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Influence of Pushing *Versus* Holding Isometric Exercises at Different Joint Angles on Hamstring-Quadriceps Strength Ratio and Functional Performance: A Time-Under-Tension Approach to Injury Risk Reduction

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Abstract

Background: The hamstring-to-quadriceps (H:Q) strength ratio is a critical determinant of knee stability, functional performance, and injury prevention. Optimizing this ratio is essential for reducing injury risk, particularly among athletes and physically active individuals. Isometric training, characterized by pushing and holding exercises, is commonly used to enhance strength. However, the comparative effects of these two methods at different joint angles, particularly within the framework of time under tension (TUT), remain underexplored.

Objective: To compare the effects of pushing versus holding isometric exercises at varying knee joint angles on H:Q strength ratio, functional performance, time under tension (TUT), and perceived exertion among recreational athletes.

Methods: Thirty participants were randomly allocated into two groups—pushing or holding isometrics—and trained for six weeks using a time-under-tension protocol. Pre- and post-intervention assessments included the H:Q ratio (*via* hand-held dynamometry), Single-Leg Hop Test, Star Excursion Balance Test (SEBT), TUT, and Rate of Perceived Exertion (RPE).

Results: Both groups demonstrated significant improvements in H:Q ratio, hop performance, and SEBT scores ($p < 0.05$). The pushing group showed greater gains in H:Q ratio and hop distance, while the holding group exhibited longer TUT and enhanced balance control. RPE scores were higher in the pushing group, indicating greater exertion demands.

Conclusion: Both pushing and holding isometric protocols effectively enhanced lower limb strength and function. Pushing isometrics were more effective for improving the H:Q ratio and explosive performance, whereas holding isometrics better enhanced dynamic balance and muscular endurance. Incorporating joint angle–specific isometric training may serve as a strategic tool for tailored rehabilitation and injury prevention.

Keywords: Isometric Exercise; Hamstring–Quadriceps Ratio; Dynamic Balance; Time Under Tension; Rehabilitation; Athletic Performance

Introduction

The hamstring-to-quadriceps (H:Q) strength ratio is a critical factor influencing lower limb biomechanics, injury prevention, and athletic performance. An imbalance in this ratio, where quadriceps strength significantly exceeds hamstring strength, has been associated with an increased risk of anterior cruciate ligament (ACL) injuries, hamstring strains, and patellofemoral dysfunction, particularly in sports requiring explosive movements and rapid directional changes [2, 18]. Various training methodologies have been employed to optimize the H:Q balance, with a strong emphasis on isotonic and eccentric exercises. However, recent studies suggest that isometric training may offer distinct neuromuscular and mechanical advantages, particularly in enhancing joint stability and injury resilience [15, 37]. Despite the growing interest in isometric training, there is limited evidence comparing the effects of different isometric contraction types on H:Q ratio and functional performance [29].

Isometric contractions can be classified into *pushing* (active force production) and *holding* (static resistance) types, both of which elicit different neuromuscular responses [37]. Holding isometric contractions involve sustained force without movement, emphasizing joint stabilization, prolonged time under tension (TUT), and muscle endurance [5]. In contrast, pushing isometric contractions require active force generation, which may lead to greater muscle recruitment, increased rate of force development, and higher torque production [29, 38]. While these mechanisms have been explored in isolated settings, direct comparisons between pushing and holding isometrics in relation to H:Q balance remain limited [1, 4].

Additionally, joint angle specificity plays a crucial role in muscle recruitment, torque generation, and neuromuscular adaptation. Studies suggest that quadriceps activation is higher at extended knee angles (30°), while hamstring dominance increases at deeper flexion angles (90°), thereby influencing the overall strength ratio [13, 20]. Despite these findings, there is no standardized method for determining the optimal knee joint angle for isometric training interventions to enhance H:Q balance [15, 23].

Furthermore, time under tension (TUT) has been identified as a key determinant of strength adaptation, with prolonged TUT shown to improve muscle hypertrophy, neuromuscular efficiency, and endurance [3, 22]. However, its role in isometric training settings has not been fully explored, particularly in relation to joint angles and contraction types [14, 16].

Despite the recognized importance of H:Q balance in sports performance and rehabilitation, research comparing pushing versus holding isometric contractions at different knee joint angles remains scarce. Given the angle-specific nature of strength adaptations, it is critical to investigate how different isometric contraction types influence the H:Q ratio and functional performance across various joint angles [13, 26]. While TUT has been widely studied in dynamic resistance training, its application in isometric protocols remains unclear, further justifying the need for a systematic analysis of its impact [3, 22].

