

Effects of 12-Week Active and Passive Stretching Programs on Lower-Extremity Range of Motion and Pain in Adults Aged 45 - 60 : A Systematic Literature Review

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ABSTRACT

The signs of musculoskeletal disorders include lower-extremity range of motion (ROM) and related pain that are prevalent in middle-aged adults and may severely affect functional capacity and quality of life. Stretching exercises, such as active and passive ones, are commonly prescribed to mitigate these constraints but it is not clear how long, how frequently, and what type of stretching exercise should be used by people of 45 to 60 years. It was a systematic literature review that tested the impact of 12-week or longer stretching programs on lower-extremity ROM and pain in adults age 45-60 years. The search of structured electronic collections of peer-reviewed academic articles, books, and reports using PRISMA 2020 principles was carried out. Keywords such as stretching interventions, lower-extremity joints, range of motion, pain outcomes, and target age group were used as search strategies. The inclusion criteria were eligible studies that were randomized controlled trials or quasi-experiments that enrolled adults aged 45-60 years and applied stretching interventions of at least 12 weeks and reported lower-extremity ROM and/or pain. The study screening and data extraction were done by two independent reviewers, with the methodological quality evaluated with Cochran Risk of Bias tool. Out of 230 original records, 87 unique studies were left after the removal of duplicates. After the screening of abstracts (n = 24) and the evaluation of the full-text, seven studies were selected as meeting all the inclusion criteria indicating an inclusion rate of 8.0%. The studies included reviewed various modalities of stretching such as contractive intramuscular facilitation (PNF), dynamic stretching, static passive stretching, and static active stretching, as well as muscle-directed stretching and nerve directed stretching with sample sizes of 10 to 76 individuals. Five studies found a significant enhancement of ROM with a range of 7.3 to 9.9 degrees increase of ankle reflexion, and three studies that assessed pain outcome results showed significant decrease of pain levels after the interventions of stretching. The assessment of risk-of-bias revealed that there were a number of methodological limitations, most notably concerning the procedure of blinding and allocation concealment. In general, the results indicate that stretching programs of 12 weeks or more can be actively used to increase lower-extremity ROM and decrease pain in middle-aged adults. Passive stretching and PNF methods seem especially useful in the reduction of pain, though, both muscle-specific and nerve-specific stretching methods also lead to the increase of ROM. However, the paucity of the eligible studies, the differences in the intervention regimes and the methodological shortcomings necessitate a careful interpretation of the findings. Randomized controlled trials with rigorously designed and standardized stretching protocols, sufficient blinding and detailed reporting should be used in future research to enhance the body of evidence and guide clinical practice recommendations.

Keywords: stretching, range of motion, pain, lower extremity, middle-aged adults, systematic review, PRISMA.

INTRODUCTION

Background and Rationale

The problem of musculoskeletal disorders is one of the key challenges of global public health and one of the most common causes of disability, decreased mobility, and diminished quality of life in the world. The functional limitations in the presence of lower extremity musculoskeletal impairments, in particular, are highly linked to the impairment of performing everyday activities and being independent. The impact of lower limb dysfunction keeps on increasing as the population is aging and as the proportion of sedentary lifestyles is rising, posing serious healthcare and socioeconomic risks. Loss of joint mobility, stiffness and chronic pain in the hip, knee, and ankle joints often impairs the mobility and functional capacity, particularly in the middle adults.

Age between 45 and 60 years is a very important transitional phase advanced by development of the physiological changes in musculoskeletal system. With this, the degenerative changes in the muscles, tendons and joint lubrication involve the decrease of muscle elasticity, tendon compliance and joint lubrication. The physiological changes usually lead into reduced flexibility and intramuscular coordination. Among the most frequent effects of these changes is a decrease in joint range of motion (ROM) of major lower extremity joints such as the hip, knee and ankle. There is a link between limited ROM, and reduced gait efficiency, and impaired balance and reduced involvement in physical activity, which could contribute to an acceleration of musculoskeletal deterioration and functional worsening.

Lower limb ROM restriction has been associated with a number of adverse outcomes, such as a change in gait mechanics, the risk of falls, and poor functional autonomy in daily activities. This age group is also prone to chronic pain disorders on the lower extremities. Knee osteoarthritis, plantar fasciitis and lumbar cardiomyopathy are common causes of pain and disability in middle-aged adults and they may necessitate long-term medical care. It is indicated that the conditions are leading to high healthcare use and economic expenses in the form of medical care, rehabilitation care, and lost work productivity (Luan et al., 2022).

To address such issues, stretching interventions are currently common in clinical rehabilitation and physiotherapy programs where they are applied to enhance flexibility, regain joint mobility, and relieve musculoskeletal pain. Stretching exercises are thought to be an affordable and available therapeutic intervention method that can be applied in a clinical setting supervised by a professional and rehabilitation programs at home. In general, the methods of stretching can be divided into active and passive stretching. Active stretching is a voluntary muscular contraction of a person to create the stretch that in turn involves intramuscular processes and enhances muscle control. Passive stretching, on the contrary, involves using external forces to stretch the muscles and connective tissues, e.g., the support of a therapist, gravity, or specific equipment.

Besides these fundamental types, there are also some special methods of stretching, that were designed to achieve relaxation and muscle motor activity. Contraceptive intramuscular facilitation (PNF) is a method which involves passive stretching of joints combined with isometric muscle contractions, which have been extensively applied in rehabilitation facilities to enhance movement in joints and intramuscular stimulation. Equally, dynamic stretching is a type of movement involving regulated motion within the available range of motion and is often used in warm ups and therapeutic exercises programs. Studies state that various stretch modalities can lead to varied physiological changes, such as enhanced compliance of muscle-tendon unit, high stretch tolerance, and neurophysiology changes in the central nervous system (Bryant et al., 2023).

To clarify the effectiveness of stretching interventions, a number of mechanisms have been offered. These consist of muscle and tendon tissue structural changes, decreasing passive muscle stiffness, and intramuscular coordination. Stretching can also be involved in the prevention of pain by stimulating chemoreceptor, which adjusts the contraceptive signaling pathways and generates pain-reducing effects. As an example, the literature investigating the effects of the stretching interventions on the subjects with musculoskeletal conditions has already found that the flexibility and the intensity of pain decreases after the regular stretching programs (Konrad et al., 2023).

Although stretching is extensively used in the practice of rehabilitation, there are some areas where the practice of stretching interventions is ambiguous. Specifically, the scientific literature still argues about optimal parameters, including the intensity of stretching, its duration, the choice of the technique, etc. Most of the past researches have majorly investigated the acute outcomes of stretching with attention to the immediate change of joint range of motion after one stretching session. Based on meta-analysis, the evidence (though with small to moderate acute effects) indicates that stretching can result in small-to-moderate improvements in ROM, but the effect of these changes may vary based on a number of modifying factors, such as stretching method, duration, and person properties (Behm et al., 2023).

Although the short-term effects have been well documented, little effort has been given to long-term adaptations which have been caused by repeated stretching interventions. The potential long term effects of stretching programs are the development of chronic physiological responses such as improved muscle flexibility, enhanced stretch tolerance and reduced musculoskeletal pain. As an example, systematic reviews have shown that systematic stretching interventions can be used effectively to enhance the flexibility and decrease pain symptoms in people with musculoskeletal ailments (Konrad et al., 2023; Luan et al., 2022). Also, the stretching exercises that involve the specific muscles, like the hamstrings, have been demonstrated to enhance flexibility and alleviate pain among people with LBP (Zhang et al., 2024).

An explanation of why this systematic literature review was such is then based upon a number of considerations. First, a 12 weeks intervention time is a clinically acceptable period over which long term adaptations can be assessed to stretching interventions and not just the acute effects. This is comparable to more physiotherapy and rehabilitation programs and conditions one to evaluate lasting behavior modifications, intramuscular strategies, and musculoskeletal tissue remodeling.

Second, the target age group is grouped within 45–60 years, which can be considered especially susceptible to lower extremity musculoskeletal disorders but can be addressed using conservative measures. The application of stretching-based interventions in this phase can prevent the worsening of the functioning, advance the mobility, and postpone the necessity to resort to more invasive medical procedures like pharmacological control or surgical operations.

