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Article

# The biomechanical impact of static or dynamic stretching on balancing ability: A systematic review and meta-analysis

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**Abstract:** This study aims to evaluate the biomechanical effects of static stretching (SS) and dynamic stretching (DS) on balance abilities through a systematic review and meta-analysis. Following the PRISMA and PERSIST guidelines, a comprehensive search was conducted in July 2024 across PubMed, Web of Science, Cochrane, Embase, and EBSCO databases for randomized controlled trials assessing the influence of SS and DS on balance abilities in healthy adult populations. A total of twelve studies involving 308 participants were included in this analysis. The primary meta-analysis revealed that static stretching (SS) significantly impaired static balance abilities compared to dynamic stretching (DS), with an effect size of −0.05. Additionally, regression analysis identified stretching duration as a significant source of heterogeneity in static balance, highlighting considerable biomechanical variation. No significant changes were observed for center of pressure (COP) or dynamic balance. Bubble charts illustrated that as stretching duration increased, the effect size on static balance decreased, with multiple effect sizes clustering around the 20 s–200 s duration. Overall, dynamic stretching (DS) is superior to static stretching (SS) in enhancing balance abilities among healthy populations, particularly regarding static balance. Regression analysis indicated that stretching duration is a critical biomechanical factor influencing static balance, with optimal effects observed within the range of 20s to 200s.

**Keywords:** static stretching; dynamic stretching; balance ability; biomechanics; meta-analysis

## 1. Introduction

Balance ability is a fundamental and multifaceted aspect of human motor function, serving as the cornerstone for a wide range of physical activities. It encompasses the remarkable capacity to maintain body stability in both static and dynamic conditions, a skill that is not only essential for preventing falls but also plays a pivotal role in enhancing athletic performance and facilitating the seamless execution of various daily tasks [1,2].

In the realm of sports, a strong balance ability can mean the difference between a successful performance and a potential injury[3]. For athletes, it enables them to execute complex maneuvers with precision, maintain control during high-speed movements, and react swiftly to changing circumstances on the field or court. In daily life, it allows individuals to navigate uneven surfaces, climb stairs, and perform routine activities with confidence and ease.

Balance is a complex interplay of multiple factors, with sensory input, muscular strength, and the biomechanical properties of the musculoskeletal system all contributing significantly to this intricate process [4]. Sensory input from the eyes, ears, and proprioceptors in the muscles and joints provides the body with crucial information about its position in space. Muscular strength, on the other hand, is essential for generating the forces required to maintain balance. The biomechanical properties of the musculoskeletal system, such as the alignment of bones, the flexibility of joints, and the elasticity of muscles and tendons, also play a vital role in determining an individual's balance ability.

Stretching exercises have long been an integral part of both athletic training and everyday workouts. They are widely used to improve flexibility, reduce muscle tension, and enhance balance ability by modifying the length and stiffness of muscles and soft tissues. Among the various stretching methods available, static stretching (SS) and dynamic stretching (DS) stand out as two of the most commonly practiced forms [5].

Static stretching is a well-recognized and widely-used flexibility training technique. It involves extending muscles and soft tissues to a specific length and holding this position for a designated duration [6]. This method offers several benefits, including an increase in the range of motion (ROM) and muscle compliance, as well as enhancing the muscle-tendon unit’s (MTU) capacity to store elastic energy [7]. The biomechanical effects of static stretching can be attributed to alterations in the viscoelastic properties of the muscle-tendon complex. When a muscle is held in a stretched position, the viscoelastic elements within the muscle gradually adapt, leading to a decrease in muscle stiffness and an increase in compliance [8]. This can have implications for balance, as changes in muscle stiffness can affect the body's ability to respond to external forces and maintain equilibrium.

Static stretching is commonly employed in pre-exercise warm-ups, with the aim of mitigating the risk of sports injuries and enhancing athletic performance. However, the exact implications of these biomechanical changes on balance ability remain a subject of debate. Some studies suggest that static stretching may have a negative impact on balance, while others indicate that it may have no significant effect or even a positive influence. For instance, a study by Smith et al. [9] found that static stretching for a prolonged period before a balance-sensitive task led to a decrease in the ability to maintain postural stability.

Dynamic stretching, in contrast, involves controlled movements that take joints through their full range of motion. This technique is designed to improve muscle flexibility and prepare the body for physical activity. Unlike static stretching, which involves holding a fixed position, dynamic stretching emphasizes the gradual stretching of muscles through motion. It typically includes a series of movement patterns, such as walking lunges and leg swings, which not only elevate muscle temperature and increase blood flow but also activate both the muscular and nervous systems [10,11].

The biomechanical benefits of dynamic stretching are numerous. It enhances the neuromuscular response, allowing for more efficient muscle activation and coordination. By increasing joint mobility, it enables the body to move more freely and with greater ease. Additionally, dynamic stretching prepares the body for the demands of athletic performance by improving the stretch-shortening cycle (SSC), a key component in activities requiring rapid changes in direction and speed [12]. It may also improve balance performance by elevating muscle temperature and hydration, which are crucial for optimal muscle function [13].

Despite the widespread use of static and dynamic stretching in athletic training, the literature on their impact on balance ability is filled with inconsistent findings. Research by Behm et al. has shown that static stretching may temporarily diminish muscle strength output, potentially due to neural factors such as reduced spinal excitability and impaired motor neuron activation [14–16]. These neural adaptations can lead to decreased performance in balance tasks, as effective balance requires optimal muscle activation and coordination. Additionally, static stretching may alter the mechanical properties of the muscle - tendon unit, leading to reduced stiffness in the force-length curve [17,18], which could indirectly affect both static and dynamic balance.

Conversely, dynamic stretching, characterized by controlled movements within the joint's range of motion [19], may trigger post-activation potentiation (PAP), enhance neural drive, activate a greater number of motor units, and increase the sensitivity of contractile proteins to calcium ions ($Ca^{2+}$) [20,21]. These physiological and biomechanical changes can have a positive impact on balance, especially during dynamic activities.

However, not all studies agree on the effects of static and dynamic stretching on balance. For example, research by Chaouachi et al. found that varying intensities of static and dynamic stretching sequences did not significantly impair sprint speed, agility, or jump performance in elite athletes [22]. Similarly, Little and Williams reported that static stretching had no detrimental effect on sprint times in high-level professional male soccer players [23]. Moreover, a study involving middle-aged athletes indicated that static stretching did not significantly affect performance in vertical jumps or other dynamic tasks; instead, it actually improved dynamic balance ability [24].

A recent systematic review by David G. et al. examined the effects of static and dynamic stretching on explosive power and sprint performance related to the stretch-shortening cycle (SSC) [10]. However, the impact of these stretching techniques on balance ability remains inconclusive. This inconsistency in the literature highlights the need for a more comprehensive understanding of how these stretching methods influence balance through biomechanical mechanisms.

