(ISSN: 0973-7049(P))

The Bioscan AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES 21(3): S.I (3), 1172-1188, 2026 www.thebioscan.com

RELATIONSHIP BETWEEN HAMSTRING FLEXIBILITY GAINS AND REDUCTION IN STRETCH-RELATED DISCOMFORT FOLLOWING DIAPHRAGMATIC BREATHING-BASED FLEXIBILITY TRAINING IN AMATEUR ATHLETES: A SECONDARY ANALYSIS

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DOI: https://doi.org/10.63001/tbs.2026.v21.i03.S.I(3).pp1172-1188

KEYWORDS

Hamstring Flexibility, Stretch Tolerance, Diaphragmatic Breathing, Active Knee Extension, NPRS, Amateur Athletes, Secondary Analysis.

Article Info

Received: 30.06.2026

Accepted: 10.07.2026

Published: 29.07.2026

Abstract

Background

Changes in flexibility are commonly reported as gains in joint range, yet the athlete's tolerance of stretching is an equally important clinical outcome. Hamstring range can increase through mechanical, sensory, neuromuscular, and postural influences, while the discomfort perceived near the end of a stretch may affect how much range an athlete can use comfortably. Diaphragmatic breathing has potential relevance because it can be integrated into stretching while also influencing respiratory control, trunk stabilization, and relaxation. The present secondary analysis examined the relationship between objective hamstring flexibility gain and reduction in stretch-related discomfort using data from an experimental study in amateur athletes.

Objective

To determine whether improvement in Active Knee Extension (AKE) is associated with reduction in Numeric Pain Rating Scale (NPRS) scores during stretching, and to compare the pattern of objective and subjective improvement between athletes receiving diaphragmatic breathing plus flexibility training and those receiving flexibility training alone.

Methods

Data from 60 amateur athletes aged 18–30 years were analyzed. Group A (n=30) received diaphragmatic breathing exercises in addition to traditional stretching and flexibility exercises, whereas Group B (n=30) received the same traditional flexibility program without the breathing component. Average bilateral AKE and NPRS during stretching were recorded before and after intervention. Within- and between-group changes were evaluated using paired and independent t-tests. Pearson correlation examined the relationship between AKE improvement and NPRS reduction and also explored whether age or weekly training frequency was related to flexibility gain. Statistical significance was set at $p<0.05$.

Results

Average AKE gain was 11.80 ± 2.28° in Group A and 6.86 ± 2.29° in Group B ($t=8.369$, $p<0.001$; Cohen $d=2.16$). NPRS reduction was 3.37 ± 0.69 points in Group A and 2.08 ± 0.54 points in Group B ($t=8.045$, $p<0.001$; Cohen $d=2.08$). Across all 60 participants, flexibility gain showed a moderate positive association with reduction in stretching-related discomfort ($r=0.521$, $p<0.001$). Age was not significantly associated with AKE improvement ($r=0.138$, $p=0.2944$), and weekly training frequency showed essentially no relationship with AKE change ($r=-0.008$, $p=0.9487$). Clinically meaningful improvement, defined in the source study as an AKE gain of at least 8°, occurred in 96.7% of Group A and 26.7% of Group B.

Conclusion

Greater gains in hamstring flexibility were accompanied by greater reductions in stretch-related discomfort. The stronger objective and subjective response in the diaphragmatic breathing group suggests that breathing-based flexibility training may influence not only the range achieved but also the athlete's tolerance of stretching. These findings support evaluating flexibility and stretch discomfort together rather than relying on range of motion alone.

INTRODUCTION

Hamstring flexibility is routinely assessed in sports physiotherapy because the posterior thigh muscles must accommodate rapid changes in hip and knee position during running, sprinting, kicking, jumping, lunging, and deceleration. The biceps femoris, semitendinosus, and semimembranosus cross both the hip and knee and therefore participate not only in force production but also in controlling limb motion and pelvic position. Reduced flexibility may alter the way movement is distributed across the hip, pelvis, and lumbar region and has been discussed as one factor relevant to hamstring strain and movement impairment in sporting populations [1–3].

Flexibility is often treated as a purely mechanical characteristic, but the range demonstrated during a clinical test is influenced by more than tissue length. Passive stiffness, neural sensitivity, stretch perception, protective muscle activity, postural strategy, and the willingness of the individual to tolerate end-range tension all contribute to the final range reached. This is important in athletic populations because an athlete may show a measurable increase in range while still experiencing substantial discomfort during stretching, or may report greater comfort before a large change in range is apparent.

Conventional hamstring flexibility programs use static stretching, dynamic stretching, proprioceptive neuromuscular facilitation, active mobility, foam rolling, and related techniques. These interventions can increase range of motion, although the magnitude and duration of the response vary according to dose, technique, training status, and the individual [4,5]. Studies comparing stretching methods have repeatedly shown that range of motion can improve without requiring a single universal method, suggesting that both mechanical and sensory adaptations contribute to the clinical response [6,7].

The concept of stretch tolerance has become particularly useful when interpreting changes in range of motion. At the end of a hamstring stretch, the athlete experiences increasing tension or discomfort. If that sensation is interpreted as threatening or excessive, protective activity and voluntary resistance may limit further movement. A reduction in perceived discomfort may therefore allow the athlete to express more of the available range even when structural tissue changes are modest. For this reason, pairing an objective measure such as Active Knee Extension with a subjective measure such as NPRS during stretching can provide a more complete picture of flexibility adaptation.