This study aims to compare the effects of pushing versus holding isometric exercises performed at different knee joint angles (30°, 60°, and 90°) on the H:Q strength ratio and functional performance, with a focus on injury risk mitigation and rehabilitation techniques using a TUT-based approach. By addressing this research gap, the study seeks to provide evidence-based recommendations for optimizing strength training and rehabilitation strategies aimed at improving muscle balance, reducing injury risk, and enhancing athletic performance.

Methods

Study Design and Ethical Approval

This randomized comparative experimental study investigated the effects of pushing versus holding isometric exercises performed at multiple knee joint angles (30°, 60°, and 90°) on the hamstring-to-quadriceps (H:Q) strength ratio and functional performance, using a time-under-tension (TUT)–based approach. Ethical clearance was obtained from the Institutional Scientific Review Board (SRB) of Meenakshi Academy of Higher Education and Research (Ref. No: MAHER/FOP/SRB/2025/12). All participants provided written informed consent prior to participation.

Participants

Thirty recreational and sub-elite athletes (male and female; age 18–35 years) were recruited. Inclusion criteria included being physically active, pain-free, and engaged in sports participation for at least one year. Exclusion criteria included current lower-limb injury, major surgery within the past 12 months, neuromuscular or systemic disorders, or inability to perform isometric exercises. Participants with fully rehabilitated prior injuries were permitted.

Study Procedure

Participants were randomly allocated into two groups: a pushing isometric contraction group and a holding isometric contraction group (n = 15 per group). Both groups performed isometric exercises at knee flexion angles of 30°, 60°, and 90°.

Training sessions were conducted three to five times per week for six weeks under physiotherapist supervision to ensure proper execution and participant safety. Warm-up and cool-down activities were included to prevent fatigue and injury.

Outcome Measures

Hamstring–Quadriceps (H:Q) Strength Ratio

The H:Q ratio was assessed using a handheld dynamometer (HHD) to evaluate muscle balance and injury risk potential. Participants were seated with the knee flexed at 60°, a position known to yield reliable maximal isometric contractions. For quadriceps assessment, the HHD was placed just above the ankle on the anterior surface, and participants were instructed to extend maximally against resistance. For hamstring measurement, the HHD was placed posteriorly, and participants performed maximal knee flexion (Figure 1). The higher of two trials was recorded for each muscle, and the H:Q ratio was calculated as:

$$\text{H:Q Ratio} = \frac{\text{Hamstring Peak Force}}{\text{Quadriceps Peak Force}} \times 100$$

This ratio expressed as a percentage reflects lower-limb muscle balance and injury susceptibility [13, 38].

Functional Performance Tests

Functional capacity was measured using the **Single-Leg Hop Test**

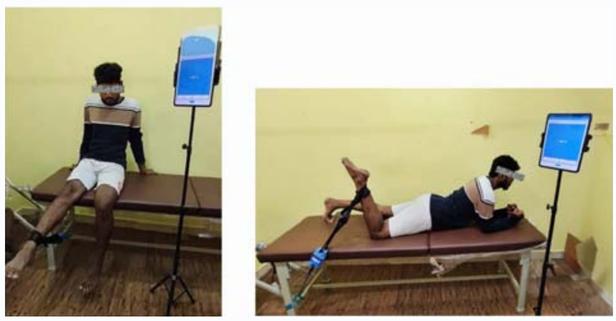

Figure 1: Assessment of quadriceps and hamstring strength using a handheld dynamometer.
(A) Quadriceps strength assessment at 60° knee flexion (seated position).
(B) Hamstring strength assessment at 30° knee flexion (prone position).

Figure 2: Single-leg hop test for measuring functional lower-limb power and symmetry.

Figure 3: Star Excursion Balance Test (SEBT) for evaluating dynamic balance and reach distance in anterior, posteromedial, and posterolateral directions.

(SLHT) and the **Star Excursion Balance Test (SEBT)**.

In the SLHT, participants performed maximal single-leg forward hops, landing on the same leg without losing balance (Figure 2). The best distance from three trials was recorded.

In the SEBT, participants reached in three directions (anterior, posteromedial, and posterolateral) while balancing on one leg (Figure 3). The mean reach distance across three trials was used as the composite SEBT score.

Time-Under-Tension (TUT)

TUT represented the total time (in seconds) that muscles sustained contraction. In the holding group, TUT reflected the duration of sustained static contractions until fatigue; in the pushing group, it represented the total contraction time across repetitions.