To date, no meta-analysis has systematically compared the effects of static stretching (SS) and dynamic stretching (DS) on balance ability, nor their respective Cohen's effect sizes (ES). Given the importance of balance in both athletic performance and daily activities, it is crucial to synthesize the existing literature to evaluate the effects of static and dynamic stretching on balance ability. This analysis seeks to explore how these stretching methods influence both static and dynamic balance, considering the biomechanical factors that may mediate these effects. By addressing the gaps in the current literature, this systematic review and meta-analysis aims to provide valuable insights that can inform training practices and enhance athletic performance, ultimately leading to a better understanding of the complex relationship between stretching, biomechanics, and balance [25–28].

## 2. Methods

### 2.1. Literature inclusion and exclusion criteria

This comprehensive review was meticulously executed in strict accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. These guidelines are a cornerstone for ensuring the quality and transparency of such research. Additionally, it adhered to the detailed recommendations put forth by Moher et al [29] specifically tailored for systematic reviews incorporating a meta-analysis.

Inclusion criteria: ① the study population consisted of healthy adult subjects; ② the interventions and comparison interventions included SS and DS interventions; ③ the outcome indicators measured were static balance, dynamic balance, and COP; ④ the study design was a randomized controlled trial (RCT) or a controlled trial (CT). The exclusion criteria included: ① literature that was identified as duplicated; ② literature reviews and systematic evaluations; ③ studies from which outcome data could not be extracted or that did not report indicators relevant to this study; ④ non-experimental studies that did not present results from specific balance tests.

### 2.2. Literature search

Searches were comprehensively carried out in multiple authoritative databases including PubMed, Web of Science, Cochrane, Embase, and EBSCO. Boolean logic was employed to construct a meticulous search strategy. The search terms included a variety of expressions related to muscle stretching exercises, such as different combinations of static and dynamic stretching in titles or abstracts. These were combined with terms related to balance and randomized controlled trials. Specifically, the strategy involved: (“Muscle Stretching Exercises” [Mesh]) OR (Static-Active Stretching [Title/Abstract]) OR (Stretching Static-Active [Title/Abstract]) OR (Active Stretching [Title/Abstract]) OR (Static-Passive Stretching [Title/Abstract]) OR (Stretching Static-Passive [Title/Abstract]) OR (Static Stretching [Title/Abstract]) OR (Dynamic Stretching [Title/Abstract]) OR (Stretching Dynamic [Title/Abstract]) AND (balance [Title/Abstract]) AND (randomized controlled trial [Title/Abstract]) OR (randomized [Title/Abstract]) OR (placebo [Title/Abstract]). The search was conducted up to 1 July 2024, and the literature was restricted to articles published in the English language. Additionally, references from relevant studies were screened.

### 2.3. Literature screening and data extraction

In the process of this study, two researchers meticulously and independently screened the retrieved literature. They carefully extracted essential data including the authors, detailed intervention content, pre- and post-intervention data, as well as the sample size. In case of any discrepancies, they promptly engaged in discussions with additional researchers to reach a consensus.

### 2.4. Risk of bias in included studies

The risk of bias was meticulously evaluated in accordance with the guidelines outlined in the Cochrane Handbook [30]. This assessment focused on several critical aspects, including the representativeness of the study samples, adherence to randomization and blinding principles, and the completeness and transparency of the information provided. Each included study was carefully classified into categories of low, unclear, and high risk of bias based on these comprehensive criteria. This thorough evaluation ensures the reliability and validity of the findings, allowing for a more accurate interpretation of the results in the context of the systematic review.

### 2.5. Statistical methods

For the data analysis in this study, Stata 17.0 software was utilized. Continuous variables were synthesized through the standardized mean difference (SMD). Heterogeneity was meticulously assessed via the Q test and $I^2$ test. Fixed-effect models were employed when heterogeneity was low ($P < 0.1$, $I^2 > 50\%$). Additionally, subgroup analyses and meta-regression were carried out to explore heterogeneity sources, and Egger's test was used to evaluate publication bias.

## 3. Results

### 3.1. Basic characteristics of literature and screening results

A comprehensive and systematic database search was carried out across multiple relevant databases, leaving no stone unturned in the quest to gather all potentially relevant information. In addition to the database search, the references of related documents were carefully traced to ensure that no valuable sources were overlooked. As a result of these meticulous efforts, a total of 691 documents were initially obtained. After screening for duplicates and reviewing the titles, abstracts, and full texts using document management software, 12 documents were ultimately included in the analysis (**Figure 1**). The specific characteristics of the literature are presented in **Table 1**. The study population consisted exclusively of healthy individuals, with the intervention forms categorized as SS and DS. In total, 308 participants were included in the sample.

### 3.2. Methodological quality assessment

The results of the Cochrane risk of bias evaluation are presented in **Figures 2** and **3**. In this assessment, one article within the randomized sequence was categorized as having an unclear risk of bias, while the remaining articles were classified as having a low risk. Regarding allocation concealment, five articles were assessed as low risk, whereas the rest were deemed unclear. Given that this study involved an exercise intervention trial, all 12 papers were identified as having either a high or unclear risk of bias, leading to their exclusion from the report [31]. The evaluation of the completeness of outcome data revealed that three articles had unclear biases, while the remainder was assessed as low risk. Furthermore, selective reporting was a concern, with one article classified as high risk, five as unclear, and the rest at low risk. Ultimately, the overall classification resulted in one article being categorized as high risk and eleven as medium risk, contributing to an overall assessment of low risk of bias in the literature [32]. To further investigate potential publication bias, Egger's test for all outcome indicators was conducted using Stata 17.0 software. The results indicated no significant publication bias for static balance (*P* > 0.05) and center of pressure (COP) (*P* > 0.05). However, dynamic balance exhibited some publication bias (*P* < 0.05), which warrants careful consideration when interpreting the results and drawing conclusions from the findings. This nuanced understanding of bias is essential for ensuring the integrity and applicability of the research outcomes.