Breathing behaviour may be relevant to this interaction. Individuals frequently hold their breath or increase upper-chest breathing when a stretch becomes uncomfortable. Breath holding can increase general bracing and effort, whereas slow controlled breathing may encourage relaxation and reduce unnecessary muscular guarding. The physiological effects of slow breathing include changes in autonomic regulation and cardiorespiratory control [8,9]. Research on breathing and pain perception also suggests that slower, deeper breathing can influence how discomfort is processed and experienced [10,11].

The diaphragm additionally has a postural role. It contributes to intra-abdominal pressure and stabilization of the trunk during limb movement [12]. Dynamic imaging and physiological studies have shown that the diaphragm participates in postural tasks rather than acting only as an inspiratory muscle [13,14]. This is relevant to hamstring flexibility because the pelvis is the proximal attachment region of the hamstrings, and efficient lumbopelvic control may reduce compensatory strategies during hip flexion and knee extension.

The thoracolumbar region also provides a functional bridge between breathing mechanics and the posterior kinetic chain. Fascia and associated connective tissues form a continuous network capable of transmitting force between regions [15]. The lumbar attachments of the diaphragm, its interaction with abdominal and pelvic-floor musculature, and the posterior-chain relationship of the hamstrings provide a plausible anatomical basis for integrated respiratory and movement strategies [16]. These relationships should not be interpreted as proof that breathing mechanically lengthens the hamstrings; rather, they support a broader model in which breathing may influence the context in which stretching occurs.

Previous work directed at the diaphragm has demonstrated musculoskeletal effects beyond respiratory outcomes. González-Álvarez et al. reported changes in posterior-chain kinematics following a diaphragm stretching intervention [17], while reviews of diaphragmatic function emphasize its relevance to postural control and spinal stabilization [18]. In rehabilitation populations, diaphragmatic breathing has also been combined with core or corrective exercise, suggesting that respiratory training may function as an adjunct to musculoskeletal treatment rather than as an isolated breathing technique [19–21].

The source experimental study from which the present analysis was derived compared diaphragmatic breathing plus a progressive flexibility program with the same flexibility program alone in amateur athletes. The primary analysis demonstrated greater improvement in AKE and greater reduction in NPRS in the breathing group. A further clinically relevant question is whether these two outcomes move together. If participants who gain more flexibility also report greater reduction in stretch discomfort, the finding would support the idea that flexibility adaptation and stretch tolerance are linked rather than independent responses.

Therefore, the present paper uses the same dataset from a different analytical perspective. Instead of focusing only on whether one intervention is superior, it examines the relationship between objective flexibility gain and subjective reduction in discomfort and considers whether age or training frequency meaningfully explains the observed flexibility response. This perspective may help clinicians interpret flexibility outcomes more comprehensively and may support the use of paired objective and subjective measures in sports rehabilitation.

RESEARCH QUESTION

Is improvement in hamstring flexibility associated with reduction in stretch-related discomfort in amateur athletes undergoing flexibility training, and is this combined response more pronounced when diaphragmatic breathing is integrated into the flexibility program?

HYPOTHESIS

Null Hypothesis (H0)

There will be no significant relationship between improvement in Active Knee Extension and reduction in NPRS during stretching, and the addition of diaphragmatic breathing will not produce a greater combined objective-subjective response than flexibility training alone.

Alternative Hypothesis (H1)

Greater improvement in Active Knee Extension will be associated with greater reduction in NPRS during stretching, and athletes receiving diaphragmatic breathing with flexibility training will demonstrate a stronger combined objective-subjective response than athletes receiving flexibility training alone.

OBJECTIVES OF THE STUDY

- To quantify the change in average bilateral Active Knee Extension in both intervention groups.
- To quantify the change in stretch-related discomfort measured with NPRS in both groups.
- To determine the relationship between AKE improvement and NPRS reduction across the study sample.
- To examine whether age and weekly training frequency are associated with flexibility gain.
- To compare clinically meaningful improvement and percentage change between the two groups.

MATERIALS AND METHOD

Study Design

This paper represents a secondary analysis of data from an experimental comparative study evaluating diaphragmatic breathing as an adjunct to hamstring flexibility training in amateur athletes. The original study included two parallel groups and pre- and post-intervention assessment of hamstring flexibility and stretch-related discomfort.

Study Setting and Participants

The study involved amateur athletes associated with the physiotherapy and sports rehabilitation setting of Pacific Medical University, Udaipur. Sixty male and female athletes aged 18–30 years were included. Participants represented football, running, volleyball, basketball, cricket, kabaddi, badminton, and tennis. The mixed-sport sample reflected common amateur activities involving repeated running, jumping, kicking, lunging, and directional changes.

Group Allocation

Participants were equally divided into Group A (n=30) and Group B (n=30). Group A performed diaphragmatic breathing exercises together with traditional stretching and flexibility exercises. Group B performed the same traditional stretching and flexibility exercises without the diaphragmatic breathing component.

Eligibility Criteria

Participants were amateur athletes involved in sports at least three times per week, demonstrated limited hamstring flexibility according to the study screening procedure, and were willing to participate in the intervention. Athletes with a recent lower-limb injury within three months, a neuromuscular disorder, or current participation in another structured flexibility program were excluded.

Intervention Framework

The traditional flexibility program progressed from basic muscle preparation and static hamstring stretching to dynamic mobility, PNF stretching, posterior-chain control, and functional flexibility work. Group A completed the same program with a structured breathing component. Diaphragmatic breathing was initially practiced in supported positions, progressed to seated or quadruped practice, was integrated into stretching, and later emphasized slow controlled expiration during the stretch phase. Group B completed the flexibility progression without this breathing instruction.