Rate of Perceived Exertion (RPE)

Perceived effort was evaluated using the Borg CR10 scale, where 0 indicated “no exertion” and 10 indicated “maximum exertion.” Average RPE values were calculated for each session to determine subjective exercise intensity [1, 2].

Exercise Protocols

Pushing Isometric Training

The pushing isometric training focused on *maximal voluntary effort (MVE)* against resistance without visible joint movement, targeting force production and motor unit recruitment. Participants performed three to four sets of three to five repetitions per session at each joint angle (30°, 60°, and 90°), maintaining contractions until voluntary fatigue. The total contraction duration per repetition was recorded as TUT.

1. Supine Resistance Band Leg Press

- This exercise primarily targeted the quadriceps and gluteal muscles. Participants lay supine and pushed a resistance band fixed at the foot away from the trunk.
- The angle-specific setup allowed measurement of torque differences between early (30°) and deep (90°) flexion angles, simulating multi-angle quadriceps recruitment.
- The posture ensured low compressive stress on the knee joint, making it safe for progressive strengthening .

2. Standing Resistance Band Hamstring Curl

- The exercise isolated the hamstrings, performed in a standing position with the band fixed to an anchor point.
- The motion emphasized concentric activation at the initiation of the curl and static force maintenance at terminal flexion.
- The upright posture activated hip stabilizers, enhancing proximal stability during distal isometric effort .

3. Seated Isometric Knee Extension (with Strap/Band)

- A resistance strap or band was used to restrict motion while the participant exerted forward force.
- The seated position minimized compensations and provided consistent lever arm length for torque measurement.
- This exercise allowed precise control of knee angle and direct quantification of joint-angle–specific strength .

4. Banded Bird-Dog Leg Curl

- This multi-joint exercise engaged the hamstrings and core simultaneously.
- The isometric contraction at 30°, 60°, and 90° activated both posterior chain and trunk stabilizers, improving kinetic chain integration.
- The posture minimized lumbar strain while improving neuromuscular coordination .

Across all pushing isometrics, rest intervals were 30–60 seconds between sets and 2–3 minutes between exercises. This ensured adequate phosphagen recovery while maintaining neural drive.

The complete sequence and technique of the pushing isometric exercises are illustrated in Figures 4–7.

Holding Isometric Training

The holding isometric protocol emphasized static endurance, postural stability, and sustained muscle activation at submaximal intensity (70–80% of MVC). Each contraction was maintained until fatigue, and the total duration was recorded as TUT.

1. Wall Squat Hold

- Performed with the back against a wall, the exercise targeted the quadriceps and core stabilizers.
- Angles of 30°, 60°, and 90° were used to assess quadriceps endurance at different muscle lengths.

Figure 4: Supine banded leg press exercise (pushing isometrics).

Figures 4–7: Pushing Isometric Exercise Series.
Demonstration of the exercises included in the pushing isometric training protocol. Each exercise was performed at 30°, 60°, and 90° knee flexion angles emphasizing maximal voluntary contraction (MVC) and time under tension (TUT).
Figure 4: Supine banded leg press exercise.
Figure 5: Standing banded hamstring curl.
Figure 6: Seated banded knee extension.
Figure 7: Banded bird-dog leg curl.

- The neutral spine posture minimized lumbar loading and improved control over knee flexion .

2. Prone Hamstring Dumbbell Hold

- Participants held a dumbbell between their ankles while lying prone, maintaining static knee flexion.
- This position isolated the hamstrings and minimized compensatory hip activation.
- The exercise enhanced endurance at mid-range hamstring lengths.

3. Single-Leg Hamstring Bridge Hold

- Performed in a supine bridge position, this exercise emphasized unilateral posterior chain stability.
- It improved pelvic alignment, hamstring endurance, and core synergy .

4. Front Squat Isometric Hold

- Using a light barbell or crossed-arm position, participants maintained a front squat at 30°, 60°, or 90°.
- The anterior load promoted core engagement and balanced anterior–posterior muscle coactivation.

Figures 8–11: Holding Isometric Exercise Series.
Illustration of the exercises performed in the holding isometric training protocol. All exercises were executed at 30°, 60°, and 90° knee flexion angles, emphasizing sustained isometric contraction, stability, and endurance through time under tension (TUT).
Figure 8: Wall squat isometric hold – static quadriceps activation for endurance and joint stabilization.
Figure 9: Prone hamstring dumbbell hold – sustained contraction targeting hamstring strength at varied flexion angles.
Figure 10: Front squat isometric hold – upright position emphasizing quadriceps and core stability (as shown).
Figure 11: Single-leg hamstring bridge hold – unilateral posterior-chain activation improving balance and hip control.