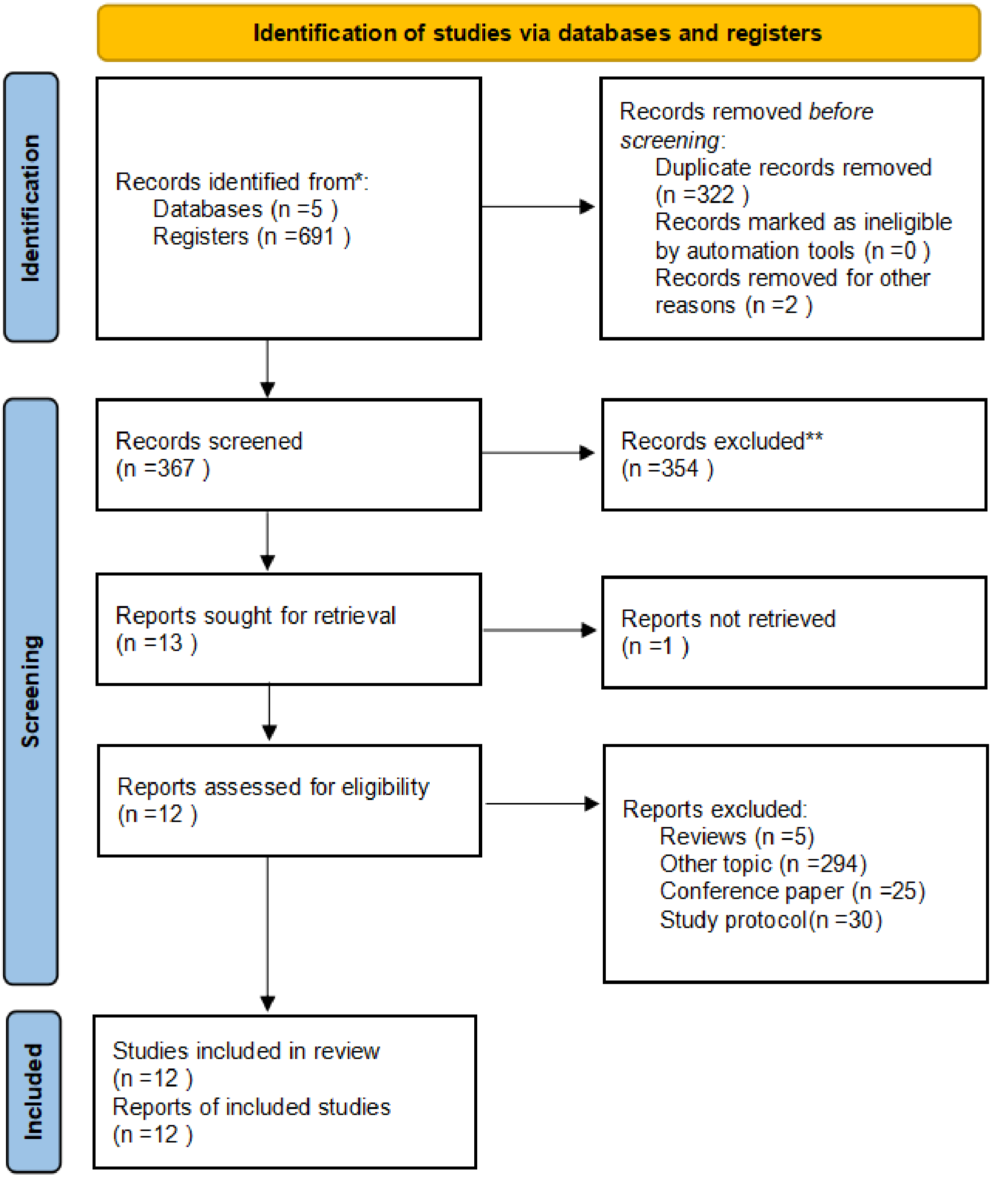

**Figure 1.** Literature screening process.

**Table 1**. Literature specific characteristics

| | | **Characteristics of subject** | | | | **Interventions information** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **study** | **Country** | **Number (Female/Men)** | **age (mean[SD])** | **height** | **weight** | **Type of exercise** | **Tensile position** | **frequency ( min/times)** | **experimental method** | **supervised or no supervised** | **outcome** |
| Kensuke Oba 2023 | Japan | 12M 3F | 23.9 ± 2.4 | 172.4 ± 8.1 | 62.5 ± 7.6 | SS、 DS、 Control | Plantar flexor | 4×30s | RCT | supervised | COP |
| Dimitris Chatzopoulos 2014 | Greece | 31F | 17.3 ± 0.5 | 1.66 ± 0.05 | 55.9 ± 5.4 | SS、 DS、 Control | Upper and lower limb muscles | 7min | RCT | supervised | Static balance |
| Mohammadtaghi Amiri-Khorasani 2015 | Iran | 24 F | 22.08 ± 0.77 | 159.75 ± 5.37 | 59.76 ± 5.48 | SS、 DS、 Combined 、 Control | Gastrocn emius , biceps femoris, hip flexors and extensors | 15S SS<br>15S DS | RCT | supervised | Static balance |
| JongMin Lim 2022 | Korea | 20 | 23.32 ± 2.23 | SS164.4±2.45<br>DS 165.8±1.55 | SS 60.1±7.71<br>DS 58.7±7.52 | SS、 DS | Plantar flexor | 3×30s | RCT | supervised | COP |
| Wenqing Wang 2013 | America | 8M 7F | 25.1 ± 4.3 | 172.7 ± 9.0 | 66.7 ± 13.0 | SS、 DS、 Control | Quadriceps, hamstrings and plantar flexors | 4×30s | RCT | supervised | Dynamic balance |
| M. Yilmaz Menek2024 | Turkey | 15M 17F | 21.75 ± 1.43 | 169.37 ± 8.56 | 61.87 ± 10.65 | DS、 SS、PMT | Hamstrings, quadriceps, gastrocnemius | 10×20s | RCT | supervised | Static balance |
| L. BELKHIRIA-TURKI 2014 | Tunisia | 28M | 22.73 ± 1.9 | 179.4 ± 7.05 | 78.60 ± 7.03 | SS、 DS、 Control | Hamstrings, quadriceps, gastrocnemius | 4×15s<br>8×15s<br>12×15s | RCT | supervised | Dynamic balance |
| Natalia Romero-Franco2020 | Spain | 32M | 24.9 ± 4.6 | 1.77 ± 0.07 | 66.8 ± 4.9 | SS、 DS、 Control | Gastrocnemius, biceps femoris and quadriceps femoris | 20s | RCT | supervised | COP |
| Yeong-Hyun Cho2021 | Korea | 11M | 22.7±0.9 | 174.0±10.8 | 76.9±8.0 | SS、 DS、PNF Control | Upper and lower limb muscles | 3×20s | RCT | supervised | Dynamic balance |

**Table 1**. (*Continued*).

| study | Country | Characteristics of subject | | | | Interventions information | | | | | outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Number (Female/Men )** | **age (mean[SD])** | **height** | **weight** | **Type of exercise** | **Tensile position** | **frequency ( min/times)** | **experimental method** | **supervised or no supervised** | |
| Eui-Young Jung2023 | Korea | 44 | SG 26.09 ± 1.76<br>DG 26.27 ± 1.68 | SG 169.82 ± 7.55<br>DG 174.35 ± 7.98 | SG 169.82 ± 7.55<br>DG 174.35 ± 7.98 | SS、 DS、 Control、Ballistic stretching | Plantar flexor | 4×45s | RCT | supervised | Dynamic balance |
| Niamh Morrin2013 | England | 10F | 27 ± 5.0 | 162.7 ± 4.9 | 56 ± 7.0 | SS、 DS、 Combined 、 Control | Gluteus maximus, quadriceps, hamstrings and gastrocnemius | 2×30s | RCT | supervised | COP |
| Ye-ri Ji2021 | Korea | 15M 15F | 21.9±0.6 (DS)<br>20.8±0.3 (SS) | 168.8±2.9 (DS)<br>165.5±2.0 (SS) | 65.0±4.4 (DS)<br>60.3±3.2 (SS) | SS、 DS | SS wedge board<br>DS lunge, forward kick | 9min | RCT | supervised | Static balance |