Outcome Measures

Hamstring flexibility was assessed using the Active Knee Extension test. With the participant positioned supine and the hip held at approximately 90° flexion, the participant actively extended the knee to the maximum comfortable range without compensation. Measurements were recorded for both limbs

(ISSN: 0973-7049(P))
The Bioscan AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES 21(3): S.I (3), 1172-1188, 2026 www.thebioscan.com

and an average value was used for the principal analysis. Greater post-intervention AKE values indicated improved hamstring flexibility.

Stretch-related discomfort was assessed using the Numeric Pain Rating Scale. Participants rated discomfort experienced during hamstring stretching on a 0–10 scale, with 0 representing no discomfort and 10 representing maximum discomfort. Reduction in NPRS from pre- to post-intervention represented improved tolerance of stretching.

Derived Variables

AKE improvement was calculated as post-intervention average AKE minus pre-intervention average AKE. NPRS reduction was calculated as pre-intervention NPRS minus post-intervention NPRS. In the source statistical plan, an AKE gain of at least 8° was used to categorize clinical improvement. Percentage improvement values were also summarized to place the magnitude of objective and subjective change on a relative scale.

Statistical Analysis

Descriptive statistics were expressed as mean ± standard deviation or frequency as appropriate. Normality testing in the source analysis supported the use of parametric procedures. Paired t-tests evaluated within-group pre-post changes, and independent t-tests compared the magnitude of change between groups. Pearson correlation was used to examine the relationship between AKE improvement and NPRS reduction and to explore associations of flexibility gain with age and weekly training frequency. Chi-square analysis evaluated the association between group allocation and clinical improvement category. Significance was set at $p<0.05$.

RESULTS

All 60 athletes included in the source dataset were available for this secondary analysis, with 30 participants in each group. The overall mean age was 22.98 ± 2.62 years. Group A had a mean age of 23.40 ± 2.85 years and Group B 22.57 ± 2.34 years. The groups were statistically comparable in age, sex distribution, BMI, baseline AKE, and baseline NPRS, providing a reasonable basis for comparing the pattern of change between interventions.

Baseline Profile

Variable	Group A	Group B	p value
Age (years)	23.40 ± 2.85	22.57 ± 2.34	0.2209
BMI (kg/m²)	23.20 ± 3.07	22.49 ± 2.83	0.3602
Training days/week	4.26 ± 0.68	4.27 ± 0.97	—
Average AKE pre (°)	47.89 ± 5.43	45.97 ± 4.87	0.1540
Average NPRS pre	6.29 ± 1.20	6.38 ± 0.99	0.7522

The absence of significant baseline differences in AKE and NPRS is important for the present perspective because it indicates that the later relationship between change in range and change in discomfort was not based on markedly different starting values between groups.

Objective Flexibility Gain

Group	Pre AKE (°)	Post AKE (°)	Mean change (°)	Paired t	p value
A	47.89 ± 5.43	59.68 ± 6.02	11.80 ± 2.28	28.282	<0.001
B	45.97 ± 4.87	52.82 ± 5.39	6.86 ± 2.29	16.373	<0.001

Both groups improved significantly in average AKE. However, the mean gain in Group A exceeded that in Group B by almost five degrees. Between-group analysis confirmed a significant difference in change (t=8.369, p<0.001), with Cohen d=2.16, representing a very large effect in favour of the breathing-integrated program.

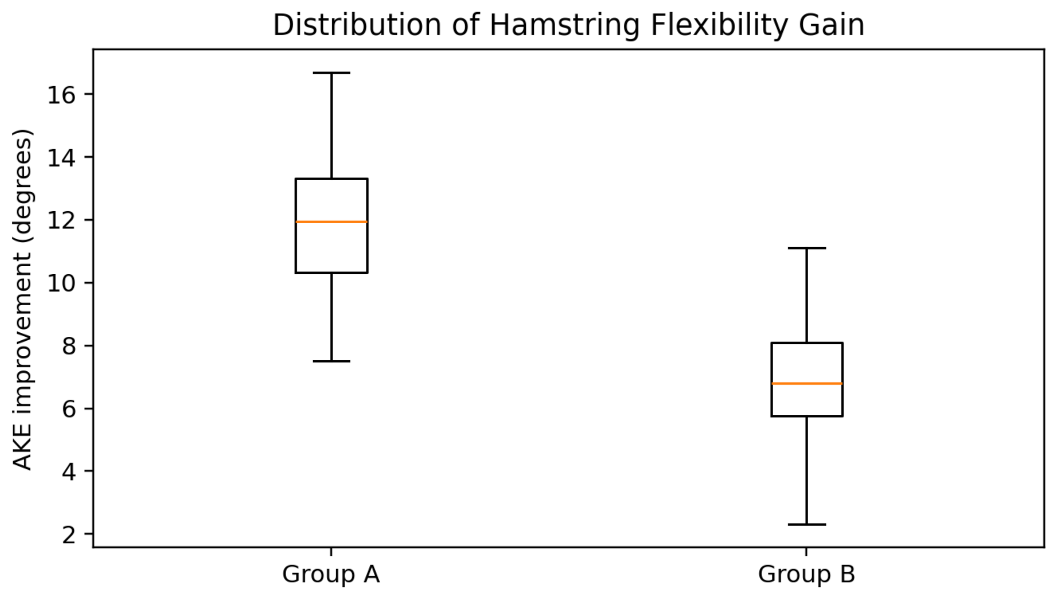

Figure 1. Distribution of AKE improvement in Group A and Group B.

Reduction in Stretch-Related Discomfort

Group	Pre NPRS	Post NPRS	Mean reduction	Paired t	p value
A	6.29 ± 1.20	2.93 ± 1.29	3.37 ± 0.69	26.088	<0.001
B	6.38 ± 0.99	4.30 ± 0.98	2.08 ± 0.54	21.152	<0.001

NPRS decreased significantly in both groups, demonstrating that conventional flexibility training itself improved the comfort of stretching. The decrease was nevertheless substantially larger in Group A. The between-group difference in NPRS reduction was significant (t=8.045, p<0.001), and Cohen d=2.08 indicated a very large effect.

