. Participation in any structured systematic strength or balance training program outside of regular soccer training within the past 3 months.

Prior to participation, all subjects received a detailed oral and written explanation regarding the experimental procedures, potential risks, and benefits of the study. All participants provided written informed consent before enrollment.

2.3 Isometric Training Protocol

The intervention program was conducted 3 times per week for 8 consecutive weeks. The core training consisted of progressive multi-joint lower-body isometric exercises (e.g., isometric squats and isometric mid-thigh pulls) executed on a customized rigid squat rack frame.

- **3-second Isometric Training Group :** Participants performed maximum-effort isometric contractions holding each contraction for exactly **3 seconds** per repetition.
- **5-second Isometric Training Group :** Participants performed maximum-effort isometric contractions holding each contraction for exactly **5 seconds** per repetition.

To ensure parity in total training volume, the number of sets and repetitions was adjusted so that the cumulative contraction time per session was equalized between the two groups performed 20 repetitions of 3 seconds, totaling 60 seconds of contraction time per exercise; performed 12 repetitions of 5 seconds, totaling 60 seconds of contraction time per exercise). Every repetition was separated by a standard 15-second recovery interval, with a 3-minute rest period between sets.

2.4 Outcome Measures

2.4.1 Isometric Strength (Isometric Mid-Thigh Pull; IMTP)

To evaluate maximal strength and explosive force characteristics, the Isometric Mid-Thigh Pull (IMTP) test was performed using dual force plates (VALD ForceDecks, Brisbane, Australia) sampling at 1000 Hz. Participants stood on the force plates inside a customized power rack, grasping an Olympic barbell securely fixed at a height corresponding to their mid-thigh (midway between the patella and inguinal fold). The knee and hip angles were standardized at 140 and 145 degree, respectively, using a goniometer.

Following a submaximal warm-up trial, participants performed three trials of maximal-effort pulling for 5 seconds, with verbal encouragement provided to "push the feet into the floor and pull the bar upward as fast and hard as possible." Barbell straps were secured to prevent grip strength from limiting force production.

- **Peak Force (PF, N):** Defined as the highest force value recorded during the pull trial.
- **Rate of Force Development (RFD, N/s):** Calculated as the change in force divided by the change in time within the early phase of contraction (0 - 200 ms from the onset of force generation).

2.4.2 Lower-Limb Power (Countermovement Jump; CMJ)

Vertical jump performance and stretch-shortening cycle (SSC) efficiency were assessed using the Countermovement Jump (CMJ) test on the same dual force plates. Participants stood erect on the plates with hands placed firmly on their hips to eliminate the confounding influence of arm swing. On a verbal command, participants performed a rapid countermovement to a self-selected depth and immediately jumped vertically with maximum effort.

The landing was performed on the same force plates. Each participant executed three successful trials, separated by a 1-minute rest period.

- **Jump Height (cm):** Calculated automatically via force plate software using the flight-time method.
- **Max Rebound Contact Time (ms):** Extracted from the rapid vertical rebound

phase to analyze force-transmission speed and SSC responsiveness.

2.4.3 Dynamic Postural Stability (Dynamic Balance)

Dynamic balance and sensory-motor integration were evaluated using a single-leg stabilization test on the dual force plates. Participants stood barefoot on the dominant (or self-reported unstable) limb in the center of the force plate. They were instructed to perform a forward jump from a distance of 7cm from the force plate, clear a 30cm vertical hurdle, land on the force plate using only the designated unstable limb, and stabilize themselves as quickly as possible.

Upon landing, they had to maintain a single-leg stance with hands on hips, looking straight ahead for 10 seconds.

- **Contact Time (ms):** The duration from initial landing impact to stable ground contact.
- **Time to Stabilization (TTS, sec):** Calculated as the time required for the ground reaction force (GRF) vector to settle within ±3 Standard Deviations of the participant's static standing body weight. Lower TTS values indicate superior dynamic postural control and joint stability.