All exercises were performed with controlled breathing and neutral alignment to avoid compensations. Sessions were terminated upon fatigue or form deterioration.

The detailed positions and execution of the holding isometric exercises are demonstrated in Figures 8–11.

Statistical Analysis

Data were analyzed using JASP software. Descriptive statistics (mean ± SD) were used for all outcomes. Paired *t*-tests compared pre- and post-intervention scores within groups, and independent *t*-tests compared between-group means. Repeated-measures ANOVA evaluated multi-angle variables (TUT and RPE). Significance was set at $p < 0.05$. Cohen's *d* effect sizes were interpreted as small (0.2), medium (0.5), or large (≥0.8).

Results

Hamstring–Quadriceps Strength Ratio

Both intervention groups demonstrated improved H:Q ratios following six weeks of isometric training. The pushing group exhibited a larger improvement (86.15 ± 26.04% to 92.94 ± 10.50%) compared to the holding group (83.92 ± 13.96% to 85.63 ± 11.56%), reaching statistical significance ($p < 0.05$). These results suggest that the pushing protocol more effectively enhanced hamstring recruitment relative to quadriceps, promoting muscular balance and potentially lowering injury risk (Table 1) (Figure 12).

Table 1: Presents the pre- and post-test mean H/Q ratio values for both groups.
Figure 12: Illustrates the comparative gains in H/Q strength ratio, showing greater improvement in the pushing group.
Table 1: Pre- and Post-Test Mean H/Q Ratio (%) by Group.

Group	Pre H/Q (%) (Mean ± SD)	Post H/Q (%) (Mean ± SD)
Holding	83.92 ± 13.96	85.63 ± 11.56
Pushing	86.15 ± 26.04	92.94 ± 10.50

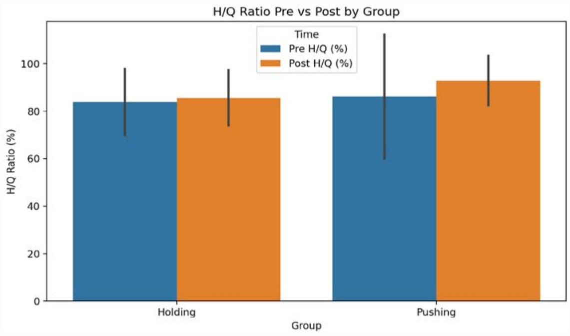

Figure 12: Comparison of Pre- and Post-Test H/Q Ratios Between Holding and Pushing Groups.

Functional Performance

Both groups improved significantly in functional performance. The SLHT distance increased from 159.40 ± 32.75 cm to 166.37 ± 30.33 cm in the holding group and from 171.00 ± 21.73 cm to 183.53 ± 21.07 cm in the pushing group. The greater increase in the pushing group suggests enhanced neuromuscular efficiency and explosive force generation.

In the SEBT, both groups improved their composite scores (holding: 90.41 ± 9.21 to 95.48 ± 8.55; pushing: 90.26 ± 6.59 to 95.90 ± 6.94), reflecting enhanced dynamic balance and postural control (Table 2 and Figure 13) and (Table 3 and Figures 14, 15).

Time-Under-Tension (TUT)

The holding group maintained longer contraction durations at all angles (27.19 ± 3.47 s at 30°, 25.25 ± 3.52 s at 60°, 24.11 ± 4.06 s at 90°)

Table 2: Displays the pre- and post-test hop distances by group.
Figure 13: Provides a graphical comparison of performance improvement, with higher gains observed in the pushing group.
Table 2: Pre- and Post-Test Single-Leg Hop Distance (CM).

Group	Pre-Test (Mean ± SD)	Post-Test (Mean ± SD)	Absolute Change
Holding	159.4 ± 32.75	166.37 ± 30.33	+6.97 cm
Pushing	171.0 ± 21.73	183.53 ± 21.07	+12.54 cm

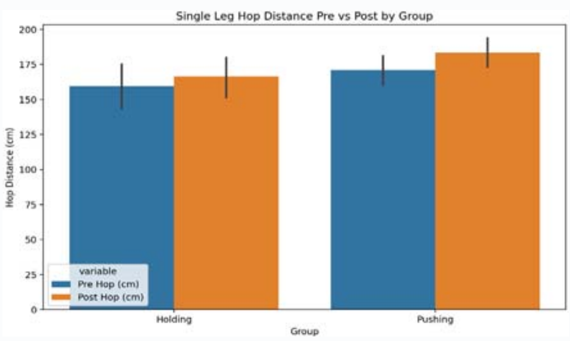

Figure 13: Single-Leg Hop Distance Improvements in Both Groups.