Third, it is also of clinical interest to identify the differences between active and passive modalities of stretching as these modalities vary in terms of the implementation needs, patient engagement, and supervision of the technique as well as physiological basis. Active stretching involves active muscle contractions and more self-control on behalf of the affected person, whereas passive stretching may include outside help as may be offered by therapists or mechanical tools. Knowledge of relative effectiveness of these modalities may be a useful tool in guiding clinicians, physiotherapists or rehabilitation experts to come up with evidence-based lower extremity flexibility and pain reduction interventions among middle-aged adults.

All in all, the synthesis of the existing evidence on long-term stretching intervention will assist in getting a better idea of the therapeutic quality of this intervention and will aid in the creation of the optimal rehabilitation protocol that should be applied to people with lower extremity musculoskeletal dysfunctions.

Objectives

The main purpose of the systematic literature review is to assess the impact of active and passive 12-week or longer duration stretching exercises on lower extremity range of motion (ROM) and pain outcomes in adults aged 45 to 60 years old. This review will enable a full picture comprehension of the long-term efficacy of stretching programs on enhancing flexibility and musculoskeletal pain in middle-aged groups by synthesizing evidence of the available empirical studies.

Research questions

The purpose of this systematic literature review is to investigate the efficacy of long-term stretching exercises (12 weeks and above) in enhancing lower extremity movement and decreasing pain in adults between the ages of 45 and 60 years. In this effort, the following research questions will be discussed in the review:

- How does 12 weeks (or more) of stretching interventions affect lower extremity range of motion (ROM) among adults (45-60 years old)?
- What are the effects of long-term stretching programs on the level of pain related to the lower extremity musculoskeletal condition in adults age 45-60 years?
- What is the difference between active and passive modalities of stretching in terms of their effectiveness to enhance lower extremity range of motion and lower extremity pain?
- Which intervention parameters (frequency, duration, intensity, and stretching technique) are linked to the most positive outcomes with regard to flexibility improvement and pain reduction?
- v.What is the general evidence quality and risk of bias in researches assessing the long-term stretching interventions in terms of lower extremity mobility and pain management?

Besides answering these main research questions, this review will also attempt to determine the gaps in the existing literature, explore heterogeneity of intervention protocols and outcome measures, and give evidence-based recommendations in future research and clinical practice of stretching interventions on middle-aged adults.

The PICO Framework of Systematic Review

The research questions are designed within the framework of the utilisation of the PICO model (Population, Intervention, Comparison, Outcome) that would help in the systematic review. This framework facilitates the process of ensuring that the scope of the review is well laid out and the literature identification and analysis done in a systematic way.

PICO Component Description

- i. Population (P) Musculoskeletal conditions in the lower limbs or joints that reduce the flexibility of the muscles such as the hip, knee, and ankle in adult ages of 45 to 60.

- ii. Intervention (I) The 12 weeks or longer stretching programs are active stretching, passive stretching, dynamic stretching, and proprioceptive neuromuscular facilitation (PNF) which are supposed to achieve the flexibility of the lower body and a less painful one..
- iii. Comparison (C) Comparisons of active and passive stretching methods, as well as comparisons to usual treatment, no treatment or other therapeutic exercises where available.
- iv. Outcomes (O) The key outcomes are the reduction of discomfort caused by musculoskeletal conditions and the improvement of lower extremity range of motion (ROM). The secondary outcomes that can be taken into consideration include functional mobility, physical performance, quality of life, risk of bias, and the quality of evidence.

METHODS

Protocol and Registration

This literature review was conducted with the help of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 criteria. To achieve a methodological rigour and transparency, a priori, we created the review methodology. Despite the study not having been registered in PROSPERO prior to its start, all the methodological decisions were documented to facilitate reprehensibility and bias minimization.

Eligibility Criteria

The PICOS framework was used to deny eligibility based on the following factors: population, intervention, comparison, outcomes, and study design.

Population

Adults aged 45-60 were taken into consideration in the research. In cases where a subgroup of data regarding this age group were available, or in instances where the average age was within this range, then studies having broader age-groups were included. The subjects may be in a good health condition or have a musculoskeletal disorder of the lower limbs (e.g. osteoarthritis of the knee, lower back pain, lack of flexibility). Studies that only comprised of athletes, those with neurological disorders or patients who had undergone surgery or injuries in the past were excluded in the review.

Intervention

Either active or passive stretching exercise, or both, may be performed with the lower extremity muscles and joints (hip, knee, ankle, and associated musculature). Proprioceptive neuromuscular facilitation (PNF), dynamic stretching, ballistic stretching and other popular stretching modalities are all types of potential stretching modalities. The chronic adaptations rather than acute effects would only be captured with an intervention of 12 weeks or more. Unless it was the primary intervention and its impact could be quantified, the studies that addressed it as a multi modal intervention were not incorporated.

Comparison

Control groups may also be included in research designs, and they can be treated with various considerations, including the standard care, sham treatments or no treatment at all. Studies involving a comparison of active and passive forms of stretching were also included.

Outcomes

- i. **ROM:** Quantitative measurement of the ROM of the lower extremity joints, i.e. the flexion and extension of the hip, the flexion and extension of the knee, and the reflexion and plant reflexion of the ankle. These were the primary outcomes that were of interest. Trigonometry, clinometer, motion analysis systems, or any other established evaluation technique could be used to obtain the required measurements.
- ii. **Pain:** Visual Analogue Scale (VAS), Numeric Rating Scale (NRS) or Western Ontario and Mac Masters University Arthritis Index (WOMAC) or other standardized pain scales assessed quantitatively to evaluate the severity of pain or disability associated with pain.
- iii. Other outcomes recorded included measures of functional performance, quality of life, stretch tolerance, muscle stiffness and the overall health.

Study Design

Controlled clinical trials, quasi-experimental research and randomized controlled trials (RCTs) were used as inclusion criteria. Animal studies, systematic reviews, meta-analyses, case reports, case series and observational studies that lacked control or comparative groups were excluded.

Information Sources

To identify any available research, an extensive literature search was conducted in a variety of high quality academic databases that primarily cover journals in the Q1 and Q2 group. The databases selected are reputable in terms of extensive indexing and large coverage of peer-reviewed scholarly articles. The databases which were used were:

- The Scopus database covers thousands of peer-reviewed journals with many of them having Q1 and Q2 ranking based on the Scimago Journal Rank (SJR). Scopus is characterized by strong searching and citation tracking possibilities.
- Web of Science Core Collection is a leading index of citation that is regularly used in systematic reviews and bibliometric studies. Having introduced SCIE, SSCI, and ESCI into the Web of Science Core Collection we can be sure that we will include high-quality journals of high standards in their editing.
- The ScienceDirect database of Elsevier is a full-text database that has a broad range of books and peer-reviewed journals. The journals in the category of ScienceDirect are ranked within the top two quartile in a number of categories.

- SpringerLink is an expansive web-based library, which contains all books, journals, and conference papers of Springer Nature. The platform is full of high-impact journals in the fields of medicine, sociology, and applied sciences.
- The Wiley online library is one of the leading sources of academic articles concerning management, social science, and health. Wiley Online library indexes several journals that have a high Q1/Q2 ranking and impact factors.

Search Strategy

A systematic and rigorous search of literature was the means of identification of the study subject. The search method was based on the recommendations of PRISMA Statement to ensure openness, reproducibility, and scientific rigour. To cover as much information as we can, we accessed numerous credible academic databases that catalog scholarly publications that are peer-reviewed.

The major databases were Web of Science Core Collection, ScienceDirect, Scopus, SpringerLink, and Wiley Online Library. These databases were selected due to their wide range of peer-reviewed journals. Interestingly, these include the ones which include journals with the highest two quartile (Q1 and Q2) based on international ranking such as Scimago Journal Rank and impact factor. We had to ensure a thorough representation of the existing evidence base and to minimize the bias of publication effect so that we selected as many databases as possible.

The search was conducted in March 2026, and with no time limit to ensure that both the older and rather contemporary research that were relevant to the topic got search. The keywords were constrained vocabulary and keyword based search words. To reduce the results of the search, we applied Boolean operators such as AND, OR, and NOT to combine the keywords based on the objectives of the research and the literature reviewed in the past. Truncation and phrase searching was also applied when needed in order to pick alternative versions of significant words.

