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SYSTEMATIC REVIEW

Optimising the Dose of Static Stretching to Improve Flexibility: A Systematic Review, Meta-analysis and Multivariate Meta-regression

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Abstract

Background Static stretching is widely used to increase flexibility. However, there is no consensus regarding the optimal dosage parameters for increasing flexibility.

Objectives We aimed to determine the optimal frequency, intensity and volume to maximise flexibility through static stretching, and to investigate whether this is moderated by muscle group, age, sex, training status and baseline level of flexibility.

Methods Seven databases (CINAHL Complete, Cochrane CENTRAL, Embase, Emcare, MEDLINE, Scopus, and SPORTDiscus) were systematically searched up to June 2024. Randomised and non-randomised controlled trials investigating the effects of a single session (acute) or multiple sessions (chronic) of static stretching on one or more flexibility outcomes (compared to non-stretching passive controls) among adults (aged ≥ 18 years) were included. A multi-level meta-analysis examined the effect of acute and chronic static stretching on flexibility outcomes, while multivariate meta-regression was used to determine the volume at which increases in flexibility were maximised.

Results Data from 189 studies representing 6654 adults (61% male; mean [standard deviation] age = 26.8 ± 11.4 years) were included. We found a moderate positive effect of acute static stretching on flexibility (summary Hedges' $g = 0.63$, 95% confidence interval 0.52–0.75, $p < 0.001$) and a large positive effect of chronic static stretching on flexibility (summary Hedges' $g = 0.96$, 95% confidence interval 0.84–1.09, $p < 0.001$). Neither effect was moderated by stretching intensity, age, sex or training status, or weekly session frequency and intervention length (chronic static stretching only) [$p > 0.05$]. However, larger improvements were found for adults with poor baseline flexibility compared with adults with average baseline flexibility ($p = 0.01$). Furthermore, larger improvements in flexibility were found in the hamstrings compared with the spine following acute static stretching ($p = 0.04$). Improvements in flexibility were maximised by a cumulative stretching volume of 4 min per session (acute) and 10 min per week (chronic).

Conclusions Static stretching improves flexibility in adults, with no additional benefit observed beyond 4 min per session or 10 min per week. Although intensity, frequency, age, sex and training status do not influence improvements in flexibility, lower flexibility levels are associated with greater improvement following both acute and chronic static stretching. These guidelines for static stretching can be used by coaches and therapists to improve flexibility.

Clinical Trial Registration PROSPERO CRD42023420168.

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Key Points

Evidence from randomised and non-randomised controlled trials indicates a moderate increase in flexibility following a single session of static stretching (acute) and a large improvement over multiple sessions (chronic).

Improved flexibility from static stretching occurs irrespective of the stretch intensity, age, sex and training status—and in the case of chronic static stretching—the weekly training frequency and the intervention length. Furthermore, apart from the muscles of the spinal column, similar improvements in flexibility occur regardless of the muscle group stretched. However, flexibility improved more in those with poor flexibility than in those with average flexibility.

Improvements in flexibility are maximised after achieving a static stretching volume of 4 min per muscle group per session (acute) and 10 min per muscle group per week (chronic).

1 Introduction

Flexibility is the capacity to move a joint or group of joints unrestricted through its available range of motion (ROM) [1–3]. The American College of Sports Medicine recognises flexibility as one of five health-related components of physical fitness [4]. Muscle stretching, the primary way to improve flexibility, is widely used by coaches, athletes, and allied health, exercise and medical professionals to increase ROM [5], improve physical performance [6, 7] and supposedly mitigate injury risk [8, 9]. The most common, accessible and simplest form of stretching is static stretching, which involves moving a joint to near its end ROM (until a stretch sensation is felt in the muscle) and holding still [10–13]. Stretching is thought to improve flexibility by increasing stretch tolerance [14], changing the viscoelastic properties of the musculotendinous tissues (i.e. musculotendon stiffness) [5], or changing the muscle architecture (i.e. muscle fascicle length and pennation angle) [15].

Despite the widespread use of static stretching in both sports and clinical settings, there are no clear recommendations on the optimal dose of static stretching for improved flexibility. This is in stark contrast to the large body of research on optimal dosage parameters for other physical fitness parameters including both aerobic and resistance training to improve cardiorespiratory endurance [16–20] and muscle strength and hypertrophy [21–23], respectively. For apparently healthy adults, the American College of Sports Medicine recommends that static stretching be performed two to three times per week, with each stretch held to the point of feeling tightness or slight discomfort for 2 to 4 sets of 15–30 s per muscle group [4]. Unfortunately, this recommendation was generally based on evidence from low-quality randomised controlled trials, uncontrolled or non-randomised trials, and observational studies [24].