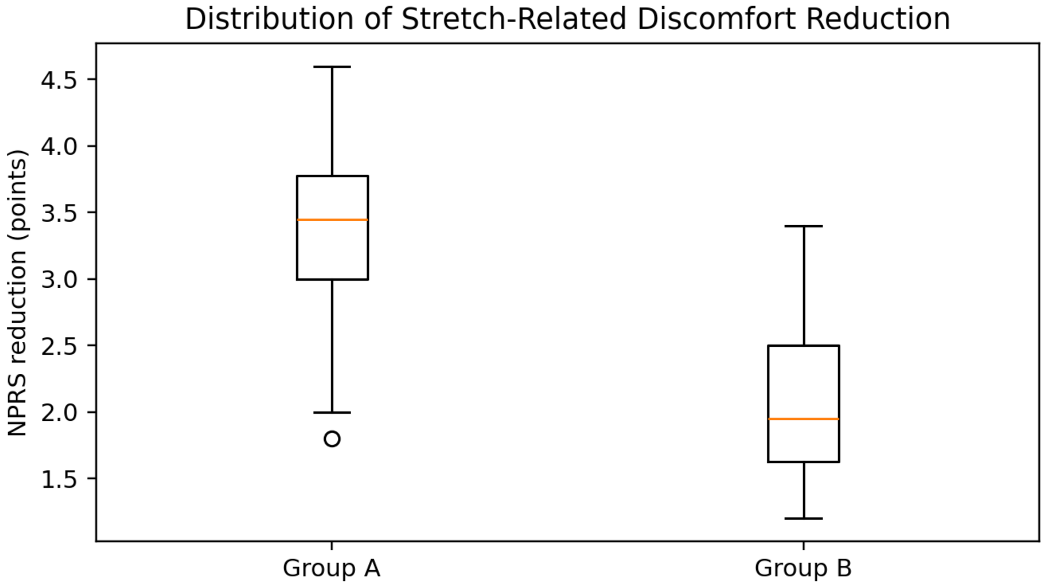

Figure 2. Distribution of NPRS reduction in Group A and Group B.

Relationship Between Flexibility Gain and Discomfort Reduction

Relationship	Pearson r	p value	Interpretation
AKE change vs NPRS reduction	0.521	<0.001	Moderate positive association
Age vs AKE change	0.138	0.2944	Not significant
Training days/week vs AKE change	-0.008	0.9487	Not significant

Across the complete sample, AKE improvement and NPRS reduction were moderately and positively correlated ($r=0.521$, $p<0.001$). In practical terms, athletes who gained more knee-extension range generally also reported a larger reduction in discomfort during stretching. The association was not perfect, indicating that objective flexibility and subjective stretch tolerance are related but remain distinct clinical dimensions.

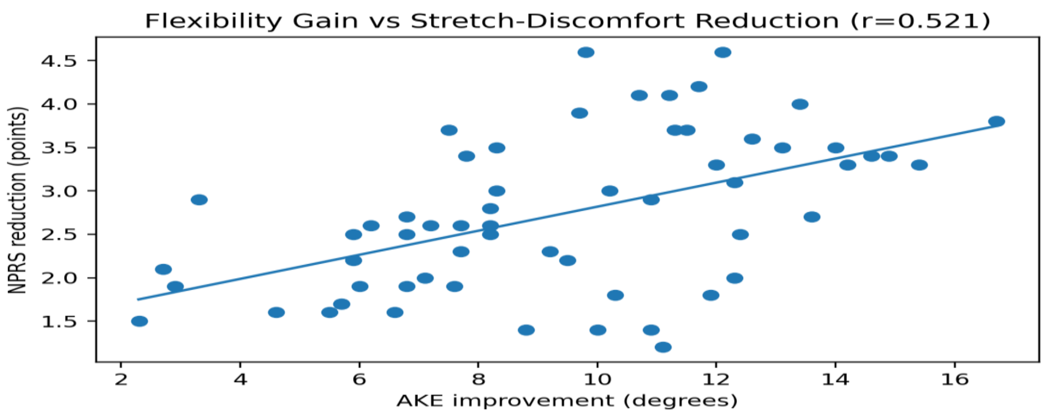

Figure 3. Relationship between AKE improvement and NPRS reduction across all participants.

(ISSN: 0973-7049(P))
The Bioscan AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES 21(3): S.I (3), 1172-1188, 2026 www.thebioscan.com

Age showed only a weak, non-significant relationship with AKE change (r=0.138, p=0.2944). Weekly training frequency was essentially unrelated to flexibility gain (r=-0.008, p=0.9487). Within the characteristics measured in this study, these findings suggest that the observed flexibility response was not meaningfully explained by age or the number of training days per week.

Relative Magnitude of Objective and Subjective Improvement

Outcome	Group A	Group B
AKE percentage improvement	24.64%	14.92%
NPRS percentage reduction	53.61%	32.62%
Cohen d for between-group AKE change	2.16	—
Cohen d for between-group NPRS reduction	2.08	—

When change was expressed as a percentage, Group A demonstrated larger relative improvement in both outcomes. The difference was particularly marked for stretch-related discomfort, where the reduction exceeded half of the baseline NPRS value in Group A. The parallel direction of these percentage changes supports the interpretation that breathing-integrated flexibility training influenced both the range achieved and the comfort with which the range was approached.