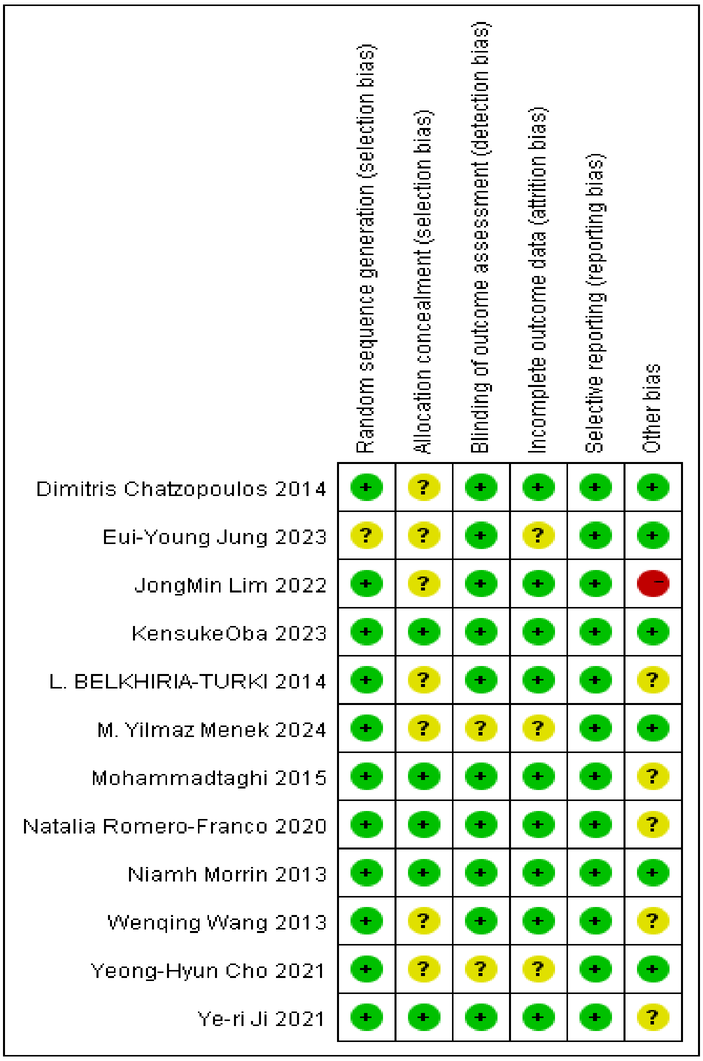

**Figure 2.** Risk of biass ummary.

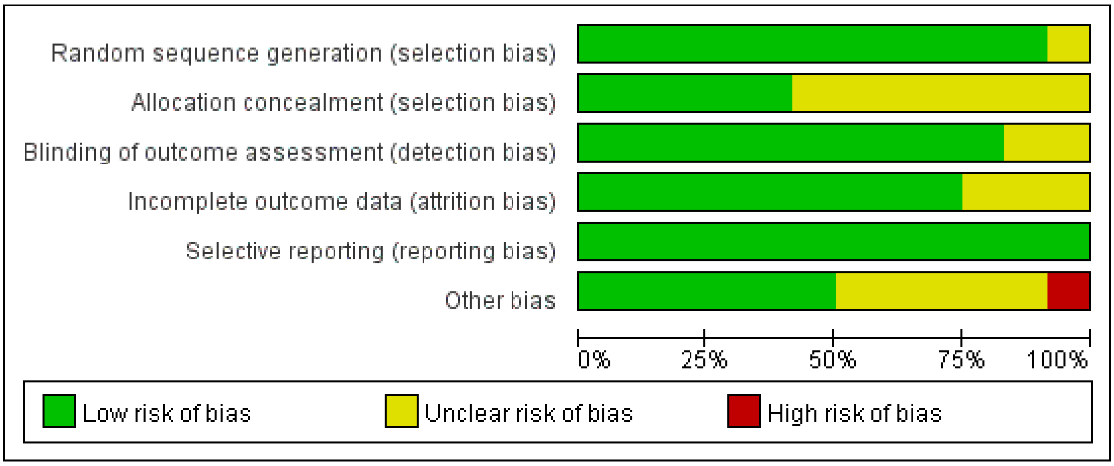

**Figure 3.** Bias evalution.

### 3.3. Meta-analysis results

A comprehensive meta-analysis of static equilibrium, center of pressure (COP), and dynamic equilibrium was meticulously conducted. As vividly illustrated in **Figure**

**4**, static equilibrium was significantly reduced following static stretching (SS) compared to dynamic stretching (DS), with an effect size of SMD −0.05 (95% confidence interval [CI] −0.36 to 0.26, $p = 0.003$, $I^2 > 50\%$). **Figure 5** demonstrates that neither COP SMD 0.15, (95% CI −0.15 to 0.44, $p = 0.075$) nor dynamic equilibrium as shown in **Figure 6**, SMD 0.07, (95% CI −0.16 to 0.30, $p = 0.980$) reached statistical significance, both exhibiting low heterogeneity ($I^2 < 0.05$). Given that varying stretching durations may have contributed to the observed heterogeneity, a regression analysis was performed to examine the impact of stretching times.