Attempts to explore the optimal dose of static stretching to improve flexibility have been few, and with conflicting results. Apostolopoulos et al. [25] systematically reviewed studies investigating the effect of stretch intensity and position on ROM, but were unable to draw confident conclusions because of a lack of high-quality studies. Medeiros et al. [26] meta-analysed the results of 18 studies and found that static stretching improved hamstring ROM among healthy young adults, but did not examine specific dosage recommendations. In a follow-up meta-analysis, Medeiros and Martini [11] found that static calf stretching improved ankle ROM, with similar effects observed for low-volume (< 50 min), moderate-volume (50–84 min) and high-volume (> 84 min) stretching. In a similar meta-analysis, Thomas et al. [12] found static stretching for either 5–10 or more than 10 min per week improved ROM compared with less than 5 min per week. More recently, a meta-analysis of 32 studies by Arntz et al. [27] found that total stretching duration was positively associated with improved flexibility, although there were no differences between low-intensity, moderate-intensity, and high-intensity stretching on the increase in flexibility [27]. Likewise, Konrad et al. [28] found no difference between low-intensity and high-intensity stretching, indicating that stretching beyond the point of discomfort or pain is not necessary to maximise improvements in flexibility. While these reviews collectively provide insight into the effect of static stretching on flexibility, none has strictly examined the impact of static stretching alone, which is particularly relevant given its popularity. Moreover, while the effects of intensity and duration have been explored, no meta-analysis has examined the influence of total single-session or weekly stretching volume on flexibility outcomes. It is possible that the total time a muscle is stretched is the most important factor to improve flexibility, but this remains unknown.

Collectively, there is a lack of high-quality evidence to support the American College of Sports Medicine's recommended dosage parameters for static stretching. Given the widespread use of static stretching, identifying the most appropriate parameters is of great importance for fitness, healthcare and sports medicine professionals to optimise flexibility-based outcomes when prescribing static stretching. Specifically, quantifying the relationship between dose (static stretching) and response (improvements in flexibility) is essential to optimise the benefits of static stretching. The primary aim of this systematic review and meta-analysis was to determine the magnitude of change in flexibility following a single session (acute) and multiple sessions (chronic) of static stretching, and to explore the optimal dosage parameters (e.g. intensity, duration, frequency, volume) required to maximise these changes. The secondary aim was to examine whether these dosage parameters were moderated by muscle group, age, sex, training status and baseline level of flexibility.

2 Methods

2.1 Protocol and Registration

This systematic review and meta-analysis protocol was preregistered with the International Prospective Register of Systematic Reviews (PROSPERO) [ID: CRD42023420168]. We followed the 2020 Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement [29].

2.2 Eligibility Criteria

Studies were included if they met the following criteria:

1. *Population* Humans aged 18 years and older, without restrictions based on sex, training status or health status.
2. *Intervention* Static stretching exercise (single session [acute]) or training (multiple sessions [chronic]). Studies that combined static stretching with other interventions, such as resistance training, were excluded. Studies were also excluded if participants completed a warm-up after initial testing (acute) or prior to each stretching intervention session (chronic).
3. *Comparison* Passive (non-stretching) control group (between-subjects designs) or contralateral extremity (within-subject designs).
4. *Outcome* Objectively measured flexibility (e.g. ROM [°], distance [cm]) reported as pre-intervention and post-intervention or change scores (means and standard deviations [SDs]).
5. *Study design* Randomised or non-randomised controlled trials with baseline and follow-up measures using within-subject or between-subjects study designs. Other study designs (e.g. experimental, case–control, cross-sectional, cohort, review, qualitative, non-empirical) were excluded.
6. *Study language, publication status and timeframe* Full-text refereed journal articles published in English regardless of date of publication [30, 31]. Conference abstracts/papers, commentaries, editorials, dissertations or grey literature were excluded.

2.3 Information Sources and Search Strategy

We searched seven databases (CINAHL Complete [via EBSCOhost], Cochrane CENTRAL, Embase [via Ovid], Emcare [via Ovid], MEDLINE [via Ovid], Scopus, and SPORTDiscus [via EBSCOhost]) on 6 June, 2024. We applied Bramer and colleagues' [32] recommended optimal combination of databases and designed the search strategy in consultation with University of South Australia academic librarians experienced in systematic literature searching. The search strategies for databases are shown in Appendix S1 of the Electronic Supplementary Material (ESM). Additional studies were identified by searching the reference lists of eligible studies and topical systematic reviews and meta-analyses [33].