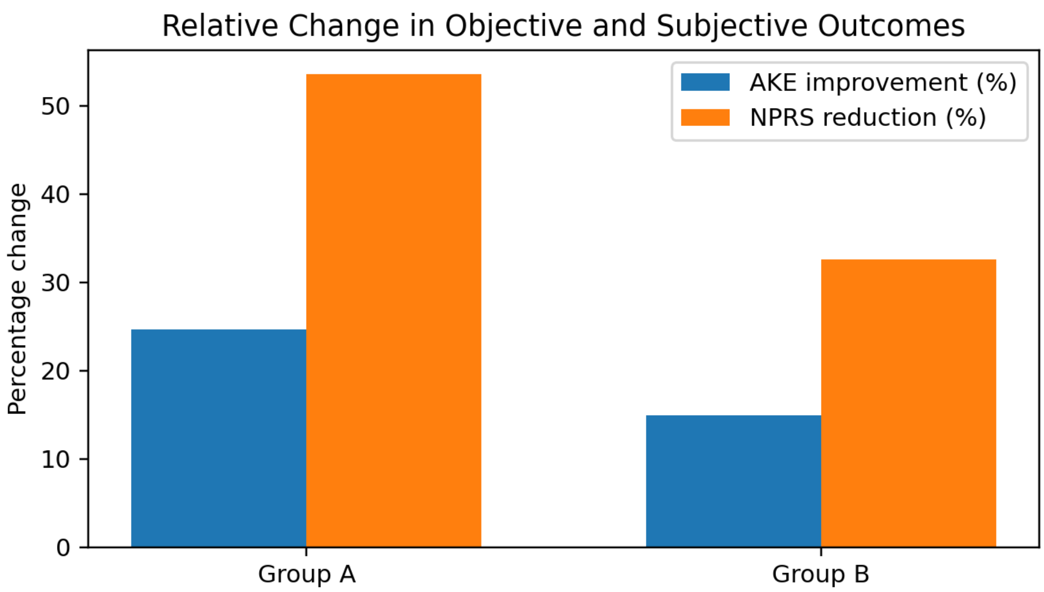

Figure 4. Percentage improvement in AKE and percentage reduction in NPRS.

Clinical Improvement

Group	Clinically improved	Not clinically improved	Improvement rate
A	29	1	96.7%
B	8	22	26.7%

(ISSN: 0973-7049(P))

The Bioscan AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES 21(3): S.I (3), 1172-1188, 2026 www.thebioscan.com

Using the predefined threshold of an AKE gain of at least 8°, 29 of 30 participants in Group A were categorized as clinically improved compared with 8 of 30 in Group B. Chi-square analysis in the source statistics demonstrated a significant association between treatment group and clinical improvement (χ^2=28.202, p<0.001). This finding indicates that the larger mean response in Group A was broadly distributed across participants rather than being driven by a small number of extreme responders.

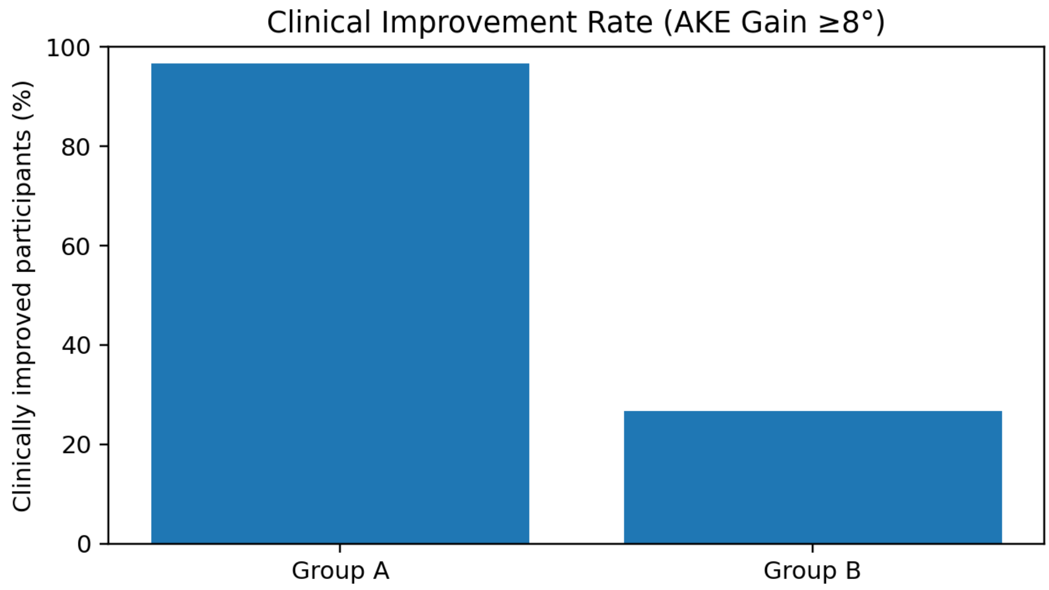

Figure 5. Percentage of participants meeting the clinical improvement threshold.

Summary of Principal Findings

The results present a consistent pattern. Traditional flexibility training improved both AKE and NPRS, but adding diaphragmatic breathing produced larger changes in each outcome. More importantly for the present secondary perspective, improvement in AKE was positively related to reduction in NPRS. This indicates that objective gain in hamstring flexibility and subjective improvement in stretch tolerance tended to occur together. The lack of meaningful correlation of AKE gain with age or training frequency further suggests that the paired objective-subjective response was more closely related to the intervention process than to these measured participant characteristics.