Table 3: Summarizes composite reach distances for each group.
Figure 14: Visualizes SEBT performance before and after training, highlighting balanced gains across both groups.
Figure 15: Boxplot showing the distribution of SEBT composite scores pre- and post-intervention for each group. Whiskers indicate score variability and individual outliers.
Table 3: Composite SEBT Score Pre- and Post-Test.

Group	Pre-Test (Mean ± SD)	Post-Test (Mean ± SD)	Absolute Change
Holding	90.41 ± 9.21	95.48 ± 8.55	+5.08
Pushing	90.26 ± 6.59	95.90 ± 6.94	+5.64

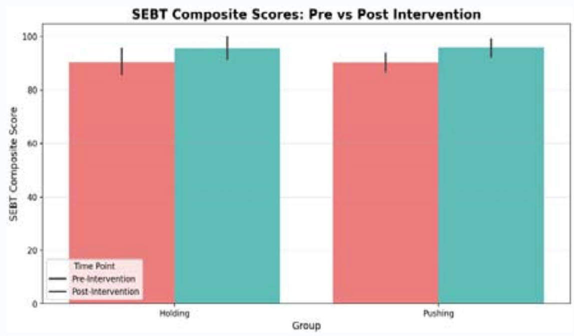

Figure 14: Bar Chart Comparing Pre- and Post-Intervention SEBT Composite Scores in Holding and Pushing Groups.

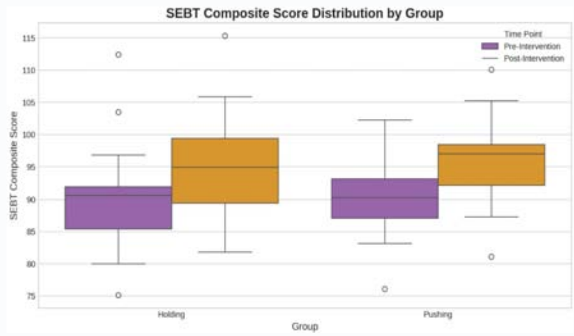

Figure 15: Boxplot Showing the Distribution of SEBT Composite Scores Pre- and Post-Intervention for Each Group. Whiskers Indicate Score Variability and Individual Outliers.

compared to the pushing group (17.89 ± 3.33 s, 15.68 ± 3.25 s, and 14.18 ± 3.41 s, respectively; $p < 0.001$).

This finding confirmed the endurance bias of holding isometrics, emphasizing sustained motor unit activation and oxidative capacity enhancement (Table 4 and Figure 16).

Rate of Perceived Exertion (RPE)

The pushing group reported higher exertion levels (mean RPE 7.02 ± 0.75) compared to the holding group (5.87 ± 0.84), indicating greater perceived effort during forceful contractions ($p < 0.001$). This suggests that pushing isometrics demand higher motor drive and metabolic activation than holding tasks (Table 5 and Figure 17).

Results Summary

The results of this study revealed that both pushing and holding isometric interventions led to measurable improvements in hamstring-quadriceps (H/Q) strength ratio, functional performance, time under tension (TUT), and perceived exertion levels. In terms of H/Q ratio, the holding group improved from 83.92 ± 13.96% to 85.63

Table 4: Presents the TUT averages at different angles.
Figure 16: Compares holding vs. pushing durations across the three joint angles.
Table 4: Time Under Tension (Seconds) at Each Joint.

Group	30° (Mean ± SD)	60° (Mean ± SD)	90° (Mean ± SD)
Holding	27.19 ± 3.47	25.25 ± 3.52	24.11 ± 4.06
Pushing	17.89 ± 3.33	15.68 ± 3.25	14.18 ± 3.41

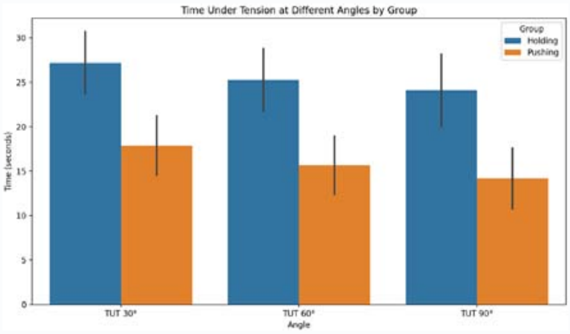

Figure 16: TUT Comparison Across Joint Angles.