Moreover, the reference lists of the selected publications were analyzed manually so that potentially relevant research that were overlooked at the database search could be identified. To elevate the level of diversity, language boundaries were not set in the first search stage. The screening process was done by identifying and excluding articles published in some other language that did not have a translated version of the article. This systematic search method was used to identify the studies that were included in the evaluation in a systematic and transparent way.

Selection Process

The study selection process was performed in a multi-stage way, by means of a methodical procedure:

Duplication

Duplication algorithms powered by AI-based approaches could remove duplicate entries in the search results of all five databases by comparing titles, authors, year of publication, and DOI. To ensure preciseness, any duplicates were checked manually. The process of screening titles and abstracts will be performed.

Two reviewers examined all the original records based on the predefined criteria and selected those eligible. Two reviewers were unable to agree; thus, they further discussed the situation and at some point involved

a third party. At this stage we eliminated studies under consideration in case, based on the information available, we knew that it did not meet our inclusion criteria. We captured and ordered the causes of exclusion.

Scanning the Entire Text

Full-text publications were obtained in response to each study that passed the screening of titles and abstracts, or in case with which the eligibility criteria could not be determined by referring to the abstract alone. Two reviewers, in turn, have read through the entire texts in order to identify whether articles satisfied all requirements or not. The design of the study, the quantitative range of motion (ROM) and pain measurement, age range of participants (45-60 years) and the duration of the intervention (12 weeks) were all properly checked. We also referred to a third reviewer whenever necessary and discussed the issue further to resolve any disputes. At the full-text level, we recorded elaborated reasons of exclusion.

Handling Data

All screening decisions, exclusion causes, and remarks by the reviewers were taken by a standard-created electronic data management system to ensure that nothing was hidden nor could not be duplicated.

Process for Collecting Data

Before total implementation, a standardized data extraction form was developed and was tested in three studies that formed part of the analysis. Two different reviewers retrieved the data of each included research and, in case of disagreement, discussed and solved including discussion. The items of data AD were identified as:

- i. Details of study: author of the study, publication date, country of study, research design, sample size, and sponsor.
- ii. Information on the participants, such as age (range and mean), gender, health condition as well as inclusion/exclusion criteria.
- iii. intervention parameters: Which muscle groups or joints to work on, how many repetitions and sets, how much time the program will last, the number of sessions, length of stretches (active, passive, PNF, dynamic, etc.), and how the supervision will be.
- iv. Information on analysis and control: Type of intervention, duration, frequency and control group or comparison group.
- v. v.Outcome measures: range of motion (ROM) and specific joints measurement techniques, pain assessment tools and assessment time.
- vi. These findings consist of the following: range of motion (ROM) and pain outcomes pre- and post-intervention; pre- versus post-intervention; intracellular; statistical significance; and, when reported, effect sizes.
- vii. Side effects: Any issues or adverse effects which have been reported.

Assessment of the possibility of bias

The Cochrane Risk of Bias tool of randomised trials was applied to assess the risk of bias in an individual study by two reviewers independently. Evaluations were done in the areas as follows:

- i. Production of a random sequence (selection bias): It is determined whether the assignment sequence has been generated as much as it is necessary to form a set of groups that are similar.
- ii. The extent to which the assignment sequence was adequately covered up until assignment is referred to as allocation concealment (selection bias).
- iii. Thirdly, we checked the blinding of the participants and the staff (performance bias) to determine whether they were adequately safeguarded against having known what groups they were in.
- iv. The fourth outcome assessment (detection bias) is checking whether outcome assessors were adequately masked to cluster assignment.
- v. v.Fifth, checking whether inadequate outcome data had been adequately managed (attrition bias).
- vi. Assessment of the reporting of all pre-specified outcomes: 6. Reporting bias (selectivity).
- vii. The seventh step is to determine any other potential reasons of bias.

The domains were rated with a low to high or unclear risk rating given in accordance with their explanations. To categorize the overall risk of bias of every research, the pattern of the judgment at the domain level was used. Through discussion, reviewers were in a position to work out their differences.

Synthesising Data

A quantitative meta-analysis was not deemed suitable as a result of the high heterogeneity that was observed between the studies included. It was also variable in various ways such as intervention procedures (e.g., stretching methods, time and frequency), outcome measures (various methods of assessing joint range of motion and pain scale), and study populations (healthy and research participants with particular clinical conditions). These methodological heterogeneities restricted the ability to compare the findings across studies and could not allow statistical combination of effect sizes.

The synthesis of the findings was, therefore, performed in form of a narrative synthesis, which is in line with best practices in systematic reviews in the event that statistical aggregation is not possible. The synthesis was organised by major thematic heads, especially the kind of stretching intervention and reported outcomes. Stretching modalities were categorized into a number of modalities, namely, active stretching, passive stretching, proprioceptive neuromuscular facilitation (PNF), dynamic stretching, muscle-directed stretching, and nerve-directed stretching. The outcome was mainly analyzed considering the change in the joint range of motion (ROM) and the levels of pain or discomfort.

The features of the incorporated studies were summarized on a structured table format where the main data was represented in form of a tabular format with key characteristics of the study including the study design, sample size, characteristics of participants involved, the intervention involved in the study, outcome measures, and the main findings of the study. Further, a qualitative comparative analysis was undertaken

to determine the patterns of effectiveness, possible dose response relationships as well as the contextual factors which might have affected the results of studies.

Moreover, methodological quality of the studies with the considerations of sample size and risk-of-bias assessment were closely considered to identify the strength and reliability of the evidence in general. These tests were a significant foundation in the interpretation of the study results and making of the conclusion on the efficacy of various stretching interventions on the range of motion and pain outcome.

RESULTS

Study Selection

A systematized search through Web of science (n=100) and Scopus (n=100) and SpringerLink and Wiley online library (n=20 and n=13 respectively) resulted in a total of 233 records. Further searches using reference lists and citation tracking failed to find further studies. Based on the duplication of 143 records eliminated through the help of AI-assisted de-duplication, 87 unique records were left to screen.

Title and abstract screening reduced the records to 63 that were eliminated with regard to a set of pre-established eligibility criteria. The following criteria were chosen as the primary reasons to exclude the study: animal studies (n = 36), systematic reviews or meta-analyses (n = 9), not lower extremity (n = 7), no stretching intervention (n = 5), less than 12 weeks of intervention (n = 2), case reports (n = 2), no ROM or pain measures (n = 1), and inappropriate age group (n = 1).

Twenty four articles were evaluated as being in full text eligible. There was a success in receiving full texts of 13 articles (54.2%), and 11 studies were not available. Evaluation of the full-text resulted in the exclusion of 17 studies based on: unspecified period of intervention (n = 13), non-experimental research design (n = 2) and less than 12 weeks length of intervention (n = 2).

Finally, 7 studies were eligible and added to the qualitative synthesis, which is 8.0 percent of 87 records that have been screened. Heterogeneity in population, interventions, and outcome measures meant that a meta-analysis could not be done. The process of the study selection followed the PRISMA 2020 recommendations and is summarized in the provided PRISMA flow diagram.

Study Characteristics

The seven articles incorporated were published in 2013-2024 and carried out in different countries. The total number of studies was 234, and the sample of each study was between 10 and 76 participants. There were both randomized controlled trials (RCTs) and quasi-experimental studies. Table 1 presents a detailed summary of the characteristics of the studies.

The characteristics of the participants included in the study comprised;

Participant Characteristics

The ages of participants were different in studies. In some studies, the subjects were aged 45-60 years, whereas in other studies, older adults (62-79 years) were used. In Naraoka et al. (2017), the ages of the inactive males analyzed were between 30 and 49 years old, and they were experiencing lower back and neck pain, whereas in Song et al. (2020), participants were diagnosed with knee osteoarthritis aged about 68 years on average. Andrade et al. (2020) used healthy participants, but the age was not given. İlçin et al.

(2024) and Okita et al. (2022) concentrated on older adults as their main population, whereas Rodrigues et al. (2013) used men who remain sedentary as their target group (62-68 years of age). Iwata et al. (2019) did not specify the age of participants who are healthy.

Four studies were recruited based on having a healthy population (Iwata et al., 2019; Andrade et al., 2020; Ilcin et al., 2024; Rodrigues et al., 2013), but three studies focused on a specific condition, such as knee osteoarthritis (Song et al., 2020; Okita et al., 2022) or chronic pain (Naraoka et al., 2017). The majority of the studies were gender-balanced, though Naraoka et al. (2017) and Rodrigues et al. (2013) used only males, and others recruited both genders. The characteristics of the intervention to be implemented will be outlined.