2.4 Selection Process

Records were imported into EndNote (v20.2.1; Clarivate Analytics, Philadelphia, PA, USA) and de-duplicated, and then into Covidence (Veritas Health Innovation, Melbourne, VIC, Australia) for further de-duplication and record screening. Titles and abstracts were independently screened against inclusion criteria by two of the following authors experienced in conducting and publishing systematic reviews (LI, HB, BG, SG and GT). Full-text studies were then independently screened against inclusion criteria by the same authors and ND. Conflicts were resolved by majority consensus using a third author (LI for studies reviewed by HB, ND, BG, SG and GT; and HB for those reviewed by LI, ND, BG, SG and GT).

2.5 Data Collection Process and Data Items

Data were extracted by a single author (LI) using a custom-made standardised Excel spreadsheet (Microsoft, Redmond, WA, USA) and were verified by a second author (ND). A third author (HB) resolved conflicts. The following data were extracted:

(a) lead author name and year of publication;
(b) article title;
(c) descriptive characteristics (e.g. sample size, sex, age, health status, training status, baseline level of flexibility) for the experimental and control groups;
(d) region of the body and muscle group(s) stretched;
(e) exercise prescriptions, including duration of stretching intervention (weeks), frequency of stretching sessions (per week), number of stretches performed per session, number of repetitions per stretch, duration of each repetition (seconds) and intensity of each stretch (i.e. below the point of discomfort, until the first point of resistance or until a gentle stretch was felt [low inten-

sity]; between discomfort and pain OR firm, noticeable tension was felt, or tightness [moderate intensity]; pain and beyond or maximal/end ROM [high intensity]);

(f) whether stretching was supervised or unsupervised;

(g) whether stretching was performed unilaterally, bilaterally or both;

(h) participant compliance;

(i) study design (independent control group, crossover design or contralateral extremity used as the control);

(j) type of static stretching (active, passive, both or unclear);

(k) main outcomes (pre-intervention and post-intervention means and SDs or change scores) for objectively measured flexibility for both the experimental and control groups.

When reported, published means and SDs were extracted; when visualised, WebPlotDigitizer (v4.6; Ankit Rohatgi, Melrose, MA, USA [http://apps.automeris.io/wpd/]) was used to estimate means and SDs [34].

2.6 Risk of Bias Assessment

Study quality was independently assessed by two authors (LI and ND) using the Physiotherapy Evidence Database (PEDro) scale, with conflicts resolved by a third author (HB). As it is not viable to blind participants in static stretching intervention studies, and therapists and assessors are rarely blinded, items 5, 6 and 7 were removed from the 10-point PEDro scale. Exclusion of items 5–7 is consistent with several recently published exercise intervention systematic reviews using the PEDro scale [21, 27, 35]. With an adjusted maximum score of 7, the methodological quality of the included studies was interpreted as excellent (i.e. PEDro score 6–7), good (i.e. PEDro score 5), moderate (i.e. PEDro score 4) or poor (i.e. PEDro score 0–3) [36].

2.7 Certainty of Evidence

The certainty of evidence was independently assessed by two authors (LI and HB) using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) quality rating analysis [37]. We assessed acute and chronic studies separately and categorised the certainty of evidence as high, moderate, low and very low. As 158 of the 188 (84%) included studies were randomised controlled trials, the certainty of evidence started at high. Certainty was determined by the confidence in the effect estimate and adjusted based on limitations in study design or execution, inconsistency of results, indirectness of evidence and imprecision. Certainty was downgraded if: > 25% of participants were from studies with a PEDro score < 5 out of 7 (i.e. poor or moderate methodological quality) [risk of bias] [36, 38, 39]; $I^2 > 50\%$ (i.e. substantial or considerable heterogeneity) [inconsistency of results] [39]; there were significant differences in populations, outcomes or interventions used between studies (indirectness); data from < 800 participants per outcome were analysed (imprecision) [40]; and Egger's test was significant (publication bias). Conversely, the certainty of evidence was upgraded by a level if each of the following criteria were met: a large magnitude of effect (i.e. standardised mean difference [SMD] > 0.8); the presence of a dose response; and plausible residual opposing confounding.