Table 5: Details the RPE scores between groups.
Figure 17: Graphically represents perceived exertion differences across interventions.
Table 5. Mean RPE Scores at Each Angle (30°, 60°, 90°).

Group	30° (Mean ± SD)	60° (Mean ± SD)	90° (Mean ± SD)	Average RPE
Holding	5.33 ± 1.05	5.93 ± 0.70	6.33 ± 1.11	5.87 ± 0.84
Pushing	6.27 ± 0.80	7.07 ± 0.80	7.73 ± 0.80	7.02 ± 0.75

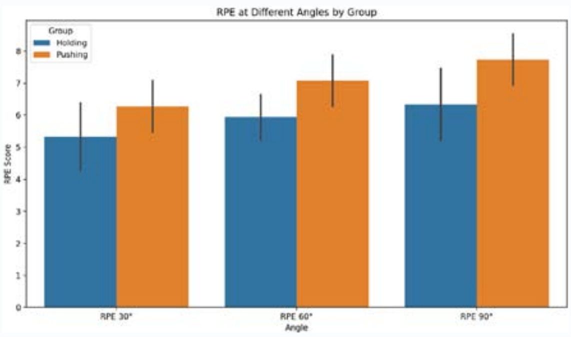

Figure 17: Average RPE Across Groups.

± 11.56%, while the pushing group demonstrated a greater increase from 86.15 ± 26.04% to 92.94 ± 10.50%, suggesting enhanced muscle balance, particularly in the pushing group.

Functional performance assessed through the Single-Leg Hop Test showed significant improvements, with the holding group increasing from 159.40 ± 32.75 cm to 166.37 ± 30.33 cm, and the pushing group from 171.00 ± 21.73 cm to 183.53 ± 21.07 cm. Similarly, the SEBT composite score improved in both groups, with the holding group rising from 90.41 ± 9.21 to 95.48 ± 8.55 and the pushing group from 90.26 ± 6.59 to 95.90 ± 6.94, reflecting enhanced dynamic balance.

Regarding TUT, the holding group exhibited significantly longer muscle engagement durations at all angles, while the pushing group showed shorter but more intense bursts. Lastly, the Rate of Perceived Exertion (RPE) was higher in the pushing group (7.02 ± 0.75) compared to the holding group (5.87 ± 0.84), indicating a greater intensity perception during pushing tasks.

Collectively, these findings suggest that while both interventions were effective, pushing isometrics yielded greater strength and power gains, whereas holding isometrics favored muscular endurance and control.

Discussion

The present study investigated the comparative effects of pushing and holding isometric exercises performed at different knee joint angles on the hamstring-to-quadriceps (H:Q) strength ratio, functional performance, time-under-tension (TUT), and perceived exertion in recreational athletes. The findings demonstrate that both isometric training modes can improve muscle balance and functional outcomes, though each offers distinct advantages in terms of strength, endurance, and neuromuscular control.

Hamstring–Quadriceps Ratio and Muscle Balance

Improvement in the H:Q ratio was observed in both groups, with the pushing group showing a more substantial increase (from 86.15% to 92.94%) than the holding group (from 83.92% to 85.63%). A balanced H:Q ratio is essential for dynamic knee stability, especially in activities requiring sprinting, deceleration, or directional changes. Ratios close to or exceeding 0.6 (60%) are considered protective against hamstring strains and anterior cruciate ligament (ACL) injuries [10, 13].

The greater improvement in the pushing group likely reflects higher motor unit recruitment and force generation due to maximal voluntary isometric contraction against resistance. This aligns with previous findings suggesting that isometric exercises performed with maximal intent can enhance joint torque, intramuscular coordination, and neural drive [8, 37]. The pushing mode, involving force application against external resistance, induces greater neuromuscular adaptation compared to holding positions that emphasize static tension maintenance.

Functional Performance: Hop and SEBT Tests

Functional performance, measured through the Single-Leg Hop Test (SLHT) and Star Excursion Balance Test (SEBT), improved significantly in both groups. The pushing group achieved greater improvements in SLHT distance, suggesting superior gains in explosive power and dynamic strength. Such findings are consistent with studies demonstrating that maximal isometric efforts at joint-specific angles can enhance force transmission and sport-related movements [4, 20].

Conversely, the SEBT performance improvements were more pronounced in the holding group. The prolonged contraction durations in holding isometrics likely promoted proprioceptive adaptation and enhanced neuromuscular control, leading to better balance performance. The improvements observed in both tests reaffirm that isometric training, regardless of type, contributes significantly to lower-limb functional stability, which is a key determinant of return-to-sport readiness [14, 38].