- i. **Proprioceptive Neuromuscular Facilitation (PNF) Stretching:** Song et al. (2020) used a 12 weeks intervention where each week consisted of three sessions, each session was approximately 60 minutes (warm-up and cool-down). The intervention was to improve the movement of the joints and the coordination of the muscles. In contrast, İlçin et al. (2024) compared the acute results of the PNF contract-relax technique on ankle range of motion WOM after one session. Both articles showed both long-term and short-term effects on joint flexibility.
- ii. **Dynamic Stretching:** The research by Iwata et al. (2019) explored ten hamstring dynamic stretching sessions, each of which took 30 seconds of dynamic stretching and performed 15 times.
- iii. **Passive Stretching:** Naraoka et al. (2017) used the video-guided treatment based on the quadriceps femoris, hamstring, iliopsoas, trapezius, and pectoralis major muscles, and the 40-minute sessions. Okita et al. (2022) applied 12 sessions within four weeks with the focus on the hamstring, surae, quadriceps, adductors, and abductors.
- iv. **Nerve- vs. Muscle-Directed Stretching:** Andrade et al. (2020) made a comparison between nerve-directed stretching on the sciatic nerve and muscle-directed stretching on plantar flexors in 12 weeks.
- v. **v.General Stretching:** In the study by Rodrigues et al. (2013), the stretching of the coxofemoral area was carried out over 12 weeks, and the test subjects were injected with 2 sessions a week (30-45 minutes) but the type of stretching was not mentioned.
- vi. **The frequency and length of sessions were different:** interventions included once a week and daily sessions, with 30 to 45 minutes (Rodrigues et al., 2013) or 60 minutes (Song et al., 2020) of the length of a session. With the exception of Okita et al. (2022), all of the interventions took 12 weeks or more, and most of them followed the 12-week protocol.

Outcome Measures

Range of Motion (ROM)

Diverse clinical and biomechanical measures of range of motion (ROM) were used across the studies included, which was different due to the various study objectives and methodology used. In Naraoka et al. (2017) and Rodrigues et al. (2013), lower-limb flexibility was assessed by functional tests that comprise the finger-to-floor distance and straight-leg raise as the indirect measure of hamstring and posterior chain flexibility. Conversely, Ilcin et al. (2024) specifically looked at the ankle dorsiflexion ROM in weight-bearing positions, which is a measurement that is often employed to determine functional ankle mobility during activities of gait.

In a number of researches, more instrument-based methods were used to enhance the accuracy of measurements. Andrade et al. (2020) measured maximal ankle reflexion ROM radiometry with ultrasonically, thus allowing the joint movement and underlying muscle–tendon mechanism to be assessed concurrently. On the same note, Iwata et al. (2019) measured passive knee ROM with an kinetic dynamiter, which enabled the use of standard control of joint movement velocity and torque.

The other studies used traditional clinical evaluation instrument. To measure active and passive joint ROM, Song et al. (2020) used both active and passive joint ROM to assess both functional and assisted mobility, whereas Okita et al. (2022) used trigonometry, which is one of the most common techniques of measuring knee ROM used in clinical and rehabilitation settings. The combination of these varied methodologies gave complementary information on the joint flexibility and mobility behaviors after the interventions of stretching.

Pain Outcomes

A subgroup of the included research reported pain-related outcomes measured with the validated clinical instruments. Song et al. evaluated the severity of the pain through the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain sub scale that is extensively used in the research based on musculoskeletal and osteoarthritis related disorders. In the meantime, Naraoka et al. (2017) and Okita et al. (2022) assessed the intensity of pain with a 100-mm Visual Analogue Scale (VAS), which is a valid and sensitive measure of subjective pain that is often employed to characterize pain.

Nonetheless, a few studies, such as Iwata et al. (2019), Andrade et al. (2020), İlçin et al. (2024), and Rodrigues et al. (2013) mainly involved biochemical and functional outcomes (ROM, muscle tendon properties, etc.) and, thus, did not measure pain-related outcomes.

All in all, the interventions provided have shown a consistent pattern of enhancing flexibility and joint mobility, although some of the studies also reported a decrease in the level of pain. However, high heterogeneity was noted in stretching modalities, duration of intervention, outcome measures and assessment instruments. This methodological inconsistency reduced the ability to compare the results between studies and prevented the implementation of a formal quantitative meta-analysis..

Study Design

In this review, randomised controlled trials (RCTs), controlled clinical trials, and quasi-experimental trials were conducted and evaluated the effect of stretching therapies on musculoskeletal outcomes. The reasons as to why these research designs were selected are the ability to possess high-quality evidence and the ability to compare the effects of interventions through incorporation of control or comparative groups.

The studies were discarded when they involved animal models, systematic reviews, meta-analyses, case reports, case series, or observational studies without a control or comparison group. Omitting such designs contributed to ensuring that the techniques were valid and made the evidence in this review more credible.

Information Sources

The useful research that were found after a comprehensive search of numerous large academic databases, which are known to index high-quality publications, was found. Such databases give much information on academic publications and many of them are on the first (Q1) and second (Q2) quartile of the SCImago

Journal Rank (SJR) listing. The utilization of more than one database contributes to ensuring that a broad scope of relevant research were located and minimized the likelihood of publication bias.

The primary source was Scopus database as there is much information about thousands of peer-reviewed papers on various fields. SJR has a number of indexed journals in the Q1 and Q2 category. There also are strong search and citation-tracking functionality of Scopus that facilitates an easier way of locating and filtering relevant information in a systematic manner.

Web of science core collection was also indicated as a valuable source of knowledge. People consider it to be one of the best citation indexing resources and they frequently utilize it in systematic reviews and bibliometric studies. Citation indexes are major citation indexes, such as the Science Citation Index Expanded (SCIE), the Social Sciences Citation Index (SSCI), and the Emerging Sources Citation Index (ESCI); each of them is included in the Core Collection. They collaborate to ensure that they include high-quality journals with strict editorial and peer-review standards.

We also searched through the portal of ScienceDirect of Elsevier. ScienceDirect has an enormous amount of full-text and peer-reviewed articles and scholarly publications covering a broad range of disciplines including the health sciences, the biological sciences, and the social sciences. Many of the journals on this site rank in the 25 percent of their disciplines.

The search methodology also used the SpringerLink, which was a massive digital library developed by Springer Nature. The site provides access to numerous academic journals, books, and conference proceedings involving many valuable medical, social science and applied scientific publications.

Finally, more peer-reviewed material was searched in the Wiley Online Library. This site has many academic articles and publications which cut across the fields of management, health sciences, and social sciences. Most of the journals in the Wiley Online Library are impactful and belong to the Q1 and Q2 quartiles.

Search Strategy

The research topic was identified using a thorough and comprehensive literature review. To ensure that the search methodology was open, repeatable, and scientifically rigorous, the search methodology was informed by the PRISMA Statement recommendations. We have searched numerous credible literature sources that contain peer-reviewed academic articles to ensure that we obtained as much information as possible.

The most significant databases were Web of Science Core Collection, the Science Direct, Scopus, SpringerLink, and Wiley Online Library. The reason why these databases were selected is because they contain numerous peer-reviewed papers. Interestingly, they also add the journals that are in the top two quartile (Q1 and Q2) according to the global ranking such as Scimago Journal Rank and impact factor. It was necessary to ensure that the existing evidence base was well-represented and the bias of publishing impact as low as possible in order to utilize as many databases as possible.

The search was conducted in March 2026 and was not time-bound to allow both older and newer studies that were pertinent to the problem to be discovered. The vocabulary and keywords search terms were the restricted ones. We entered Boolean operators such as AND, OR and NOT in order to combine the terms in accordance with the objectives of the research and the read material previously. This enabled us to have

limited results of the search. Other forms of important terms were also found through truncation and phrase searches where the need arose.

In addition, the reference lists of the selected papers were examined manually to make sure that the database search did not miss any study that would be helpful. In the first search, no language barriers were used in order to make it more diverse. The screening process involved locating and eliminating those articles that have been published in a different language which did not have a translation. It is a systematic and transparent methodical search technique that was employed to identify the papers that were included in the review.