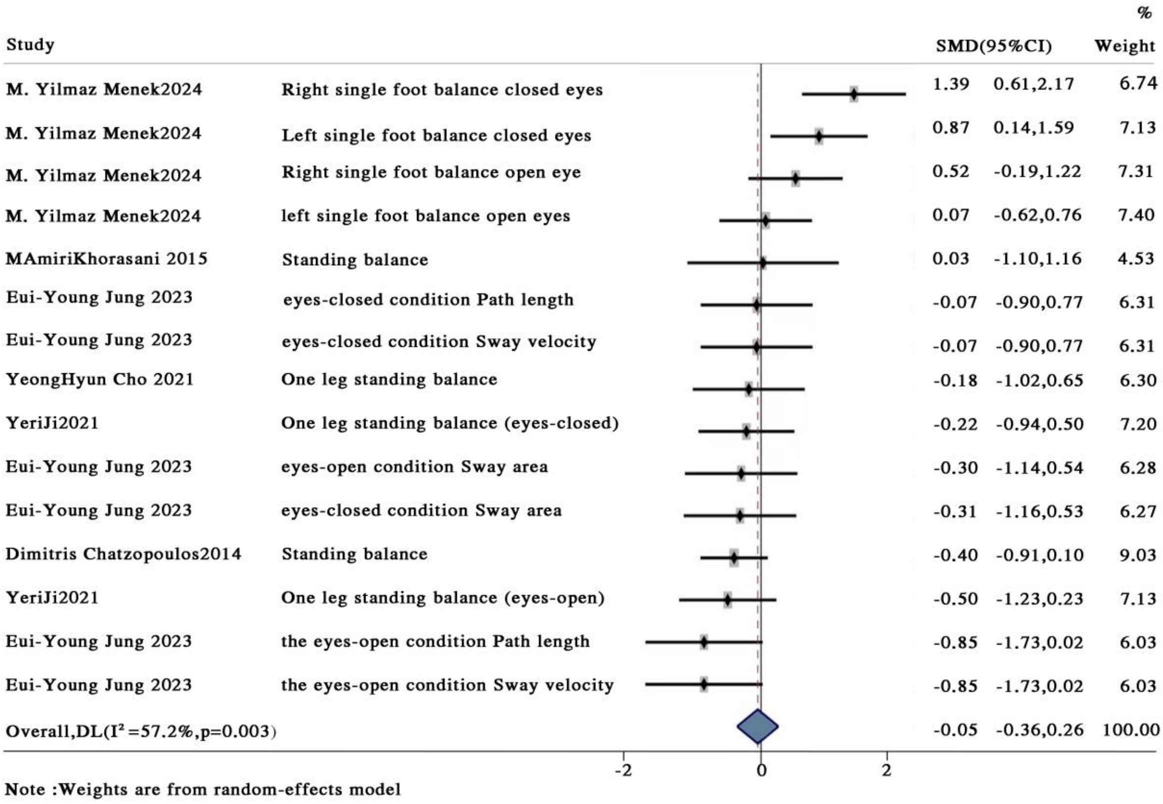

**Figure 4.** Static equilibrium forest diagram.

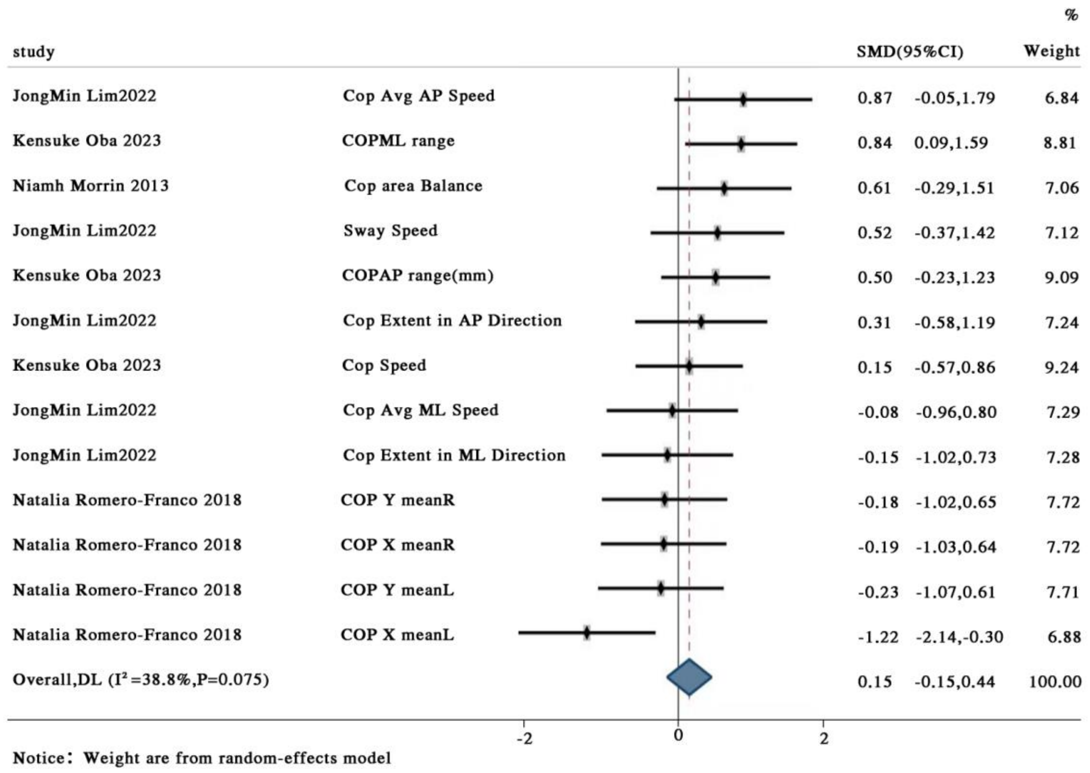

**Figure 5.** COP forest diagram.

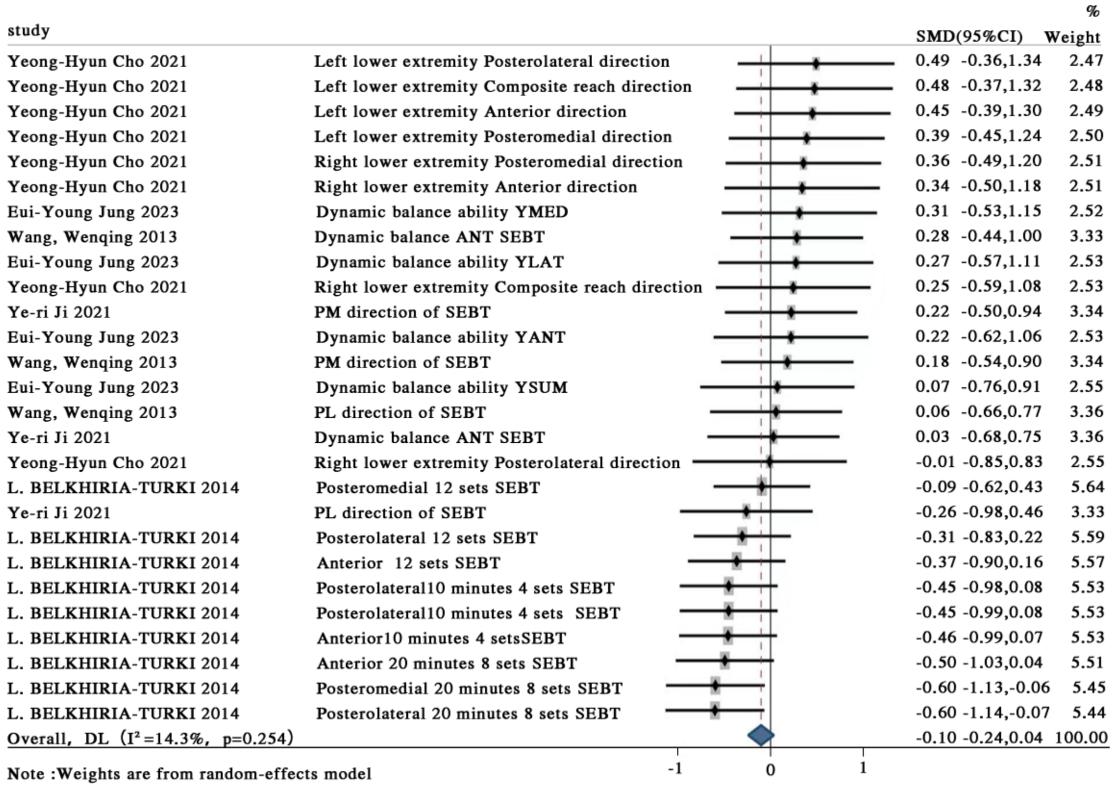

**Figure 6.** Dynamic equilibrium forest diagra.

### 3.4. Meta-regression analysis

Meta-regression analyses were conducted to evaluate the impact of variations in stretching time and balance capacity on effect sizes within both the experimental and control groups. Sufficient data were available to facilitate regression analysis of stretching time concerning static balance, center of pressure (COP), and dynamic balance, as illustrated in **Figures 7**, **8** and **9**. Stretching time emerged as a significant regressor for static equilibrium ($n = 15$, $\beta = -0.0007$ [−0.001 to 0.005, SE = 0.0006, $P = 0.001$, $r = 86.37$]), COP ($n = 13$, $\beta = 0.002$ [−0.006 to 0.11, SE = 0.004, $P = 0.636$, $r = 0.00$]), and dynamic equilibrium ($n = 27$, $\beta = -0.005$ [−0.001 to 0.007, $P = 0.394$, $r = 0.00$]). The accompanying bubble plots illustrate that the effect values for static equilibrium decrease as stretching time increases, with total stretching durations yielding ten effect values ranging from 20s to 200s. Although the effect values for dynamic equilibrium were not statistically significant, the graph indicates no notable change with increased stretching time. Conversely, the