DISCUSSION

The present secondary analysis was designed to examine the relationship between two outcomes that are often considered separately in flexibility research: the amount of hamstring range gained and the amount of discomfort reduced during stretching. The main finding was a moderate positive correlation between AKE improvement and NPRS reduction. Athletes who gained more flexibility generally also reported a greater decrease in stretching-related discomfort. This relationship adds a different interpretation to the source experimental study because it suggests that the intervention response involved both movement capacity and the subjective experience of reaching end range.

The distinction between flexibility and stretch tolerance is clinically important. Range of motion is frequently used as the primary indicator of success, yet the range reached in an AKE test depends partly on the participant's willingness and ability to tolerate increasing tension. A measurable improvement in range does not necessarily imply permanent structural elongation of muscle tissue. Stretching studies have shown that range can improve after relatively short interventions, and such changes may reflect altered sensory tolerance as well as mechanical adaptation [4,6,7]. The simultaneous reduction in NPRS seen in the present dataset is therefore not merely an additional symptom outcome; it may be part of the mechanism by which a greater range becomes comfortably available.

Both groups demonstrated significant AKE improvement, confirming that the progressive flexibility program itself was effective. This is consistent with the broad stretching literature, in which static, active, dynamic, and PNF-based methods can increase hamstring range [4–7]. Group B therefore provides an important comparison: athletes improved without diaphragmatic breathing, which indicates that conventional stretching remained a meaningful treatment. The different perspective offered by Group A is that the addition of breathing produced a larger change in range and an even larger proportional change in stretch-related discomfort.

The NPRS reduction in Group A was 3.37 ± 0.69 points compared with 2.08 ± 0.54 points in Group B. This difference may reflect improved stretch tolerance. Slow controlled breathing can influence autonomic state, and the literature on breathing and pain perception suggests that respiratory pattern can modify the experience of discomfort [8–11]. During stretching, athletes commonly brace or hold their breath as tension rises. A breathing strategy that emphasizes diaphragmatic expansion and controlled expiration may counter this tendency, reduce generalized effort, and make the end-range sensation easier to tolerate.

This interpretation is supported by the moderate positive correlation between AKE gain and NPRS reduction. If range and discomfort were completely independent, little association would be expected. Instead, the observed r value of approximately 0.52 indicates a meaningful relationship while leaving substantial unexplained variance. The result therefore supports a balanced view: improved comfort may help an athlete express more range, but it is unlikely to be the only factor responsible for flexibility gains. Mechanical changes, neuromuscular adaptation, postural strategy, and measurement variability may also contribute.

The diaphragm's postural function offers another possible explanation for the paired improvement. Hodges and Gandevia demonstrated activation of the diaphragm during postural tasks and described its role in generating intra-abdominal pressure [12,14]. Kolar et al. used dynamic MRI to further demonstrate diaphragmatic involvement in stabilization [13]. Because the hamstrings originate from the pelvis, the quality of trunk and pelvic control can influence how hip and knee range is expressed during testing. Better respiratory-postural coordination may reduce unnecessary lumbar or pelvic compensation and allow the athlete to approach the stretch with less global bracing.

The present paper does not claim that diaphragmatic breathing directly lengthens the hamstring muscle. The outcome measures cannot establish that mechanism. A more cautious interpretation is that breathing may alter the context of stretching by influencing relaxation, perceived threat, trunk stabilization, and movement control. This distinction is important because it avoids attributing short-term range changes to fascial or structural mechanisms that were not measured. The study did not include ultrasound elastography, electromyography, diaphragm imaging, intra-abdominal pressure, or heart-rate variability.

The fascial and anatomical literature nevertheless provides a plausible framework for integrated behaviour across the trunk and posterior chain. Fascia connects adjacent and distant tissues and participates in force transmission [15]. The diaphragm has lumbar attachments and interacts with the abdominal wall and pelvic floor, while the hamstrings influence pelvic position. Myers and other authors have described myofascial continuity across the posterior body [16]. These concepts may help explain why respiratory and flexibility interventions can interact, but they should be viewed as supportive anatomical context rather than direct evidence from the current dataset.

González-Álvarez et al. reported changes in posterior-chain kinematics after diaphragm stretching [17]. Although manual diaphragm stretching differs from breathing training, the study is relevant because it demonstrates that an intervention directed at the diaphragm can be associated with measurable musculoskeletal changes outside the thorax. Kocjan et al. likewise emphasized the multifunctional nature of the diaphragm and its participation in postural regulation [18]. Together with the current findings, these studies support further investigation of breathing as part of integrated movement rehabilitation.

The clinical improvement analysis reinforces the relationship-based findings. Nearly all Group A participants reached the source study's threshold of at least 8° AKE improvement, whereas fewer than one-third of Group B participants did so. A large difference in the proportion of responders means that the between-group effect was not confined to average values. From a sports rehabilitation perspective, this is useful because clinicians work with individual responders rather than group means alone. The breathing-integrated program appears to have produced a more consistent clinically meaningful response across participants.

The percentage analysis also highlights the distinction between objective and subjective adaptation. Group A improved AKE by 24.64% but reduced NPRS by 53.61%. Group B improved AKE by 14.92% and reduced NPRS by 32.62%. In both groups, the relative change in discomfort was larger than the relative change in range. This pattern is compatible with the idea that an athlete's experience of stretching may change more rapidly than the measurable range itself. It further supports recording both outcomes in flexibility research.

Age was not significantly related to flexibility gain in this sample. This is not surprising given the restricted age range of 18–30 years, which reduces the ability to detect age-related differences. Similarly, training days per week showed virtually no relationship with AKE change. Weekly frequency is a crude exposure measure and does not capture duration, intensity, sport-specific workload, previous flexibility practice, sleep, recovery, or competitive schedule. The absence of association therefore should not be interpreted as evidence that training characteristics never influence flexibility.