Selection process

Study selection was carried out in numerous steps in a systematic manner:

1. Remove duplicates

Duplication AI tools could remove the duplication of the search results of all five databases based on the title, author, publication year, and the DOI. We have checked manually to ensure that nothing was duplicated. The step of screening the titles and abstracts will be put in place.

Two reviewers noted all the original records and selected those ones that passed the already established criteria. Two reviewers failed to reach a consensus and thus discussed more on the issue and later involved a third individual. This was the time we discarded studies we were considering because we were aware of them based on the information we had that they were not in our inclusion criteria. These reasons were documented and organized.

2. Scanning the Entire Text

Each successful passing of the screening of titles and abstracts in the research resulted in the acquisition of full-text publications, or there are cases when the qualifying requirements could not be determined based on the abstract alone. The entire texts have been reviewed individually by two reviewers to determine whether the articles were able to comply with all of the standards. The design of the study, the quantitative range of motion (ROM) and pain measurement, the age parameter of the study (45-60 years) and the duration of the intervention (12 weeks) were all well checked. The other reviewer was called in whenever necessary and we discussed the issue further to resolve any differences. The reasons of the exclusion at the full-text level were written down.

3. Working with Data

An electronic data management system, created by a standard kept a record of all the screening options, exclusion reasons, and comments by the reviewers. This ensured that nothing was hidden and would not be able to be reproduced.

The data collection procedure

The data extraction form was developed as a standardized form and tested on three studies that were a part of the analysis before the complete implementation. The data of each included research was taken by two different reviewers. In case of some disagreement, they discussed the situation until they reached the decision. The identified data items were the following:

- i. Data about the study: name of the author, the date of publication, country of conduction, research design, sample size and sponsor.
- ii. Data regarding the participants including their age (range and average), gender, health and who is and is not allowed to participate.
- iii. Intervention parameters: What types of muscle groups or joints to be trained, what sets and repetitions should be done, what will be the duration of the program, what number of sessions will be involved, what are the lengths of the stretches (active, passive, PNF, dynamic, etc.), and the supervision.
- iv. Data regarding the analysis and control: what type of intervention it is, how long it takes, how often it is administered and what the control or comparison group is.
- v. v.Outcome measures The range of motion (ROM) and specific joint measurement methods, pain measurement instruments, and length of evaluation.
- vi. Such information contains: range of motion (ROM), and pain results before and after intervention; pre-intervention, post-intervention comparisons; intracellular; statistical significance, and when appropriate, effect sizes.
- vii. Side effects: Any problems or negative outcomes that have been documented.

Assessment of possible bias

The Cochrane Risk of Bias tool of randomised trials was applied by two reviewers to determine the bias risk in one study. Assessments were carried out in the next areas:

- i. Making a random sequence (selection bias): It is verified that the assignment sequence has been chosen sufficiently to form a group of groups that are similar to each other.
- ii. The success with which the sequence of assignment was secretly maintained up to the assignment is referred to as allocation concealment (selection bias).
- iii. Third, we ensured that the participants and staff were not aware of what groups to be in (performance bias).
- iv. The fourth outcome assessment (detection bias) involves checking whether the individuals who administered the outcome assessments were not aware of the group they belonged to.
- v. v.Fifth, reviewing to ensure the data that is missing on outcomes has been managed properly (attrition bias).
- vi. Evaluation of the reporting of all outcomes predetermined: 6. Reporting bias (selectivity).
- vii. The seventh step will be to seek other possible things that could be sources of bias.

The domains were rated to be low-medium to high risk or unclear based on their explanations. The shape of the domain-level evaluations were calculated to ascertain the likelihood of the research to be biased in totality. By discussing their issues, reviewers could solve them.

Procedural Installing Information

The quantitative meta-analysis was considered inappropriate due to a large level of heterogeneity among the encompassed studies. It had several differences, as well, including the ways in the intervention (e.g. the various ways to stretch the joint, the length, frequency of the stretching), the way to measure the outcome (different ways to measure joint range of motion and pain scale), and the population under study (i.e. healthy people versus people with some clinical disorder). Such methodological differences did not allow exemplification of the comparability of findings between trials and did not enable the collection of effect estimates into a statistical meta-analysis.

Consequently, the information was synthesized into a narrative, which is the most appropriate method of synthesizing information in systematic reviews when the statistical aggregation is not possible. The synthesis was structured according to major themes, such as the type of stretching intervention and the outcomes. Stretching procedures were of different kinds including active stretching, passive stretching, contraceptive intramuscular facilitation (PNF), dynamic stretching, muscle-directed stretching and nerve-directed stretching. The result was usually considered in relation to the amount of the joint range of motion (ROM) that changed and the extent of the amount of pain or discomfort.

The characteristics of included studies were assembled in a tabular format, and the significant information displayed in a table. This consisted of research design, sample size, sample characteristics, the intervention, outcome measures and the key findings. Moreover, the qualitative comparative analysis was conducted in order to identify patterns of effectiveness, potential dose-response relationship and contextual factors that might have influenced research outcomes.

Also, the quality of methodology of the study including the sample size and risk-of-bias evaluation was tightly evaluated in order to arrive at the general strength and reliability of evidence. By reading these tests, we were able to learn a lot about the data used in the study and determine how different types of stretching treatments worked in terms of pain and range of motion.

RESULTS

Study Selection

A total of 230 records were identified as a result of the systematic search of the five databases: Web of Science (n=100), Scopus (n=100), SpringerLink (n=20), and Wiley Online Library (n=13). no additional entries were to be found using further methods, e.g., scanning the reference lists and citation tracking. The AI-based algorithms removed 143 duplicated entries, and thus, 87 unique records were left to scan. The title screen-abstract screening included 63 records that were eliminated since they failed to qualify. The primary causes of exclusion at this point were: animal studies (n=36), systematic review or meta-analysis (n=9), not lower extremity (n=7), no stretching intervention (n=5), less than 12 weeks intervention (n=2), case reports (n=2), no ROM or pain outcome (n=1), and problem of age group (n=1).

The screening of the full-text screening of articles was conducted on 24 articles. The retrieved articles were 13 (54.2 of the retrieved articles) articles that were effectively retrieved with full text and 11 articles that had limited or no full access to the text. A full-text review resulted in the dismissal of seventeen articles. The causes of elimination at this stage were the following: the period of intervention was not specified or vaguely.

None of it was documented (n=13), published as an experimental study (n=2), and a duration of intervention of under 12 weeks (n=2). A synthesis of seven articles was conducted qualitatively and met all the inclusion criteria. This represents a total inclusion rate of 8.0 percent of the 87 records that were found after the duplication. No quantitative synthesis (meta-analysis) was done because there was great heterogeneity on the treatments, outcomes and populations. The study selection process is summarised based on the PRISMA 2020 flow diagram rules.

Study Characteristics

The seven research in this study were done in various nations and were out between 2013 and 2024. The overall number of participants in all of the investigations was 234, with the number of participants in each study varying from 10 to 76. The research included used randomised controlled trials (RCTs) and quasi-experimental approaches to look at how stretching therapies worked. Table 1 shows a full list of the features of the studies that were considered.

Characteristics of Participants

The age of participants varied across the research considered. A number of research concentrated on persons aged 45 to 60 years, whilst others included older adults aged 62 to 79 years. For instance, Toshiyuki Naraoka et al. (2017) studied sedentary males aged 30–49 years who had pain in the lower back and neck. On the other hand, Qinghua Song et al. (2020) chose people who had been diagnosed with knee osteoarthritis. The average age of the participants was around 68 years.

Some research focused on healthy cohorts. For example, Rui J. Andrade et al. (2020) included healthy participants, however the precise age range was not explicitly stated. In the same way, Nilgün İlçin et al. (2024) and Yoshihiro Okita et al. (2022) mostly looked at older individuals, whereas Bruno G. S. Rodrigues et al. (2013) looked at sedentary males between the ages of 62 and 68. The exact ages of the healthy volunteers in the research conducted by Masatoshi Iwata et al. (2019) were not clearly specified.

The health state of individuals also differed throughout the research. Some studies involved healthy participants (Iwata et al., 2019; Andrade et al., 2020; İlçin et al., 2024; Rodrigues et al., 2013), while others focused on individuals with specific conditions, such as knee osteoarthritis (Song et al., 2020; Okita et al., 2022) or chronic musculoskeletal pain (Naraoka et al., 2017). Most studies included both male and female participants and provided gender distribution. However, Naraoka et al. (2017) and Rodrigues et al. (2013) recruited exclusively male individuals.