2.8 Data Synthesis and Analysis

Quantitative synthesis of data was performed with the 'metafor' and 'rms' packages in R, with plots produced using the 'ggplot2' package (version 4.3.1; R Core Team, https://www.r-project.org/). A multi-level meta-analysis of SMDs between conditions was conducted to examine the effects of acute and chronic static stretching on flexibility compared to non-stretching passive controls. Standardised mean differences were calculated by dividing the mean difference by the pooled SD at baseline, where the mean difference was calculated as the mean pre-post change in the stretching group minus the mean pre-post change in the control group [41]. In the instance where only the SD of the change was reported, the pooled SD of the change scores was used in place of the pooled SD of the baseline scores to calculate SMD. When a study reported medians, range or interquartile range, the mean and SD were estimated using the method proposed by Wan et al. [42]. Hedges' *g* correction was applied to the SMD to adjust for the small sample bias. In the instance where a study had multiple intervention groups, the sample size of the 'shared' control group was divided by the number of comparisons [43]. Effect sizes (*g*) were interpreted as trivial (< 0.20), small (0.20–0.49), moderate (0.50–0.79) and large (≥ 0.80) [44]. Positive effect sizes favoured the stretching condition, and negative effect sizes favoured the control condition. To account for dependency between effect sizes from the same study, a multi-level random-effects model (with the study identifier as a random factor) was conducted using a restricted maximum likelihood estimation. This was considered the most appropriate method of analysis owing to the large number of included studies (> 50) in the review [45]. The multi-level model was used to estimate the overall effect size and 95% confidence interval (CI).

Statistical heterogeneity between studies was assessed using Q and I^2 statistics. I^2 values were interpreted as negligible ($I^2 = 0$–40%), moderate ($I^2 = 30$–60%), substantial ($I^2 = 50$–90%) or considerable ($I^2 = 75$–100%) [46]. For all primary analyses, tau-squared (τ^2) was presented to provide an indication of the variability in effect sizes between studies due to a sampling error, while sigma-squared (σ^2) provided an estimate of the variability within studies due to a sampling error. We examined potential heterogeneity sources by performing the following subgroup analyses: intensity, body region (i.e. muscle group), age (<65 years, ≥ 65 years), sex (male-only, female-only, or combined sex sample), training status (sedentary, recreationally active, trained population, athlete), baseline flexibility (poor or average), intervention duration (0–3 weeks, 4–6 weeks and >6 weeks) and training frequency for the chronic meta-analysis; and intensity, age, sex, training status, baseline flexibility and body region for the acute meta-analysis. Publication bias was visualised by funnel plots and examined statistically using Egger's test. Absolute standardized residuals >2 were considered as outliers, and we conducted sensitivity analyses in which meta-analyses were repeated with outliers removed to determine their influence. To determine whether a risk of bias influenced outcomes, a multivariate meta-regression was conducted examining the association between PEDro score and effect size estimates.

Last, an exploratory multivariate meta-regression was conducted to examine the relationship between stretching volume and SMDs and to investigate if there was a threshold where further increases in stretching volume elicited no meaningful improvement in flexibility. Weekly stretching duration was considered stretching volume for the chronic analysis, while total within-session stretching duration was considered stretching volume for the acute analysis. The study identifier was again used as a random factor to account for dependency. Because of the expected non-linear nature of the relationship between static stretching and increases in ROM, a cubic spline model was chosen for the regression analysis. Cubic spline regression models with three, four and five knots were conducted and compared using a likelihood ratio test to identify the best fit [47]. For the acute stretching analysis, the three-knot model provided the best fit, and knots were located at 1, 2 and 8 min of static stretching per session. For the chronic analysis, the four-knot model provided the best fit, and knots were located at 3, 8, 16 and 173 min of static stretching per week. For the retained model, a likelihood ratio test for residual heterogeneity was conducted and a test of moderators performed.

3 Results

3.1 Study Selection

The initial database search retrieved 17,686 studies, and following removal of duplicates, 8570 titles and abstracts were screened. Of these, 535 studies underwent a full-text review, with 184 studies being eligible for inclusion in this systematic review and meta-analysis. An additional 16 studies were identified from the reference lists of the included 185 studies, of which five were eligible for inclusion. Therefore, a total of 189 studies were included in this systematic review and meta-analysis [7, 48–235]. Figure 1 presents a flow diagram of the literature search and screening process. The Kappa coefficient was used to calculate the reliability of study selection between authors, with values between 0.65 and 0.72 indicating a high level of inter-rater agreement.