effect values for COP, while also not statistically significant, exhibited a positive trend, suggesting potential implications for balance performance that merit further investigation. This nuanced understanding of how stretching duration influences balance capabilities is critical for optimizing training protocols.

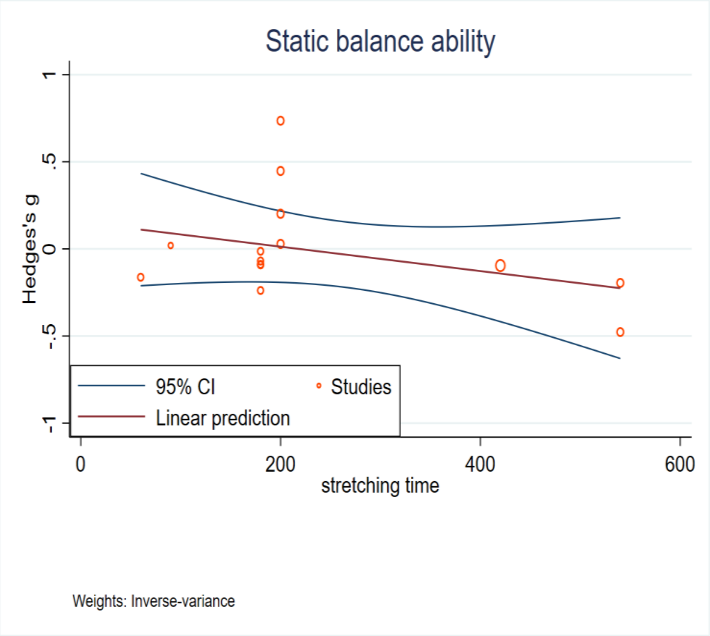

**Figure 7.** Static equilibrium bubble diagram.

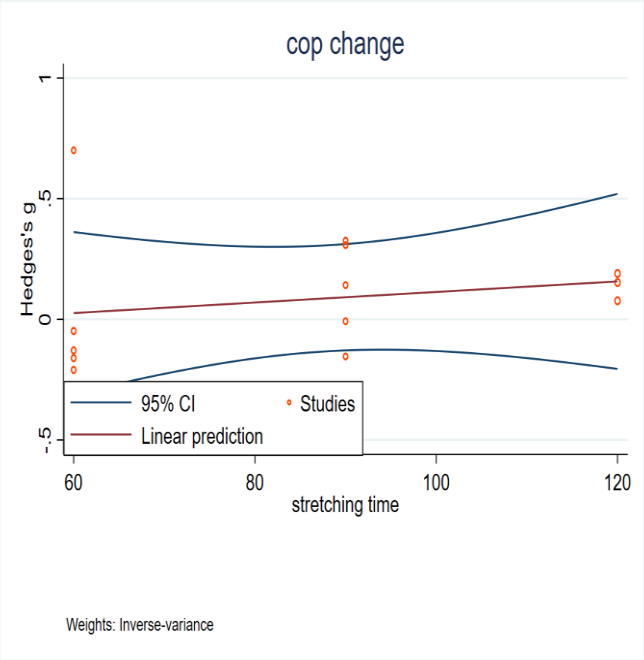

**Figure 8.** COP bubble diagram.

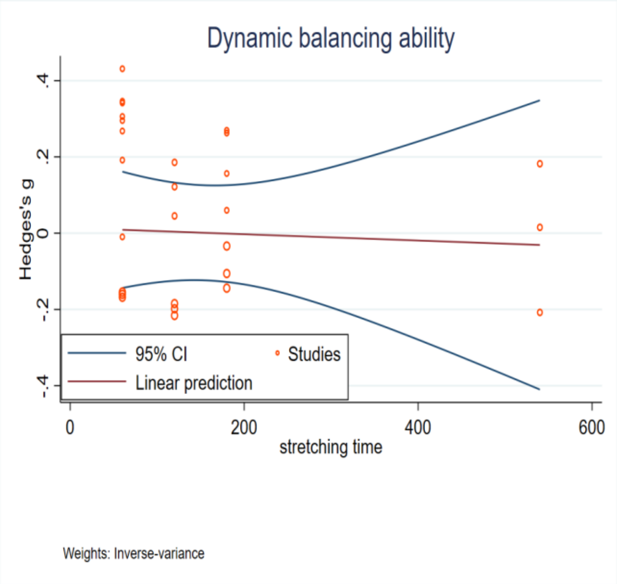

**Figure 9.** Dynamic balance bubble diagram.

## 4. Discussion

This systematic review and meta-analysis offer a comprehensive and in-depth examination of the effects of different stretching methods on balance. The results clearly demonstrate that when it comes to static balance, static stretching (SS) leads to a significant reduction compared to dynamic stretching (DS). However, in terms of the center of pressure (COP) and dynamic balance, the effects are not statistically significant. Subgroup analyses further reveal interesting insights. Neither gender nor specific muscle groups, like the plantar flexors, have an impact on balance capabilities. Moreover, our analysis pinpoints stretching duration as a crucial factor affecting static balance. Notably, this influence is particularly evident when the duration of stretching falls between 20 seconds and 200 seconds.