Characteristics of the Intervention

The studies included looked at many types of stretching, such as dynamic stretching, static passive stretching, nerve-directed stretching, and proprioceptive neuromuscular facilitation (PNF).

Proprioceptive Neuromuscular Facilitation (PNF)

Song et al. (2020) conducted a 12-week PNF stretching program with three sessions weekly, each lasting about 60 minutes, inclusive of warm-up and cool-down exercises. The intervention aimed to enhance joint mobility and neuromuscular coordination in persons with knee osteoarthritis.

Conversely, İlçin et al. (2024) examined the acute effects of the PNF contract–relax method on ankle range of motion (ROM), emphasising rapid alterations in joint flexibility after a single stretching session. These

studies together underscore the immediate and enduring effects of PNF stretching therapies on joint mobility.

Stretching in a dynamic way

Iwata et al. (2019) assessed dynamic hamstring stretching, including 10 sets of 30-second stretching exercises with 15 repetitions of lengthening and relaxation movements each set. The purpose of this intervention was to look at changes in muscular stiffness and range of motion (ROM).

Static Passive Stretching

Naraoka et al. (2017) examined the effects of video-guided active and passive stretching on several muscle groups, such as the quadriceps femoris, hamstrings, iliopsoas, trapezius, and pectoralis major, throughout a 12-week intervention period. Each session was around 40 minutes long.

Okita et al. (2022) also used a static passive stretching regimen that worked on the hamstrings, surae, quadriceps, adductors, and abductors. The intervention included 12 sessions administered over a four-week period.

Stretching for nerves vs. stretching for muscles

Andrade et al. (2020) executed a 12-week randomised controlled experiment juxtaposing nerve-directed stretching along the sciatic nerve route with muscle-directed stretching aimed at the plantar flexor muscle group. The research sought to investigate variations in tissue mechanical responses and flexibility results.

Stretching Programs in General

Rodrigues et al. (2013) conducted a 12-week stretching regimen targeting the femoral area, including two weekly sessions of 30–45 minutes each. But the authors didn't make it clear which stretching methods they utilized.

The number of treatments in the research ranged from one session per week to daily sessions. The majority of studies conducted two to three sessions weekly, with session lengths varying from 30 minutes to one hour. Most studies used 12-week programs (Song et al., 2020; Naraoka et al., 2017; Andrade et al., 2020; Rodrigues et al., 2013). The only one that used a four-week program was Okita et al. (2022).

Measures of Outcome

Range of Motion (ROM)

The assessment of range of motion (ROM) differed across the research examined. Naraoka et al. (2017) and Rodrigues et al. (2013) evaluated flexibility with finger-to-floor distance and straight-leg lift tests, quantified by trigonometry. İlçin et al. (2024) assessed ankle reflexion range of motion (ROM) in weight-bearing scenarios, serving as a functional measure of ankle mobility.

Andrade et al. (2020) assessed maximum ankle dorsiflexion range of motion (ROM) by radiometry and ultrasonically, facilitating accurate evaluation of tissue mechanical characteristics. Iwata et al. (2019) used an kinetic dynamiter to assess passive knee range of motion. Song et al. (2020) evaluated both active and passive joint range of motion, however specific measurement techniques were not clearly defined. Okita et

al. (2022) used trigonometry, a commonly employed clinical evaluation method, to quantify knee joint range of motion (ROM).

Results of Pain

Validated measuring devices were used in a number of research to look at pain outcomes. Song et al. (2020) used the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain subscale to quantify pain, a standard instrument for evaluating pain severity in persons with osteoarthritis.

Naraoka et al. (2017) and Okita et al. (2022) used the Visual Analogue Scale (VAS) with a 100-mm scale to assess pain intensity, a commonly endorsed instrument for measuring subjective pain sensations.

Nonetheless, several research, such as Iwata et al. (2019), Andrade et al. (2020), İlçin et al. (2024), and Rodrigues et al. (2013), focused mostly on range of motion (ROM) and biomechanical results, thereby excluding pain-related assessments.

In general, the therapies that were included showed increases in flexibility and joint mobility. Some studies also reported lower levels of discomfort. Nonetheless, considerable variability in research designs, stretching procedures, intervention duration, and outcome measuring techniques hindered the comparison of outcomes and obstructed the execution of a quantitative meta-analysis.

Table 1: Characteristics of Included Studies

Author (Year)	Country	Study Design	Sample Size (n)	Participant Characteristics	Intervention Type	Duration / Frequency	Outcome Measures
Song et al. (2020)	South Korea	Randomized Controlled Trial	40	Elderly adults with knee osteoarthritis (mean age ≈ 68 years)	Proprioceptive Neuromuscular Facilitation (PNF) stretching	12 weeks, 3 sessions/week, ~60 min/session	ROM, Pain (WOMAC)
Iwata et al. (2019)	Japan	Controlled Experimental Study	20	Healthy adults	Dynamic hamstring stretching	Single-session protocol with repeated sets (30 s stretching)	ROM, Passive muscle stiffness
Naraoka et al. (2017)	Japan	Quasi-experimental	30	Sedentary men aged 30–49 years with lower back and neck pain	Active and passive stretching program	12 weeks, ~40 min/session	ROM, Pain (VAS)
Andrade et al. (2020)	Portugal	Randomized Controlled Trial	20	Healthy adults	Nerve-directed vs muscle-directed stretching	12 weeks	ROM, Tissue mechanical properties

İlçin et al. (2024)	Turkey	Randomized Controlled Trial	48	Healthy older adults	PNF contract-relax stretching	Acute intervention (single session)	Ankle dorsiflexion ROM
Okita et al. (2022)	Japan	Randomized Controlled Trial	26	Patients with knee osteoarthritis	Static passive stretching	4 weeks, 12 sessions	Knee ROM, Pain (VAS)
Rodrigues et al. (2013)	Brazil	Quasi-experimental	50	Sedentary older men aged 62–68 years	General stretching exercises	12 weeks, 2 sessions/week (30–45 min)	Flexibility (ROM)

Assessment of Bias Risk

The threat of bias measurement demonstrated that the studies included had certain methodological weaknesses. The domains were rated in most cases as unclear or high risk either due to poor methodological reporting or inherent nature of blinding in intervention trials. The seventh section of Table 2 is the critical examination of seven sections of Cochrane Risk of Bias Tool.

We looked at the methodological quality of the studies we included by looking at areas that are often suggested in the PRISMA systematic review framework. These areas included random sequence generation, allocation concealment, blinding procedures, incomplete outcome data, selective reporting, and other possible sources of bias. In general, the methodological quality of the studies that were included was average. In several areas, it was hard to tell whether there was a danger of bias because of poor reporting.

Making a Random Sequence

The majority of research used random allocation processes, therefore categorising them as possessing a low risk of bias in this area (Song et al., 2020; Iwata et al., 2019; Andrade et al., 2020; İlçin et al., 2024; Okita et al., 2022). Nevertheless, the precise methodologies used to produce the random sequence were not consistently elucidated in enough depth.

Naraoka et al. (2017) did not adequately explain how they randomly assigned individuals to groups, even though the research tried to make sure that the groups had similar starting points. Consequently, this research was classified as exhibiting an ambiguous risk of bias. Rodrigues et al. (2013) also failed to disclose the use of randomisation, resulting in the research being categorised as having an indeterminate risk in this area.

Keeping the allocation secret

There wasn't much reporting on how to hide allocation. Okita et al. (2022) were the only ones to say they employed a computer-generated randomisation table, but they didn't explain how they hid the allocation before participants signed up.

Consequently, the majority of research (Song et al., 2020; Iwata et al., 2019; Naraoka et al., 2017; Andrade et al., 2020; İlçin et al., 2024; Rodrigues et al., 2013) were classified as exhibiting an indeterminate risk of bias in this area owing to inadequate reporting.

Making sure that participants and staff don't know what they're doing

It is intrinsically difficult to blind participants and intervention providers in exercise-based therapies, such as stretching regimens. Consequently, several research were evaluated as having a significant risk of performance bias.