3.2 Study Characteristics

Study characteristics are summarised in Appendix S2 of the ESM. Studies were published between 1977 and 2024 and were from 26 countries (19 high-income, four upper-middle income and three lower-income economies). One hundred and fifty-seven (83%) of the 189 included studies were randomised controlled trials, while the remaining 32 studies (17%) were non-randomised. Most studies (71% [$n=135$]) included an independent non-stretching passive control group, 21% ($n=39$) used a crossover study design, while the remaining 8% ($n=15$) used a within-subject design where participants' contralateral extremity acted as the control. There were 6654 participants (61% male [$n=3898$]; 39% female [$n=2447$]) with a mean (± SD) participant age of 26.8 ± 11.4 years. Four studies (2%) did not report participant age and 11 studies (6%) did not report participant sex. Using the Participant Classification Framework [236], 8% of studies ($n=16$) were classified by training status as sedentary (tier 0), 22% ($n=41$) as recreationally active (tier 1), 23% ($n=43$) as trained (tier 2) and 5% ($n=9$) as athletes (tiers 3–5). Training status was not reported in the remaining 42% ($n=80$) of studies. Fifty-seven studies (30%) specifically included adults with pre-defined limitations in flexibility.

Among studies, the most common body regions or muscle groups stretched were the hamstrings (47% [$n=89$]), followed by the ankle plantar flexors (32% [$n=61$]), shoulder (6% [$n=12$]), hip (4% [$n=8$]), quadriceps (4% [$n=8$]), spine (4% [$n=7$]) and distal extremities [i.e. feet, elbow, wrist or hand] (1% [$n=2$]). Two studies (1%) compared multiple-intervention groups that stretched different muscle groups. Over half of the included studies (56% [$n=105$]) examined changes in flexibility following static stretching training (repeated sessions of stretching, i.e. chronic interventions), 44% ($n=83$) examined changes in flexibility following a single session of stretching (short term, i.e. acute interventions), while a single study (1% [$n=1$]) examined both acute and chronic responses to static stretching. The intensity of stretching among studies was classified as low (13% [$n=24$]), moderate (44% [$n=84$]), high (25% [$n=47$]) and unclassified (16% [$n=31$], i.e. insufficient detail provided). The remaining three studies (2% [$n=3$]) compared the effect of different stretching intensities across multiple intervention groups.

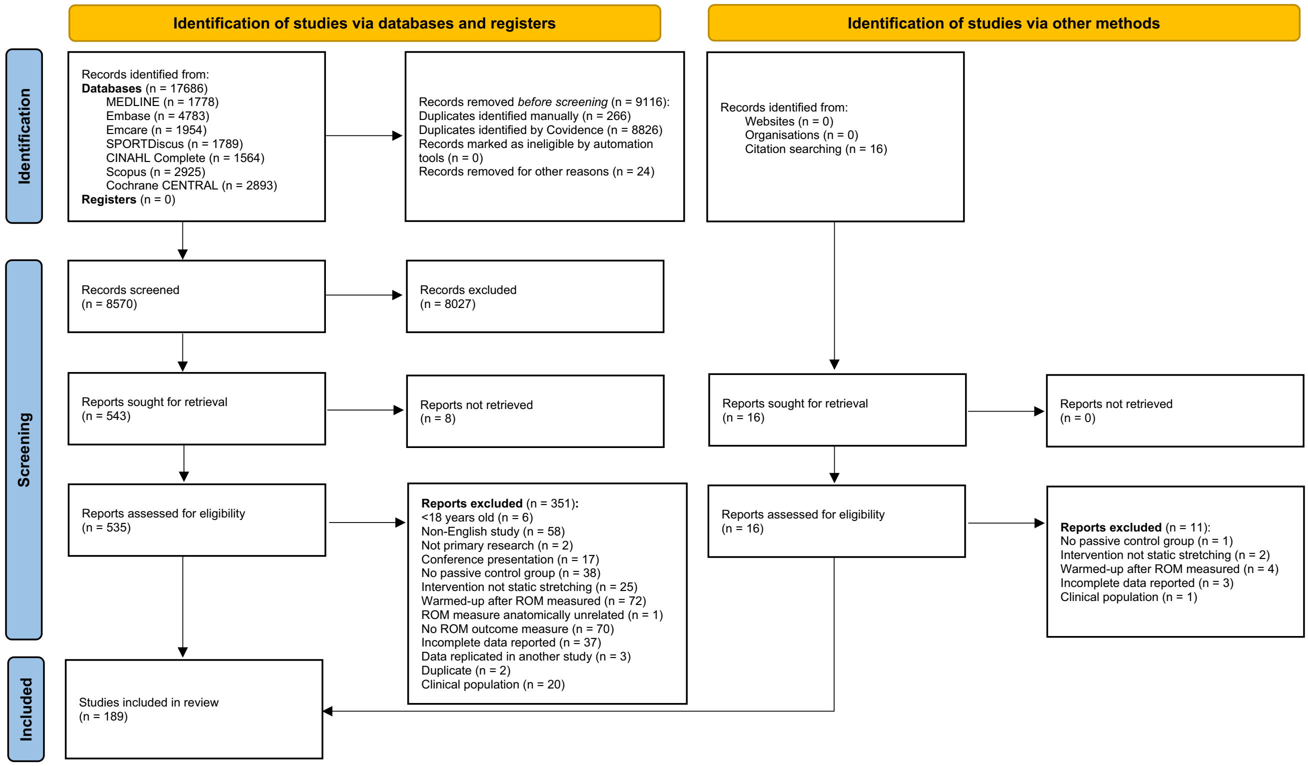

Fig. 1 Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flowchart showing the different stages of the search and study selection process