Our findings are in line with those of Behm DG et al. [10]. They suggest that static stretching may cause a temporary decrease in muscle force output, which in turn indirectly affects balance abilities. The underlying mechanism likely involves the elongation of muscles and soft tissues during static stretching, potentially disrupting the muscle length - tension relationship [33]. This disruption can impact muscle power production through its effect on the excitation-contraction coupling within the muscles [34]. Specifically, static stretching might result in a transient rise in intramuscular calcium ($Ca^{2+}$) concentration, leading to a decrease in muscle contraction force. Additionally, it could also affect proprioceptive feedback by reducing the sensitivity of muscle spindles, thus influencing postural control and balance [35,36]. However, these results contrast with the observations of Amiri-Khorasani, who reported that static stretching improved both static and dynamic balance in soccer players [37]. The reasons for this contradiction are likely complex and multifaceted. They may include differences in study populations (such as general versus athletic groups), variations in stretching protocols (like duration and targeted muscles), diverse methods for measuring balance [38], the timing of balance assessments relative to stretching protocols, and individual differences in muscle elasticity and neuromuscular adaptations. This highlights the need for further research to fully understand these discrepancies.

Despite our meta-analysis revealing no significant effects of dynamic stretching (DS) on center of pressure (COP) and dynamic balance, the majority of studies included in our systematic review support the positive impact of DS on balance capabilities. For example, Oba et al. demonstrated that dynamic stretching reduced COP deviation during one-leg standing tasks, indicating that DS may enhance balance through improved postural stability [39]. Additionally, Wang et al. found DS to be more effective than static stretching (SS) in enhancing dynamic balance [40]. The likely mechanism behind this effect is that DS, through controlled movement patterns, increases muscle temperature and blood flow while activating the neuromuscular system, which may be linked to post-activation potentiation (PAP). PAP is characterized by a temporary increase in muscle power output following high-intensity activity. However, the absence of significant changes in COP and dynamic balance observed in our study may be attributed to insufficient intensity and duration of DS to induce a noticeable PAP effect or to the possibility that the PAP effect was not adequately captured in the balance assessments.

The regression analysis in this study indicates that stretching duration significantly influences static balance, particularly when the total stretching time ranges from 20s to 200s, where the effects are most pronounced. This finding is similar to previous research by Young, which suggests that when the total duration of static stretching is less than 90s, there is more evidence indicating differential impacts on athletic performance, with shorter stretching durations not impairing performance [41]. Our bubble plots reveal that as stretching duration increases, the effect size on static balance capabilities diminishes further, corroborating Young's report that indicated one minute of stretching significantly reduced jump performance impairments more effectively than two or four minutes; thus, longer stretching durations are associated with greater losses. This phenomenon may be attributed to excessive stretching durations leading to muscle over adaptation, which subsequently impacts immediate muscle power output and balance control capabilities. Furthermore, the identification of multiple effect sizes within the 20–200 second range may indicate an ‘optimal’ stretching time window that could either maximize benefits or minimize adverse effects of stretching. These findings carry significant implications for the design of exercise and rehabilitation protocols, underscoring the importance of stretching duration in achieving improved range of motion (ROM) without compromising balance performance.

Additionally, subgroup analysis did not reveal any effects of gender or specific muscle groups on the heterogeneity of balance capabilities, suggesting that the impacts of static stretching (SS) and dynamic stretching (DS) on balance may be universal. However, this does not preclude the potential influence of muscle type, length, and individual differences on stretching responses, which warrant further exploration in future studies [42].

While this study offers valuable insights into the effects of static and dynamic stretching on balance, it is not without limitations. Notably, the relatively small sample size and the diverse contexts of the studies may introduce publication bias. Additionally, variability in stretching durations, intensities, and muscle types could impact the generalizability and interpretation of the results. Future research should aim to increase the sample size to include individuals of varying ages, genders, and activity levels, thereby allowing for a more comprehensive examination of how different types and durations of stretching influence balance abilities across diverse populations [43]. Furthermore, subsequent studies should investigate the combined effects of static and dynamic stretching protocols, exploring their interactions and cumulative impacts on both balance and overall athletic performance.

In conclusion, this systematic review and meta-analysis highlight the complex relationship between stretching techniques and balance ability. While static stretching may temporarily impair static balance, dynamic stretching appears to offer more consistent benefits. The identification of stretching duration as a critical factor influencing balance outcomes emphasizes the need for tailored stretching protocols in both athletic training and rehabilitation settings. Future investigations should continue to refine our understanding of these relationships, guiding practitioners in optimizing performance and minimizing injury risk through evidence-based stretching interventions.

## 5. Conclusion

Dynamic stretching (DS) may be more effective than static stretching (SS) in enhancing balance capabilities within healthy populations, particularly in terms of static balance performance. Subgroup analysis reveals an intriguing finding: neither gender nor specific muscle groups, such as the plantar flexors, significantly contribute to heterogeneity or influence balance capabilities.

Moreover, regression analysis underscores that stretching duration is a critical biomechanical factor affecting static balance. Excessively long stretching durations can negatively impact balance maintenance, potentially due to alterations in muscle stiffness and proprioceptive feedback mechanisms. The findings suggest that the optimal intervention effect is achieved when total stretching duration falls within the range of 20 seconds to 200 seconds. This duration appears to balance the benefits of increased flexibility and strength with the need for neuromuscular control, providing valuable insights for training strategies aimed at optimizing balance performance. Understanding these biomechanical nuances can aid in developing more effective stretching protocols tailored to enhance balance abilities in various populations.

**Author contributions:** Conceptualization, WG, YK and SK; methodology, WG and YK; software, WG and YK; validation, YK, CW and SK; formal analysis, WG, YK and CW; investigation, WG and CW; resources, CW and SK; data curation, CW and SK; writing—original draft preparation, WG, YK and CW; writing—review and editing, CW and SK; visualization, SK; supervision, SK; project administration, YK. All authors have read and agreed to the published version of the manuscript.