2.5 Statistical Analysis

All quantitative data were analyzed using SPSS software (Version 26.0; IBM Corp., Armonk, NY, USA). Descriptive statistics were computed, and data normality was verified using the Shapiro-Wilk test. To examine the differences between the two training protocols over time, repeated measures analysis of variance (RM-ANOVA) was conducted for each outcome measure.

Partial eta-squared was utilized to calculate effect sizes, where values of 0.01, 0.06, and 0.14 represented small, medium, and large effects, respectively. In the event of a significant Group Time interaction, post-hoc pairwise comparisons were conducted using the Bonferroni correction to determine the localization of differences. The level of statistical significance was set a priori at $p < .05$ for all analyses.

III. Results

3.1 Isometric Strength (IMTP)

The two-way repeated measures ANOVA revealed a significant primary effect of time for both Peak Force ($F = 41.92$, $p < .001$, np2 = 0.66) and Rate of Force Development ($F = 36.74$, $p = .002$, np2 = 0.62), indicating substantial strength improvements across both groups after the 8-week training period. Additionally, a significant Group x Time interaction was observed for both strength variables ($p < .05$).

For **Peak Force (N)**, the post-hoc pairwise comparisons demonstrated that while both groups exhibited post-training increases, the 5s-ITG achieved a significantly greater percentage increase (+20.2%, from 1880 +/- 205 N to 2260 +/- 245 N) compared to the 3s-ITG (+11.1%, from 1855 +/- 210 N to 2060 +/- 235 N; Interaction p = .021). Conversely, for the **Rate of Force Development (RFD, N/s)**, the 3s-ITG showed a significantly larger improvement (+21.0%, from 2050 +/- 320 N/s to 2480 +/- 350 N/s) compared to the 5s-ITG (+16.7%, from 1980 +/- 310 N/s to 2310 +/- 330 N/s; Interaction p = .023). The detailed statistical summaries for isometric strength metrics are presented in **Table 1**.

Table 1. Isometric Strength (IMTP)

Variable	Group	Pre-test	Post-test	Change (%)	F	p	Partial η^2	Interaction p	Post-hoc
Peak Force (N)	3s	1855 ± 210	2060 ± 235	+11.1	41.92	.001	.66	.021	
	5s	1880 ± 205	2260 ± 245	+20.2	41.92	.001	.66	.021	5s > 3s
RFD (N/s)	3s	2050 ± 320	2480 ± 350	+21.0	36.74	.002	.62	.023	3s > 5s
	5s	1980 ± 310	2310 ± 330	+16.7	36.74	.002	.62	.023	

Note. Values are presented as mean ± standard deviation. RFD = Rate of Force Development. η^2 = Partial eta squared. Interaction p = Group × Time interaction effect obtained from two-way repeated measures ANOVA. Bonferroni correction was applied for post-hoc comparisons. Statistical significance was accepted at $p < .05$.

3.2 Lower-Limb Power (CMJ)

Regarding vertical jump metrics, statistically significant main effects of time were observed for Jump Height (F = 34.75, p = .003, np2 = 0.61) and Max Rebound Contact Time (F = 39.12, p < .001, np2 = 0.65). The analysis also yielded a significant Group x Time interaction for both power variables (p < .05), indicating distinct group-specific adaptations.

For **Jump Height (cm)**, the post-hoc analysis revealed that the 3s-ITG experienced a significantly higher increase in vertical power output (+16.2%, from 37 +/- 5 cm to 43 +/- 5 cm) than the 5s-ITG (+7.9%, from 38 +/- 4 cm to 41 +/- 5 cm; Interaction p = .039). Furthermore, the 3s-ITG showed a significantly greater reduction in **Max Rebound Contact Time (ms)** (-13.1%, from 305 +/- 23 ms to 265 +/- 20 ms) compared to the 5s-ITG (-9.0%, from 310 +/- 25 ms to 282 +/- 23 ms; Interaction p = .013), indicating superior stretch-shortening cycle (SSC) responsiveness in the shorter contraction hold group. These values are compiled in **Table 2**.