A median [interquartile range of 1 (1–1)] stretching exercise, held for 30 (30–60) s, repeated for 3 (1–4) sets per exercise, for a total of 2.5 (1.5–5) min was performed per session. For studies examining the effects of chronic static stretching, the median (interquartile range) intervention duration and frequency was 6 (4–8) weeks and 5 (3–7) sessions per week, respectively. Of these studies, only 26% ($n = 28$) described participant compliance, which averaged 92% (range 68–100%). The characteristics of the stretching interventions can be found in Appendices S3 and S4 of the ESM.

3.3 Risk of Bias in Studies

Risk of bias for individual studies is summarised in Appendix S5 of the ESM. The mean adjusted PEDro score of the 189 included studies was 4.0 ± 1.1 out of 7, with scores that ranged from 1 to 7. Eighteen studies (10%) were rated as having excellent methodological quality, 41 studies (22%) as good, 75 studies (40%) as moderate and the remaining 55 studies (29%) as poor. The main methodological limitations were a lack of concealed allocation (89% [$n = 169$]), an inadequate follow-up (59% [$n = 111$]), and no intention-to-treat analyses (90% [$n = 171$]).

3.4 Synthesis of Results

3.4.1 Acute Analysis

Collectively, acute static stretching had a significant moderate effect on flexibility ($g = 0.63$, 95% CI 0.52–0.75, $p < 0.001$). There was moderate heterogeneity between studies [Q ($df = 106$) = 254, $p < 0.001$; $I^2 = 51\%$] (Appendix S6 of the ESM). There was negligible between ($\tau^2 < 0.0$) and within ($\sigma^2 = 0.2$) variability due to a sampling error. Subgroup analyses are presented in Table 1. Effects did not significantly differ by stretch intensity ($p > 0.05$). However, stretching of the spine elicited a smaller increase in ROM than stretching of the hamstrings ($g = -0.48$, 95% CI $-0.93, -0.03$, $p = 0.04$), while those participants with average baseline flexibility had smaller improvements than those with poor baseline flexibility ($g = -0.43$, 95% CI $-0.67, -0.19$, $p < 0.001$). No subgroup analysis was performed for age as only two studies investigated acute static stretching in those with a mean age of 65 years and older.

Inspection of funnel plots (Appendix S7 of the ESM) and results of Egger's test indicated potential publication bias (intercept = 1.7, $p < 0.001$), and our evaluation of standardised residuals identified seven outliers [51, 52, 55, 56, 58, 63, 237]. Following the removal of the seven outliers, the

Table 1 Subgroup analysis examining the effects of stretch intensity, body region (i.e. muscle group), sex, training status, baseline flexibility and trial type on acute static stretching interventions