The mixed-sport composition of the sample increases practical relevance while also introducing heterogeneity. Football, running, volleyball, basketball, cricket, kabaddi, badminton, and tennis differ in movement demands, but all expose the lower limb to repeated cycles of force production and control. The fact that a relationship between AKE gain and NPRS reduction emerged across this varied sample suggests that the connection between flexibility and stretch tolerance may not be restricted to one sport. Sport-specific studies are still required to determine whether the strength of this relationship differs according to activity.

The present findings also have implications for outcome selection. If clinicians measure only AKE, they may miss an important change in how the athlete experiences stretching. If they record only NPRS, they may miss whether that improved comfort translates into measurable movement gain. Pairing the two provides a more clinically meaningful description: the athlete can move farther and does so with less discomfort. This dual-outcome approach may be useful when monitoring warm-up programs, return-to-sport mobility work, or rehabilitation of athletes who report recurrent posterior-thigh tightness.

The diaphragmatic breathing intervention is attractive because it is simple and does not require specialized equipment. It can be taught separately and then integrated into existing stretches, particularly by discouraging breath holding and emphasizing slow controlled expiration. Reviews of diaphragmatic breathing describe potential effects on autonomic regulation and health [22,23], while clinical studies have incorporated breathing into core stabilization and corrective exercise programs [19–21]. The present results extend that general concept to flexibility and stretch tolerance in amateur athletes.

However, the correlation between AKE and NPRS must not be interpreted as causation. It cannot be concluded from these data that reduced discomfort caused the flexibility improvement or that increased flexibility directly caused the reduction in discomfort. Both may have been influenced by the intervention or by other shared factors. Future studies could use repeated measurements across sessions to establish temporal relationships, and mediation analysis could examine whether changes in autonomic or neuromuscular variables explain part of the breathing effect.

Future work should also include objective measurements of diaphragm excursion, respiratory muscle activation, heart-rate variability, hamstring stiffness, and electromyographic activity. These measures could help distinguish whether breathing primarily affects autonomic relaxation, neuromuscular guarding, lumbopelvic stabilization, or tissue mechanics. Longer follow-up is also needed to determine whether improvements in stretch tolerance and range persist and whether they translate into performance or injury-related outcomes.

Overall, the present secondary analysis supports a broader interpretation of flexibility. Hamstring range and stretch discomfort were related but not interchangeable. The breathing-integrated group demonstrated larger improvements in both, and the two changes were moderately associated across the full sample. These findings support the clinical use of objective range testing together with a simple subjective measure of stretch tolerance when evaluating flexibility interventions.

CONCLUSION

The present secondary analysis showed that improvement in hamstring flexibility was meaningfully associated with reduction in stretch-related discomfort among amateur athletes. Both groups improved after flexibility training, but athletes who performed diaphragmatic breathing in addition to the traditional program demonstrated greater AKE gain, greater NPRS reduction, and a markedly higher rate of clinically meaningful improvement. The moderate positive correlation between AKE change and NPRS reduction indicates that athletes who gained more range generally also became more comfortable during stretching. These outcomes suggest that flexibility should be interpreted as both an objective movement characteristic and a subjective tolerance response. Diaphragmatic breathing may therefore be a useful adjunct when the clinical goal is not only to increase hamstring range but also to reduce guarding or discomfort as the athlete approaches end range. Because the study did not directly measure autonomic, respiratory, fascial, or neuromuscular mechanisms, these explanations require further investigation.

LIMITATIONS

- This was a secondary analysis of a dataset originally designed to compare intervention groups rather than to test a mechanistic model of stretch tolerance.
- The sample consisted of 60 amateur athletes aged 18–30 years, limiting generalization to professional athletes, older adults, adolescents, and clinical populations.
- The intervention period was relatively short and no long-term follow-up was available to determine whether the relationship between improved range and reduced discomfort persisted.
- NPRS is a subjective measure and can be influenced by motivation, expectation, psychological state, and individual interpretation of stretch sensation.
- The study did not directly measure diaphragm excursion, heart-rate variability, electromyographic activity, intra-abdominal pressure, muscle stiffness, or fascial behaviour.
- Group-specific correlations between AKE gain and NPRS reduction were not part of the source statistical analysis; therefore, the association is interpreted across the complete sample.
- Training frequency was recorded as days per week but did not capture training intensity, session duration, competitive load, recovery, or previous flexibility exposure.
- The study did not determine whether greater AKE and reduced stretching discomfort translated into improved sprinting, jumping, agility, sport performance, or reduced injury incidence.

RECOMMENDATIONS

- Future studies should prospectively identify stretch tolerance as a primary or co-primary outcome and examine it alongside objective range of motion.
- Repeated measurements during the intervention should be used to determine

whether reduction in discomfort precedes, follows, or develops in parallel with flexibility gain.

- Group-specific and mediation analyses should examine whether changes in autonomic regulation or trunk control explain part of the relationship between breathing and flexibility.
- Heart-rate variability, respiratory rate, diaphragm ultrasound, surface electromyography, and ultrasound elastography should be considered to explore the physiological mechanisms involved.
- Longer follow-up periods are recommended to determine whether improvements in both AKE and stretch tolerance are maintained after the supervised program ends.
- Sport-specific studies should evaluate whether the relationship differs in running, football, cricket, volleyball, badminton, kabaddi, basketball, or tennis populations.
- Future research should examine whether combined improvement in range and stretch tolerance predicts functional outcomes such as sprint mechanics, agility, kicking, jumping, or injury recurrence.
- Clinicians may consider recording a discomfort rating during standardized flexibility testing so that changes in comfortable range are interpreted together with changes in measured range.