For instance, Song et al. (2020) had the intervention group do proprioceptive neuromuscular facilitation (PNF) stretching while the control group stayed sitting and watched TV, which made it difficult to blind the participants. Naraoka et al. (2017) conducted a comparison of video-guided stretching and trainer-assisted stretching, both of which effectively mitigated blindness. Okita et al. (2022) clearly stated that neither the participants nor the therapists were blindfolded.

Other investigations inadequately defined blinding protocols, resulting in their classification as possessing an ambiguous risk of bias (Iwata et al., 2019; Andrade et al., 2020; İlçin et al., 2024; Rodrigues et al., 2013).

Concealment of Outcome Evaluation

Only a limited number of research documented blinded outcome evaluation. Okita et al. (2022) unequivocally indicated that outcome assessors were blinded to the intervention allocation, hence minimising the potential of detection bias.

Andrade et al. (2020) characterised their investigation as single-blind, however it was not clearly indicated whether the blinding pertained to participants or assessors. The other studies did not include enough information on how the assessors were blinded, thus they were put in the "unclear risk of bias" category (Song et al., 2020; Iwata et al., 2019; Naraoka et al., 2017; İlçin et al., 2024; Rodrigues et al., 2013).

Incomplete Results Data

The studies that were included typically didn't have a lot of attrition bias. Naraoka et al. (2017) and Okita et al. (2022) explicitly documented participant withdrawals and offered rationales for dropouts, hence minimising the danger of bias.

Song et al. (2020) noted inconsistencies in the number of participants recruited and those incorporated in the final analysis, resulting in an ambiguous risk assessment. The other studies (Iwata et al., 2019; Andrade et al., 2020; İlçin et al., 2024; Rodrigues et al., 2013) didn't include enough information on attrition, thus they were also put in the "unclear risk of bias" category.

Reporting that is selective

It was not possible to thoroughly examine selective reporting bias since the trial protocols or registrations for the studies that were included were not publicly accessible. As a result, it was impossible to ascertain if all predetermined results had been recorded. Consequently, all studies were categorised as exhibiting an ambiguous risk of selective reporting bias (Song et al., 2020; Iwata et al., 2019; Naraoka et al., 2017; Andrade et al., 2020; İlçin et al., 2024; Okita et al., 2022; Rodrigues et al., 2013).

Additional Sources of Bias

Several investigations found more causes of prejudice. Naraoka et al. (2017) were evaluated as having a significant risk of bias due to the active stretching group doing exercises without direct supervision, potentially influencing adherence and technique.

Okita et al. (2022) used a limited sample size ($n = 14$), thus increasing the possibility of Type II errors, hence categorising the research as possessing an indeterminate risk of bias. No further sources of bias were detected in the remaining investigations according to the information at hand.

Putting the Results Together

1. Impacts of Stretching Interventions on Range of Motion

Five out of the seven studies examined showed statistically significant improvements in lower-extremity range of motion (ROM) after stretching therapies (Iwata et al., 2019; Naraoka et al., 2017; Andrade et al., 2020; İlçin et al., 2024; Rodrigues et al., 2013). The extent of these enhancements, however, varied based on the specific stretching method and the joint structure being addressed.

2. Dorsiflexion of the ankle

Andrade et al. (2020) showed that both muscle-directed stretching and nerve-directed stretching made ankle dorsiflexion ROM much better, with nerve-directed stretching making it even better. These results imply that therapies aimed at brain structures may facilitate improved range of motion outcomes.

In a similar study, İlçin et al. (2024) found that static stretching, PNF stretching, and roller massage all made the ankle dorsiflexion ROM a lot better in healthy older persons. But roller massage made a big difference in the short term compared to static stretching and PNF.

3. Extending the knee

Iwata et al. (2019) found that dynamic hamstring stretching made passive knee extension ROM better right away, and the benefits lasted for up to 90 minutes after the stretching.

In contrast, Okita et al. (2022) observed no significant changes in knee range of motion between manual treatment and passive stretching in people with knee osteoarthritis after a four-week intervention, indicating limited short-term efficacy.

4. Flexibility in the hips and lower back

Naraoka et al. (2017) showed substantial improvements in finger-to-floor distance, indicating increased hamstring flexibility and lumbosacral mobility subsequent to passive stretching. There were improvements throughout the 12-week intervention period.

Rodrigues et al. (2013) also documented substantial improvements in hip range of motion among inactive older males subsequent to a 12-week stretching regimen.

5. Changes in Biomechanics

A number of studies have also looked at how stretching therapies affect biomechanics. Andrade et al. (2020) noted decreases in muscle stiffness and passive torque after muscle-targeted stretching, but nerve-targeted stretching decreased the stiffness of neural tissue.

Iwata et al. (2019) similarly documented decreases in passive hamstring muscle stiffness after to dynamic stretching, suggesting advantageous mechanical changes.

Effects of Stretching Interventions on Pain

Three research investigated pain outcomes; two indicated substantial decreases in pain (Song et al., 2020; Naraoka et al., 2017), but one study found no significant effects (Okita et al., 2022).

1. Pain from knee osteoarthritis

Song et al. (2020) showed that a 12-week PNF stretching program substantially decreased pain in older persons with knee osteoarthritis, as judged by the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain subscale.

2. Pain in the Neck and Lower Back

Naraoka et al. (2017) found that passive stretching worked better than active stretching to reduce lower back and neck discomfort, as evaluated by the Visual Analogue Scale (VAS).

3. No Notable Pain Effects

Okita et al. (2022) could not find any significant changes in pain outcomes between manual treatment and passive stretching in individuals with knee osteoarthritis after a four-week intervention.

The Effectiveness of Different Stretching Methods

- While direct comparisons were constrained, several research elucidated the relative efficacy of various stretching strategies.
- **Passive vs. Active Stretching:** According to Naraoka et al. (2017), passive stretching led to more long-term gains in both range of motion (ROM) and pain relief than active stretching.
- **Muscle-Directed vs. Nerve-Directed Stretching:** Andrade et al. (2020) discovered that nerve-directed stretching yielded marginally superior improvements in range of motion (ROM), whereas muscle-directed stretching achieved more significant reductions in muscular stiffness.
- İlçin et al. (2024) found that roller massage caused bigger short-term gains in ankle ROM than static stretching and PNF stretching.

Amount and duration of the intervention

The frequency of interventions differed across research, ranging from two sessions weekly (Okita et al., 2022; Rodrigues et al., 2013) to daily stretching programs (Naraoka et al., 2017). The majority of studies conducted two to three sessions weekly (Song et al., 2020; Andrade et al., 2020).

The sessions lasted between 30 and 60 minutes, and most of the therapies lasted 12 weeks. The only trial with a shorter intervention time (four weeks) did not demonstrate significant enhancements in range of motion (ROM) or discomfort, indicating that extended intervention durations may be requisite for achieving substantial musculoskeletal adaptations.

DISCUSSION

Principal Findings

This systematic review synthesized evidence from seven experimental studies examining the effects of stretching interventions lasting 12 weeks or longer on lower-extremity range of motion (ROM) and pain among middle-aged and older adults. Overall, the findings suggest that sustained stretching interventions can produce meaningful improvements in joint mobility, while evidence for pain reduction remains promising but limited. Across the included studies, improvements in ROM were consistently reported following a variety of stretching protocols, including dynamic stretching, static passive stretching, proprioceptive neuromuscular facilitation (PNF), and nerve-directed stretching. These findings support the notion that regular stretching may play an important role in maintaining or improving musculoskeletal flexibility during aging.

Five of the seven included studies reported statistically significant improvements in ROM following structured stretching programs (Iwata et al., 2019; Naraoka et al., 2017; Andrade et al., 2020; İlçin et al., 2024; Rodrigues et al., 2013). The magnitude of these improvements ranged from approximately 7–10% increases in knee extension ROM to 7–10° increases in ankle dorsiflexion (Andrade et al., 2020; Iwata et al., 2019). From a clinical perspective, even modest improvements in joint mobility can substantially influence functional capacity in aging populations. Limited ROM in the lower extremities is associated with impaired gait patterns, reduced balance performance, and increased risk of falls. Therefore, the ROM improvements observed across these studies may translate into meaningful functional benefits, including enhanced walking efficiency and improved performance of daily activities.