Subgroup		Individual estimates		Between-condition comparison		GRADE
	n	*g* (95% CI)	*p* value	Difference *g* (95% CI)	*p* value	
Intensity						
Low intensity (reference group)	16	0.69 (0.40, 0.97)	< 0.001	Reference		Low
Moderate intensity	54	0.66 (0.48, 0.83)	< 0.001	− 0.03 (− 0.36, 0.30)	0.86	Low
High intensity	23	0.61 (0.38, 0.84)	< 0.001	− 0.08 (− 0.44, 0.29)	0.67	Very low
Intensity not reported	13	0.55 (0.24, 0.86)	< 0.001	− 0.14 (− 0.56, 0.28)	0.52	Low
Body region/muscle group						
Hamstrings (reference group)	49	0.72 (0.55, 0.88)	< 0.001	Reference		Very low
Ankle plantar flexors	29	0.62 (0.42, 0.83)	< 0.001	− 0.10 (− 0.36, 0.17)	0.48	Moderate
Shoulder	5	0.53 (0.02, 1.04)	0.04	− 0.19 (− 0.73, 0.34)	0.48	Low
Hip	7	0.73 (0.31, 1.15)	< 0.001	0.00 (− 0.44, 0.46)	0.97	Very low
Quadriceps	8	0.45 (0.01, 0.89)	0.04	− 0.27 (− 0.73, 0.19)	0.24	Low
Spine	5	0.24 (− 0.18, 0.66)	0.26	− 0.48 (− 0.93, − 0.03)	0.04	Low
Distal extremities	3	0.72 (0.14, 1.30)	0.02	− 0.00 (− 0.60, 0.60)	0.99	Low
Sex						
Male (reference group)	34	0.73 (0.54, 0.91)	< 0.001	Reference		Low
Female	8	0.48 (0.06, 0.89)	0.02	− 0.25 (− 0.70, 0.20)	0.27	Low
Mixed	59	0.55 (0.42, 0.68)	< 0.001	− 0.18 (− 0.40, 0.05)	0.12	Low
Training status						
Sedentary (reference group)	5	0.82 (0.33, 1.32)	0.001	Reference		Very low
Recreationally active	23	0.58 (0.31, 0.85)	< 0.001	0.25 (− 0.81, 0.32)	0.39	Low
Trained	26	0.64 (0.40, 0.88)	< 0.001	− 0.19 (− 0.74, 0.36)	0.50	Very low
Athlete	9	0.30 (− 0.14, 0.74)	0.17	− 0.52 (− 1.18, 0.14)	0.12	Low
Baseline flexibility						
Poor (reference group)	25	0.94 (0.73, 1.14)	< 0.001	Reference		Moderate
Average/not reported	81	0.51 (0.38, 0.63)	< 0.001	− 0.43 (− 0.67, − 0.19)	< 0.001	Low
Trial type						
RCT	96	0.67 (0.55, 0.80)	< 0.001	Reference		Very low
CT	10	0.34 (0.03, 0.65)	0.03	− 0.34 (− 0.67, − 0.01)	0.04	Low

CI confidence interval, *CT* controlled trial, *RCT* randomised controlled trial

magnitude of acute static stretching on flexibility reduced to a significant small effect ($g = 0.49$, 95% CI 0.42, 0.57, $p < 0.001$), with negligible between-study heterogeneity [Q ($df = 98$) = 77, $p = 0.95$; $I^2 = 0\%$], and between ($\tau^2 < 0.0$) and within ($\sigma^2 = 0.0$) study variability due to a sampling error. There was no association between PEDro score and effect size estimates ($g = 0.03$, 95% CI − 0.06, 0.11, $p = 0.50$), and non-randomised controlled trials reported smaller increases in ROM than RCTs ($g = -0.34$, 95% CI − 0.67, − 0.01, $p = 0.04$).

A cubic model with three knots was the best fitting for the relationship between stretching volume and increases in flexibility (Fig. 2). For this analysis, we removed the study by Ateş et al. [84] because of being a clear visual outlier on the regression plots. We found significant residual heterogeneity [QE ($df = 102$) = 181, $p < 0.001$] and the test of moderators for the spline terms was not significant [QM ($df = 2$) = 3.0,

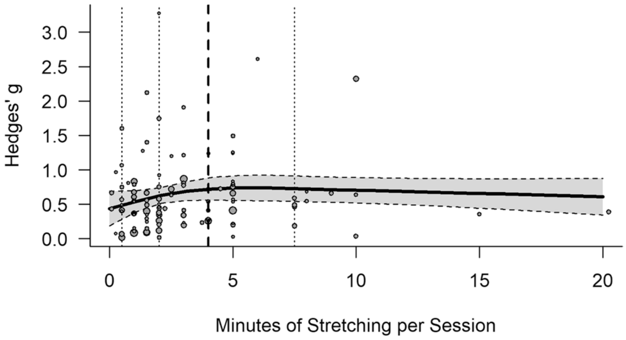

Fig. 2 Cubic spline regression model depicting the non-linear relationship between stretching volume (minutes per session) and acute increases in flexibility. The thin dashed vertical lines depict the knot placements of 1, 2 and 8 min. The thick dashed vertical line represents the threshold at which acute increases in flexibility are maximised. The shaded area depicts the 95% confidence interval

$p = 0.22$]. Inspection of the fitted curve suggested that acute increases in flexibility peaked at 4 min of static stretching per session.

3.4.2 Chronic Analysis

Overall, chronic static stretching had a significant large effect on flexibility ($g = 0.96$, 95% CI 0.84, 1.09, $p < 0.001$). We found evidence for substantial heterogeneity between studies [Q ($df = 147$) $= 396$, $p < 0.001$; $I^2 = 62\%$) [refer to Appendix S8 of the ESM]. There was negligible between ($\tau^2 = 0.0$) and within ($\sigma^2 = 0.3$) variability due to a sampling error. Subgroup analyses are presented in Table 2. Effects did not differ significantly by stretch intensity, body region, baseline flexibility status, intervention duration, age, sex, training status or trial type (Table 2; all p values > 0.05). However, individuals with normal baseline flexibility observed smaller improvements in ROM than those with poor baseline flexibility levels ($g = -0.34$, 95% CI − 0.59, − 0.08, $p = 0.01$). Weekly session frequency did not significantly impact flexibility ($g = -0.001$, 95% CI − 0.04, 0.03, $p = 0.95$).