**Ethical approval:** This article does not contain any studies involving animals performed by any of the authors.

**Conflict of interest:** The authors declare no conflict of interest.

## References

1. Kibele A, et al. Stable, unstable and metastable states of equilibrium: Definitions and applications to human movement. 2015; 14(4): p. 885.
2. Panjan, A. and Sarabon N. Review of methods for the evaluation of human body balance. 2010; 19(5–6): p. 131.
3. Granacher U, et al. The importance of trunk muscle strength for balance, functional performance, and fall prevention in seniors: A systematic review. 2013; 43: p. 627–641.
4. O’Sullivan K, Murray E, and Sainsbury D. The effect of warm-up, static stretching and dynamic stretching on hamstring flexibility in previously injured subjects. 2009; 10: p. 1–9.
5. Young WB, Behm D. Journal, Should static stretching be used during a warm-up for strength and power activities?. 2002; 24(6): p. 33–37.
6. Alter M. Science of flexibility: Human Kinetics Champaign. 1996; IL.
7. Konrad A, et al. Effects of acute static, ballistic, and PNF stretching exercise on the muscle and tendon tissue properties. 2017; 27(10): p. 1070–1080.
8. Zvetkova E, Koytchev E, Ivanov I, Ranchev S, Antonov A. Biomechanical, Healing and Therapeutic Effects of Stretching: A Comprehensive Review. Applied Sciences. 2023; 13(15):8596. https://doi.org/10.3390/app13158596
9. Coratella G, et al. Passive stretching decreases muscle efficiency in balance tasks. 2021; 16(9): p. e0256656.
10. Behm DG and Chaouachi A. Review of the acute effects of static and dynamic stretching on performance. 2011; 111: p. 2633–2651.
11. Schleip R, Müller DG. Training principles for fascial connective tissues: Scientific foundation and suggested practical applications. 2013; 17(1): p. 103–115.
12. Groeber, M., Stafilidis, S. & Baca, A. The effect of stretch–shortening magnitude and muscle–tendon unit length on performance enhancement in a stretch–shortening cycle. Sci Rep 11, 14605 (2021). https://doi.org/10.1038/s41598-021-94046-2
13. Weerapong P, Hume P, and Kolt G. Stretching: Mechanisms and benefits for sport performance and injury prevention. 2004; 9(4): p. 189–206.

14. Behm D. Effect of acute static stretching on force, balanc. 2004.
15. Trajano GS, et al. Contribution of central vs. peripheral factors to the force loss induced by passive stretch of the human plantar flexors. 2013; 115(2): p. 212–218.

16. Li M, et al. Effects of Conditioning Contractions on Lower-Body Explosive Force Post-Static Stretching. 2024.
17. Zhu Y, et al. Changes in stiffness of the specific regions of knee extensor mechanism after static stretching. 2022; 10: p. 958242.
18. Takeuchi K, et al. Acute effects of different intensity and duration of static stretching on the muscle-tendon unit stiffness of the hamstrings. 2022; 21(4): p. 528.
19. Fletcher IM. The effect of different dynamic stretch velocities on jump performance. 2010; 109: p. 491–498.
20. Blazevich AJ and Babault N. Post-activation potentiation versus post-activation performance enhancement in humans: Historical perspective, underlying mechanisms, and current issues. 2019; 10: p. 1359.
21. Balnave CD and Allen DG. The effect of muscle length on intracellular calcium and force in single fibres from mouse skeletal muscle. 1996; 492(3): p. 705–713.
22. Chaouachi A, et al. Effect of warm-ups involving static or dynamic stretching on agility, sprinting, and jumping performance in trained individuals. 2010; 24(8): p. 2001–2011.
23. Little T, Williams A. Research, Effects of differential stretching protocols during warm-ups on high-speed motor capacities in professional soccer players. 2006; 20(1): p. 203–307.
24. Handrakis JP, et al. Static stretching does not impair performance in active middle-aged adults. 2010; 24(3): p. 825–830.
25. Mulla Daanish M., Keir Peter J. Neuromuscular control: from a biomechanist's perspective. Frontiers in Sports and Active Living. 2023;5. Available from: https://www.frontiersin.org/journals/sports-and-active-living/articles/10.3389/fspor.2023.1217009. DOI: 10.3389/fspor.2023.1217009
26. Menychtas, D., Glushkova, A. & Manitsaris, S. Analyzing the kinematic and kinetic contributions of the human upper body's joints for ergonomics assessment. J Ambient Intell Human Comput 11, 6093–6105 (2020). https://doi.org/10.1007/s12652-020-01926-y
27. Lee HM, Oh S, Kwon JW. Effect of Plyometric versus Ankle Stability Exercises on Lower Limb Biomechanics in Taekwondo Demonstration Athletes with Functional Ankle Instability. International Journal of Environmental Research and Public Health. 2020; 17(10):3665. https://doi.org/10.3390/ijerph17103665
28. Salemi P, Shadmehr A, Fereydounnia S. The Immediate Effect of Static Hamstring Stretching on Dynamic Balance and Gait Biomechanical Variables in Athletes With Hamstring Tightness: A Preliminary Study. jmr. 2021;15(3):141-150.
29. Moher D, et al. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. 2009; 151(4): p. 264–269.
30. Liberati A, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. 2009; 151(4): p. W-65–W-94.
31. Chen X, et al. Effects of various exercise types on visceral adipose tissue in individuals with overweight and obesity: A systematic review and network meta-analysis of 84 randomized controlled trials. 2024; 25(3): p. e13666.
32. da Costa BR, et al. Effect of standardized training on the reliability of the Cochrane risk of bias assessment tool: A prospective study. 2017; 6: p. 1–8.
33. Rapking KM. The effects of dynamic and static stretching on range of motion and performance. 2010: Michigan State University.
34. Calderón JC, Bolaños P, and Caputo C. The excitation–contraction coupling mechanism in skeletal muscle. 2014; 6: p. 133–160.
35. Costa PB, et al. The acute effects of different durations of static stretching on dynamic balance performance. 2009; 23(1): p. 141–147.
36. Amiri-Khorasani M, Gulick DT. Acute effects of different stretching methods on static and dynamic balance in female football players. 2015; 22(2): p. 68–73.
37. Afonso José, Clemente Filipe Manuel, Nakamura Fábio Yuzo, Morouço Pedro, Sarmento Hugo, Inman Richard A., Ramirez-Campillo Rodrigo. The Effectiveness of Post-exercise Stretching in Short-Term and Delayed Recovery of Strength, Range of Motion and Delayed Onset Muscle Soreness: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. Frontiers in Physiology. 2021;12. Available from: https://www.frontiersin.org/journals/physiology/articles/10.3389/fphys.2021.677581. DOI: 10.3389/fphys.2021.677581
38. Oba K, et al. Acute effects of static and dynamic stretching for ankle plantar flexors on postural control during the single-leg standing task. 2023; p. 1–11.

39. Wang W. The Effects of static stretching versus dynamic stretching on lower extremity joint range of motion, static balance, and dynamic balance. 2013; The University of Wisconsin-Milwaukee.
40. Young W, et al. Effects of static stretching volume and intensity on plantar flexor explosive force production and range of motion. 2006; 46(3): p. 403.
41. Young WB. The use of static stretching in warm-up for training and competition. 2007; 2(2): p. 212–216.
42. Plotkin DL, Roberts MD, Haun CT, Schoenfeld BJ. Muscle Fiber Type Transitions with Exercise Training: Shifting Perspectives. Sports. 2021; 9(9):127. https://doi.org/10.3390/sports9090127
43. Arntz, F., Markov, A., Behm, D.G. et al. Chronic Effects of Static Stretching Exercises on Muscle Strength and Power in Healthy Individuals Across the Lifespan: A Systematic Review with Multi-level Meta-analysis. Sports Med 53, 723–745 (2023). https://doi.org/10.1007/s40279-022-01806-9