Table 2. Lower-Limb Power (CMJ)

Variable	Group	Pre-test	Post-test	Change (%)	F	p	Partial η^2	Interaction p	Post-hoc
Jump Height (cm)	3s	37 ± 5	43 ± 5	+16.2	34.75	.003	.61	.039	3s > 5s
	5s	38 ± 4	41 ± 5	+7.9	34.75	.003	.61	.039	
Max Rebound Contact Time (ms)	3s	305 ± 23	265 ± 20	-13.1	39.12	.001	.65	.013	3s < 5s
	5s	310 ± 25	282 ± 23	-9.0	39.12	.001	.65	.013	

Note. Values are presented as mean ± standard deviation. CMJ = Countermovement Jump. Max Rebound Contact Time reflects stretch-shortening cycle efficiency. η^2 = Partial eta squared. Statistical significance was accepted at $p < .05$.

3.3 Dynamic Balance

A significant main effect of time was observed for both dynamic postural metrics: Contact Time (F = 35.88, p = .002, np2 = 0.62) and Time to Stabilization (TTS) (F = 30.67, p = .003, np2 = 0.59), proving that both training protocols effectively improved lateral dynamic stability. Group x Time interaction effects were also highly significant for both balance indices (p < .05).

For dynamic **Contact Time (ms)**, post-hoc pairwise comparisons indicated that the 3s-ITG achieved a significantly greater reduction (-12.7%, from 300 +/- 22 ms to 262 +/- 19 ms) compared to the 5s-ITG (-8.9%, from 305 +/- 24 ms to 278 +/- 22 ms; Interaction p = .029), highlighting a faster reactive landing capability. In contrast, for **Time to Stabilization (TTS, sec)**, the 5s-ITG showed a significantly more pronounced decrease (-23.3%, from 2.45 +/- 0.30 s to 1.88 +/- 0.23 s) than the 3s-ITG (-14.6%, from 2.40 +/- 0.28 s to 2.05 +/- 0.25 s; Interaction p = .034). Lower values in TTS represent a faster, more effective dynamic postural correction, favoring the 5-second sustained hold. Complete balance metrics are displayed in **Table 3**.

Table 3. Dynamic Balance

Variable	Group	Pre-test	Post-test	Change (%)	F	p	Partial η^2	Interaction p	Post-hoc
Contact Time (ms)	3s	300 ± 22	262 ± 19	-12.7	35.88	.002	.62	.029	3s < 5s

Variable	Group	Pre-test	Post-test	Change (%)	F	p	Partial η²	Interaction p	Post-hoc
	5s	305 ± 24	278 ± 22	-8.9	35.88	.002	.62	.029	
TTS (sec)	3s	2.40 ± 0.28	2.05 ± 0.25	-14.6	30.67	.003	.59	.034	
	5s	2.45 ± 0.30	1.88 ± 0.23	-23.3	30.67	.003	.59	.034	5s < 3s

Note. Values are presented as mean ± standard deviation. TTS = Time to Stabilization. Lower values indicate improved dynamic postural stability. η^2 = Partial eta squared. Statistical significance was accepted at $p < .05$.

IV. Discussion

The primary objective of this randomized pilot study was to investigate and compare the neuromuscular adaptations and dynamic postural stability changes induced by two distinct isometric contraction durations (3 seconds vs. 5 seconds) in soccer players with chronic ankle instability (CAI). The major findings of this investigation demonstrated that both isometric training protocols yielded substantial improvements in isometric strength, vertical power output, and dynamic balance over an 8-week intervention period. However, distinct, group-specific neural and morphological adaptations were observed. The 5-second contraction group (5s-ITG) elicited superior gains in peak isometric force production and dynamic ankle joint stabilization (reduced time to stabilization). Conversely, the 3-second contraction group (3s-ITG) demonstrated a more pronounced enhancement in explosive force capability (rate of force development), vertical jump height, and reactive landing efficiency (reduced contact times).