REFERENCES

1. Opar DA, Williams MD, Shield AJ. Hamstring strain injuries: factors that lead to injury and re-injury. Sports Med. 2012;42(3):209-226.

2. Witvrouw E, Danneels L, Asselman P, D'Have T, Cambier D. Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players. Am J Sports Med. 2003;31(1):41-46.

3. Sahrmann SA. Diagnosis and Treatment of Movement Impairment Syndromes. St Louis: Mosby; 2001.

4. Behm DG, Blazevich AJ, Kay AD, McHugh M. Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals. Appl Physiol Nutr Metab. 2016;41(1):1-11.

5. Konrad A, Tilp M. The acute effects of foam rolling and stretching on range of motion and performance. J Sports Sci Med. 2020;19(4):690-696.

6. Nishikawa Y, Aizawa J, Kanemura N, et al. Immediate effect of passive and active stretching on hamstrings flexibility: a single-blinded randomized control trial. J Phys Ther Sci. 2015;27(10):3167-3170.

7. Webright WG, Randolph BJ, Perrin DH. Comparison of nonballistic active knee extension in neural slump position and static stretch techniques on hamstring flexibility. J Orthop Sports Phys Ther. 1997;26(1):7-13.

8. Russo MA, Santarelli DM, O'Rourke D. The physiological effects of slow breathing in the healthy human. Breathe (Sheff). 2017;13(4):298-309.

9. Courtney R. The functions of breathing and its dysfunctions and their relationship to breathing therapy. Int J Osteopath Med. 2009;12(3):78-85.

10. Busch V, Magerl W, Kern U, Haas J, Hajak G, Eichhammer P. The effect of deep and slow breathing on pain perception, autonomic activity, and mood processing—an experimental study. Pain Med. 2012;13(2):215-228.

11. Jafari H, Courtois I, Van den Bergh O, Vlaeyen JWS, Van Diest I. Pain and respiration: a systematic review. Pain. 2017;158(6):995-1006.

12. Hodges PW, Gandevia SC. Activation of the human diaphragm during a repetitive postural task. J Physiol. 2000;522 Pt 1:165-175.

13. Kolar P, Sulc J, Kyncl M, Sanda J, Neuwirth J, Bokarius AV, et al. Stabilizing function of the diaphragm: dynamic MRI and synchronized spirometric assessment. J Appl Physiol. 2010;109(4):1064-1071.

14. Hodges PW, Gandevia SC. Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. J Appl Physiol. 2000.

15. Schleip R, Jäger H, Klingler W. What is fascia? A review of different nomenclatures. J Bodyw Mov Ther. 2012;16(4):496-502.

16. Myers TW. Anatomy Trains: Myofascial Meridians for Manual and Movement Therapists. 4th ed. Edinburgh: Elsevier; 2020.

17. González-Álvarez FJ, Valenza MC, Torres-Sánchez I, Cabrera-Martos I, Rodríguez-Torres J, Castellote-Caballero Y. Effects of diaphragm stretching on posterior chain muscle kinematics and rib cage and abdominal excursion: a randomized controlled trial. Braz J Phys Ther. 2016;20(5):405-411.

18. Kocjan J, Adamek M, Gzik-Zroska B, Czyżewski D, Rydel M. Network of breathing: multifunctional role of the diaphragm: a review. Adv Respir Med. 2017;85(4):224-232.

19. Masroor S, et al. Effect of adding diaphragmatic breathing exercises to core stabilization exercises on pain, muscle activity, disability and sleep quality in patients with chronic low back pain: a randomized control trial. J Chiropr Med. 2023.

20. Sannasi R, et al. Diaphragm and core stabilization exercises in low back pain: a narrative review. Int J Sports Phys Ther. 2023.

21. Rashed SS, et al. Effect of adding diaphragmatic breathing to corrective exercises on thoracic kyphosis, pain and quality of life: a randomized controlled trial. 2024.

22. Hamasaki H. Effects of diaphragmatic breathing on health: a narrative review. Medicines (Basel). 2020;7(10):65.

23. Mourya M, Mahajan AS, Singh NP, Jain AK. Effect of slow- and fast-breathing exercises on autonomic functions in patients with essential hypertension. J Altern Complement Med. 2009;15(7):711-717.

24. Bernardi L, Spadacini G, Bellwon J, Hajric R, Roskamm H, Frey AW. Effect of breathing rate on oxygen saturation and exercise performance in chronic heart failure. Lancet. 1998;351(9112):1308-1311.

25. Brown RP, Gerbarg PL. Yoga breathing, meditation, and longevity. Ann N Y Acad Sci. 2009;1172:54-62.

26. Lehrer PM, Vaschillo E, Vaschillo B. Resonant frequency biofeedback training to increase cardiac variability: rationale and manual for training. Appl Psychophysiol Biofeedback. 2000;25(3):177-191.

27. Janssens L, Brumagne S, McConnell AK, Claeys K, Pijnenburg M, Goossens N, et al. Inspiratory muscle training affects proprioceptive use and low back pain. Med Sci Sports Exerc. 2015;47(1):12-19.

28. Nishimoto K, et al. Jack-knife stretching and active knee extension stretching equally improve relative flexibility of the hamstring muscles: a randomized controlled trial. J Phys Ther Sci. 2019.

29. Bandy WD, Irion JM, Briggler M. The effect of static stretch and dynamic range of motion training on the flexibility of the hamstring muscles. J Orthop Sports Phys Ther. 1998;27(4):295-300.

30. Bordoni B, Morabito B. The influence of breathing on lumbar biomechanics and fascial tension. Cureus. 2018;10(7):e3078.