Time-Under-Tension (TUT) and Neuromuscular Endurance

The holding group demonstrated longer TUT values at all joint angles, reflecting the endurance benefits of sustained contractions. This adaptation supports the hypothesis that longer TUT stimulates Type I muscle fiber adaptation and enhances postural stability [16, 22]. The pushing group, in contrast, generated shorter but higher-intensity contractions, consistent with maximal force recruitment patterns.

These findings corroborate evidence that isometric contraction type determines physiological adaptation: pushing contractions optimize torque and strength development, while holding contractions improve endurance and stability [1, 6, 44]. Hence, both modalities can be periodized strategically depending on the rehabilitation or performance goal.

Rate of Perceived Exertion (RPE)

RPE scores were higher in the pushing group (mean 7.02 ± 0.75) than in the holding group (5.87 ± 0.84), indicating that pushing tasks were perceived as more demanding. This is consistent with their higher metabolic cost and motor unit activation, resulting from sustained maximal contractions. Despite the elevated exertion, no adverse effects or overtraining symptoms were reported. Monitoring RPE provided a valuable indicator of internal load and subjective fatigue, supporting its utility in field-based strength programs [1, 2].

Implications for Injury Prevention and Rehabilitation

The study findings have significant implications for both athletic conditioning and clinical rehabilitation. Enhancing the H:Q ratio, dynamic balance, and neuromuscular endurance directly contributes to reducing lower-limb injury risk, particularly in hamstring and ACL injuries [10, 13, 38].

Holding isometrics may be prioritized during early rehabilitation phases, focusing on stability and controlled activation without joint movement. In contrast, pushing isometrics may be emphasized during performance enhancement or late-stage rehabilitation, when higher force output and power restoration are desired. Incorporating both forms within a multiphase or angle-specific training program ensures comprehensive adaptation across muscle fibers, angles, and functions.

These findings underscore the importance of individualized exercise prescription based on the athlete's sport, training phase, and biomechanical profile. Integrating both isometric strategies can yield complementary benefits—maximal strength through pushing and endurance through holding—thereby improving performance efficiency and long-term joint stability.

Conclusion of Discussion

In summary, both pushing and holding isometric exercises performed at multiple joint angles produced significant improvements in H:Q ratio, functional performance, TUT, and perceived exertion among recreational athletes.

Pushing isometrics led to greater increases in strength balance and power output, while holding isometrics enhanced endurance, stability, and neuromuscular control. These results validate the integration of both contraction types within sports conditioning and rehabilitation frameworks to promote optimal strength ratios and minimize injury risk.

From a clinical perspective, pushing isometrics can be applied for strength restoration and late-stage return-to-sport, whereas holding isometrics are ideal for early-phase rehabilitation and motor control retraining. Future studies could expand upon these findings by exploring electromyographic activation patterns and long-term adaptation responses across diverse athletic populations.

Conclusion

This study examined the comparative effects of pushing versus holding isometric exercises performed at different knee joint angles (30°, 60°, and 90°) on the hamstring–quadriceps (H:Q) strength ratio, functional performance, time under tension (TUT), and perceived exertion in recreational and sub-elite athletes. Both isometric modalities effectively enhanced muscle balance, neuromuscular control, and athletic performance, with each demonstrating distinct advantages.

The primary outcome, the H:Q ratio, improved in both groups; however, a greater increase was observed in the pushing isometric group, indicating superior gains in strength balance. This suggests that pushing isometrics are more effective for enhancing hamstring–quadriceps strength symmetry, thereby potentially reducing the risk of hamstring and anterior cruciate ligament (ACL) injuries [4, 45]. The higher motor unit recruitment and force output during maximal voluntary contractions likely explain this improvement, consistent with earlier studies emphasizing the superior torque benefits of high-intent isometric training [23, 38].

Functional performance also improved significantly in both groups. The Single-Leg Hop Test (SLHT) gains were greater in the pushing group, highlighting improvements in explosive strength and lower-limb power. In contrast, the Star Excursion Balance Test (SEBT) improved more in the holding group, demonstrating enhanced postural stability, proprioceptive control, and neuromuscular coordination—attributes essential for athletes recovering from injury and performing in multidirectional sports. These findings are in agreement with previous research suggesting that isometric training enhances both force generation and stability mechanisms [14, 26, 38].

Time-under-tension (TUT) analysis revealed significantly higher durations in the holding group across all knee flexion angles, confirming the endurance-enhancing effect of sustained isometric holds. Conversely, the Rate of Perceived Exertion (RPE) was higher in the pushing group, reflecting the increased physiological demand associated with maximal effort contractions.