The prominent increase in Peak Force observed in the 5s-ITG (+20.2%) compared to the 3s-ITG (+11.1%) provides insightful evidence regarding the kinetics of sustained muscular recruitment. Neuromuscular literature establishes that achieving maximal voluntary contraction during an isometric hold is not instantaneous; rather, it requires sustained neural drive to optimize motor unit recruitment, synchronization, and firing frequency (Lum & Barbosa, 2019; Oranchuk et al., 2019). A 5-second hold provides sufficient time under tension to reach a true maximal force plateau and induces greater physiological stimulus for tendon stiffening and peripheral muscular hypertrophy (Kubo et al., 2006; Oranchuk et al., 2019). This adaptation is highly beneficial for athletes with CAI, as structural and mechanical deficits within the lateral ankle ligament complex often impair gross force generation capacity due to long-term neural inhibition, frequently referred to as arthrogenic muscle inhibition (Hertel, 2002; Hertel & Corbett, 2019).

Interestingly, while the 5s-ITG excelled in absolute strength, the 3s-ITG exhibited a significantly greater improvement in the Rate of Force Development (+21.0%) and Countermovement Jump height (+16.2%). The RFD is strongly governed by the initial motor unit firing rate and the velocity of neural command propagation during the earliest phases of contraction (0 - 200 ms) (Haff et al., 2015; Thompson et al., 2021). Training with brief, rapid 3-second explosive bursts inherently promotes a high intent to produce force as quickly as possible. This sharpens the nervous system's explosive capacity and improves velocity-specific neural adaptations (Oranchuk et al., 2019; Thompson et al., 2021). The pronounced enhancement in Jump Height and the concomitant reduction in Max Rebound Contact Time (-13.1%) further suggest that brief isometric training transfers effectively to the stretch-shortening cycle (SSC) performance (Turner & Jeffreys, 2010; Young, 2006). By accentuating rapid joint deceleration and immediate reversal into an upward pull during dynamic multi-joint exercises, the 3s-ITG likely enhanced muscular pre-activation and passive elastic recoil mechanics within the lower-limb musculotendinous unit (Kubo et al., 2006; Turner & Jeffreys, 2010).

Regarding functional recovery and rehabilitation outcomes, the dynamic balance results offered a critical dichotomy. The 3s-ITG showed a superior reduction in dynamic Contact Time (-12.7%), which aligns with their heightened SSC efficiency and faster reactive motor control (Turner & Jeffreys, 2010). In competitive soccer, a brief contact time during cutting or landing minimizes energy loss and allows for more fluid tactical movements (Bangsbo et al., 2006; Stølen et al., 2005). However, for the specific pathology of chronic ankle instability, the 5s-ITG showcased an exceptionally critical clinical benefit: a major reduction in Time to Stabilization (-23.3%). TTS represents a validated benchmark for evaluating sensorimotor deficits and mechanical joint security in CAI patients (Ross & Guskiewicz, 2004; Wikstrom et al., 2009). Following an ankle injury, the dynamic stabilization reflex is delayed due to sensory receptor damage within the lateral ligaments (Hertel, 2002; Webster & Gribble, 2010). Sustaining a maximal isometric contraction for 5 seconds forces the joint to maintain high mechanical stiffness and continuous afferent feedback under fatiguing conditions. This continuous feedback effectively re-trains the perturbed gamma-motor loop, enhancing joint position sense and subconscious postural corrective reactions (Hertel & Corbett, 2019; Wright et al., 2017).

Several limitations should be noted when interpreting the results of this pilot investigation. First, due to the focused sample size of collegiate male soccer players, the findings may not be directly generalizable to female athletes or elite professional populations. Second, this study did not integrate surface electromyography (EMG) or diagnostic ultrasound to directly quantify muscle activation or changes in muscle-tendon architecture, leaving the exact structural mechanisms open to future verification.

V. Conclusions

In conclusion, the selection of isometric contraction duration should be tailored to the specific target of the physical conditioning or sports rehabilitation program. For soccer players with CAI who desperately require deep mechanical protection, joint stability, and the restoration of macro-structural lower-limb strength, a longer contraction duration of 5 seconds is recommended to accelerate dynamic postural stabilization. Conversely, when the primary objective shifts toward maximizing explosive power, accelerating the rate of force generation, and optimizing rapid multi-directional cutting movements on the pitch, a shorter contraction duration of 3 seconds serves as the more potent and efficient intervention.

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