Notably, the positive outcomes of stretching were also found in various intervention forms, which indicates that regular mechanic extension of musculoskeletal tissues could be the main factor causing the increase in flexibility, and not the kind of stretching method used. However, the differences between the stretching modalities suggest that the involvement of different physiological mechanisms might occur, and this aspect needs additional research.

Effects of Stretching on Range of Motion

The beneficial impact of stretching interventions on lower-extremity ROM was one of the most frequent results of the studies included in the research. Increase in improvements was noted after acute and long-term stretching programs, which points out the interplay between short-term visco elastic responses and long-term structural responses.

Dynamic stretching interventions like the ones discussed in the paper by Iwata et al. (2019) showed a relief in hamstring flexibility and knee extension ROM that lasted up to 90 minutes after the intervention. These acute changes probably can be explained by the interim decrease of passive muscle stiffness and by the increase of the stretch tolerance, due to alteration in the viscoelastic characteristics of the muscle-tendon unit. Stressful stretching can also inhibit neuromuscular reflex which enables the muscle to stretch further during the next movement.

Conversely, interventions that take longer such as 12 weeks are more likely to cause morphological and neuromuscular long-term adaptations. They can involve a longer length of muscle fascicles, changes in connective tissue rigidity, and a better function of neuromuscular levels of coordination. Andrade et al. (2020) hypothesized that repetitive stretching can also affect the mechanical characteristics of muscular and neural tissues, which can lead to anabolic changes in joint movements.

This structural remodelling of connective tissues is believed to be a major process that leads to long-term changes in flexibility. Repeated stretching may cause collagen remodeling in tendons and fascia that can result in increased compliance in tendons and fascia which can bring increased excursion of the joint. Also, there is a possibility that individuals will also be more tolerant to stretching discomfort, which enables them to achieve more end-range positions during assessments of flexibility.

The positive outcomes in ROM by Rodrigues et al. (2013) and Naraoka et al. (2017) also confirm the usefulness of the structured stretching exercises in the population of sedentary older adults. These trials showed that, even those having low levels of physical activity at the start of physical activities, can record some significant improvements in flexibility when they undertake regular stretching exercises.

Again on a real-life perspective, these findings would be that stretching interventions that could be conducted as many as two to three times a week and over an extended period of time could be enough to achieve clinically meaningful changes in joint mobility. These interventions are relatively cheap, need very minimal equipment and may be readily integrated with community or rehabilitation efforts aimed at older adults.

Effects of Stretching on Pain

Unlike the uniformity of the results with respect to ROM, there is little evidence in respect of the reduction of pain after the procedure of stretching interventions. Out of the studies included, three articles assessed pain outcomes (Song et al., 2020; Naraoka et al., 2017; Okita et al., 2022). Two of them found that the pain was reduced significantly after stretching interventions, and the other one found no significant effects.

Song et al. (2020) also discovered that a 12-week PNF stretching program resulted in a significant decrease in pain in people with knee osteoarthritis as assessed by the Western Ontario and McMaster Universities Osteoarthritis Index. In like manner, Naraoka et al. (2017) demonstrated that there were substantial reductions in low back and neck pain after a structured stretching program, which was measured by Visual Analogue Scale.

There are a number of physiological processes that can be the cause of analgesia in stretching. The inhibitory pathways triggered by mechanical stimulation of the mechanoreceptors of the muscle and connective tissue can reduce the experience of pain by the action of descending pain modulation systems. Stretching could also reduce muscle tension, local ischemia, and enhance circulation of the affected tissues. Also, the stretching can affect the sensitivity of peripheral nociceptors and this can decrease the pain signals.

In addition to physiological processes, there can be psychological reasons that help in reducing pain. Structured physical activity may help to increase self-efficacy and allow the person to feel that he or she has control over the symptoms, which can be beneficial in terms of pain perception. Such effects are psychosocial and may be of great interest to persons who have long-term musculoskeletal diseases.

Nevertheless, the lack of severe pain improvements in the study conducted by Okita et al. (2022) also suggests the heterogeneity of the results of stretching among clinical populations. The degree of change in

the pain under the influence of stretching interventions may depend on differences in the duration of interventions, the intensity of intervention, or the patient factors. Moreover, pain is a multidimensional concept, which is affected by biological, psychological, and social variables, and as a result, it is more difficult to alter than mechanical indicators, including ROM.

Seeing that the number of studies that were able to measure pain outcomes was limited, additional studies are needed to identify whether or not stretching interventions could always lead to clinically significant pain reduction in older adults.

Comparative Effectiveness of Stretching Modalities

Some of the studies included in this review also tried to compare various methods of stretching which gave some initial information as to which one was better than others.

According to Naraoka et al. (2017), passive stretching had a higher level of improvement in ROM and pain than active stretching. Passive stretching can also permit more elongation of the muscle and connective tissues since the force of stretching is administered externally that people can attain end-range positions that may not be possible when using voluntary contraction.

In the same way, Andrade et al. (2020) compared nerve-directed stretching with muscle-directed stretching and found only a little bit more improvements in ankle dorsiflexion ROM after nerve-directed intervention. The results of this finding indicate that the rigidity of neural tissue can be a major contributor to restricting the range of movement of the joint. Manipulation of neural structures, including the sciatic nerve, can thus be involved in aiding in increase in flexibilities by decrease in neural mechanosensitivity and neural sliding.

Ilçin et al. (2024) compared roller massage, PNF stretching, and static stretching and the roller massage had the highest acute effects on ankle ROM. Nevertheless, due to short-term results only evaluated in this study, it is not evident whether these effects would still occur in the long term as intervention.

Combined, these results indicate that various stretching modalities can affect various physiological components, such as muscle fibers, connective tissues, and neural pathways. Nevertheless, the small quantities of comparative studies and variation in intervention protocols do not allow conclusive remarks as to the superiority of certain techniques. Future studies ought to focus on the well-designed randomized controlled trials in direct comparison of the modalities of stretching in the standardized conditions.

Methodological Considerations and Limitations

The following are some of the methodological limitations of the studies included in the interpretation of the findings of this review.

To start with, the total number of participants who were targeted in the studies was rather insufficient because there were only 234 participants (in total). Small samples reduce the power of the statistics and predispose both type I and type II errors.

Two, heterogeneity concerning intervention procedures was high with variations in type of stretching, duration, frequency, and muscle groups. This heterogeneity complicated the process of finding the best intervention parameters and could not allow the implementation of a quantitative meta-analysis.

Third, the quality of the methods used in the studies was different. Even though some of the studies used randomized controlled designs, information about allocation concealment and blinding procedures was not adequately reported, which predisposed the research to bias. Since in exercise-based interventions, it is hard to ensure that participants were blinded, many of the studies were vulnerable to performance bias.

Fourth, the characteristics of the participants were rather different. There were studies that involved healthy populations whereas some were more concerned with clinical populations like people with knee osteoarthritis or chronic pain conditions. The findings might not be generalizable due to this heterogeneity.

Fifth, standardization of outcomes measurement was not done. Different instruments were used to evaluate ROM assessment such as goniometry, dynamometry, and motion analysis systems and the pain outcomes were determined using different scales.

Lastly, none of the studies included tested the long-term follow-up effects, so it is unclear whether the change in the flexibility or pain caused by stretching is sustainable.

Implications for Clinical Practice and Future Research

Although these shortcomings exist, the results of this review have a number of significant clinical implications and implications on future research.

The clinical and rehabilitation implication to clinicians and rehabilitation professionals is that active stretching programs that are at least 12 weeks can result in significant changes in lower-extremity flexibility in middle-aged and older adults. Considering the relationship between loss of flexibility and lack of mobility among aging people, stretching should be considered in rehabilitation and preventive exercise programs to ensure functional independence.

Stretching programs are seen to be safe, cost-effective, and easy to implement, thus seeming appropriate when it comes to community-based interventions of older adults.

There are a few major areas that future research should be based on. First, the evidence base should be strengthened through the conduction of larger randomized controlled trials with the use of standardized intervention protocols. Second, the long-term follow-up evaluation would be needed in future investigations to identify whether the gains in flexibility caused by stretching can be retained with time. Third, further studies are required to investigate the impact of stretching on pain and functional outcomes such as balance, gait performance and the risk of falls.

Lastly, comparative research on various modalities of stretching, intensities and frequencies would contribute to evidence-based practice in terms of optimization of stretching interventions in old age.

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