Collectively, these results suggest that pushing and holding isometric exercises serve complementary purposes in sports training and rehabilitation. Pushing isometrics can be prioritized during strength and power development phases, while holding isometrics may be emphasized during early-stage rehabilitation or neuromuscular endurance training.

Integrating both forms of isometric training across multiple joint angles provides a comprehensive, time-efficient, and equipment-accessible approach to improving muscle balance, functional capacity, and injury resilience in athletes [29]. Future research may explore long-term adaptations, electromyographic activation patterns, and sport-specific applications of angle-specific isometric training in elite populations.

Limitations and Recommendations

Limitations

Despite the promising findings, several limitations should be acknowledged:

1. **Sample Specificity**

The participants were limited to recreational and sub-elite athletes, which restricts the generalizability of results to elite-level professionals or sedentary populations. Future studies should include a broader athletic and clinical population to strengthen external validity.

2. **Short Intervention Duration**

The study duration was confined to four to six weeks. While this period demonstrated significant improvements, it may not reflect long-term neuromuscular adaptations or retention of performance gains.

3. **Lack of Electromyographic (EMG) Analysis**

Muscle activation patterns were not assessed, limiting the ability to explain underlying neuromuscular recruitment differences between pushing and holding contractions. The inclusion of EMG in future studies would provide deeper mechanistic insight.

4. **Uncontrolled Training History**

Although participants with recent injuries were excluded, variations in prior training exposure, sport background, and conditioning levels were not fully standardized. These factors could have subtly influenced performance outcomes.

5. **Complexity in TUT Measurement for Pushing Isometrics**

Measuring time-under-tension (TUT) was straightforward in the holding group but more challenging in the pushing group, where maximal effort was prioritized over duration. This may have affected TUT accuracy between groups.

6. **Absence of Long-Term Follow-Up**

The study did not include a follow-up period to determine whether gains in H/Q ratio, balance, and strength were maintained or transferred to real-world sports activities.

Recommendations for Future Research

1. **Incorporate EMG or Motion Analysis Tools**

Future studies should employ electromyography (EMG) or motion capture systems to quantify neuromuscular activation and joint movement patterns, enhancing understanding of contraction-specific adaptations.

2. **Expand the Sample Population**

Including elite athletes, sedentary individuals, and clinical groups such as post–ACL reconstruction patients would improve generalizability and clinical relevance.

3. **Compare with Other Training Modalities**

Combining or comparing pushing and holding isometrics with dynamic, eccentric, or plyometric training could identify optimal programming strategies for performance and rehabilitation.

4. **Examine Long-Term Outcomes**

Conducting longitudinal studies with follow-up assessments would help determine the sustainability and sport-transferability of strength and balance improvements.

5. **Standardize TUT Metrics for Pushing Isometrics**

Developing reliable methods to monitor TUT in maximal pushing conditions—potentially through digital force sensors or wearable tracking tools—would improve consistency in future research.

6. **Include Psychological and Subjective Measures**

Assessing athlete-reported factors such as confidence, motivation, and fatigue could provide a more holistic understanding of how isometric training influences performance, recovery, and adherence.

Key Points

Findings

Pushing isometric exercises produced greater improvements in the hamstring–quadriceps (H:Q) strength ratio and single-leg hop performance, while holding isometrics enhanced time-under-tension and dynamic balance. Both modes improved muscle balance, control, and functional performance across multiple joint angles.

Implications

Integrating both pushing and holding isometrics into rehabilitation and conditioning programs provides a balanced approach to improving lower-limb strength, stability, and injury resilience. Pushing isometrics can be emphasized during strength and power phases, whereas holding isometrics may be prioritized during endurance or neuromuscular retraining phases.

Caution

The findings are based on short-term training (4–6 weeks) among recreational athletes. Long-term adaptations, EMG activation data, and results in elite populations require further investigation before broader application.

Ethical Approval

Ethical approval was granted by the **Institutional Scientific Review Board / Ethics Committee, Meenakshi Academy of Higher Education and Research, Chennai, India.**

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Conflict of Interest

The authors declare no conflicts of interest related to this study.

Author Contributions

All authors contributed to the conception, design, data collection, analysis, and manuscript preparation. All authors read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Patient Involvement Statement

Study participants were not involved in the design, conduct, interpretation, or translation of the current research.

Data Sharing Statement

Data are available upon reasonable request. De-identified participant-level datasets and analytic code are available from the corresponding author (kumra292000@gmail.com) for researchers who provide a methodologically sound proposal and agree to reuse conditions.

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