Inspection of funnel plots (Appendix S9 of the ESM) and results of Egger's test indicated potential publication bias (intercept = 2.1, $p < 0.001$), and we identified seven outliers from six studies [48, 53, 61, 62, 69, 70]. A significant large effect of chronic static stretching on flexibility remained after removal of the eight outliers ($g = 0.87$, 95% CI 0.77, 0.97, $p < 0.001$), with reduced (i.e. moderate) between-study heterogeneity [Q ($df = 140$) $= 251$, $p < 0.001$; $I^2 = 46\%$]. There was negligible between ($\tau^2 = 0.0$) and within ($\sigma^2 = 0.1$) variability due to a sampling error. There was no association between PEDro score and effect size estimates ($g = -0.02$, 95% CI − 0.11, 0.08, $p = 0.70$).

A cubic model with four knots was the best fitting for the relationship between weekly stretching volume and increases in flexibility (Fig. 3). We found significant residual heterogeneity [QE ($df = 144$) $= 357$, $p < 0.001$]. The test of moderators for the spline terms was significant [QM ($df = 3$) $= 10.0$, $p = 0.02$], as were all spline coefficients ($p < 0.05$). Inspection of the fitted curve showed no notable increases in flexibility beyond 10 min of static stretching per week.

3.5 Certainty of Evidence

GRADE certainty of evidence assessments for both main effects and all subgroup analyses are shown in Appendix S10 of the ESM. Regarding the main effects, the certainty of evidence for both the acute and chronic analyses was first downgraded one level for the risk of bias, another level for potential publication bias and downgraded an additional level for inconsistency of results. The level of evidence was then upgraded for both analyses for the presence of a dose response, with the chronic analysis further upgraded for a large magnitude of effect. Therefore, the certainty of evidence for both the acute and chronic analyses was low and moderate, respectively.

4 Discussion

Upon the systematic review and meta-analysis, we found that acute and chronic static stretching resulted in significant moderate and large improvements in flexibility, respectively. Neither the acute nor chronic improvement was moderated by stretch intensity, age, sex, participant training status, or weekly session frequency and intervention length (chronic static stretching only). Less flexible individuals showed greater immediate and longer term increases in ROM compared with those with average levels of flexibility, while greater immediate improvements were observed when stretching the hamstrings compared with stretching the spine. At present, according to the included and available literature, the benefits of static stretching on flexibility were optimised at a cumulative stretching volume of 4 min per session (acute) and 10 min per week (chronic). This information provides therapists and coaches with effective and efficient parameters to adopt when prescribing static stretching to improve flexibility.

4.1 Magnitude of Change

Our finding of a large improvement in flexibility from longer term static stretching interventions is comparable to effects reported in previous systematic reviews and meta-analyses [11, 12, 26, 27]. Both Arntz et al. [27] and Konrad et al. [28] found a large improvement in flexibility from both chronic static stretching alone and static stretching plus dynamic, ballistic or proprioceptive neuromuscular facilitation stretching, respectively, while Thomas et al. [12] found moderate-to-large improvements for static stretching, active stretching and passive stretching interventions. Reviews focusing on single muscle groups have also reported large improvements in flexibility for the hamstrings [26] and ankle plantar flexors [11] following static stretching.

With respect to acute interventions, to our knowledge, the only other meta-analysis investigating changes in flexibility following acute static stretching reported a larger improvement ($d = 0.91$; 95% CI 0.71, 1.10; $p < 0.001$) compared with that of the current study [238]. However, because Shah et al.'s [238] primary aim was to investigate the effects of static stretching on neuromuscular properties rather than flexibility, flexibility data from only 23 studies met their inclusion criteria compared with the 73 studies in our current meta-analysis. Furthermore, they included studies where participants performed a warm-up after initial testing, which may have influenced the overall effect because any

Table 2 Subgroup analysis examining the effects of stretch intensity, body region (i.e. muscle group), age, sex, training status, baseline flexibility, intervention length and trial type on chronic static stretching interventions

Subgroup	*n*	Individual estimates		Between condition comparison		GRADE
		g (95% CI)	*p* value	Difference *g* (95% CI)	*p* value	
Stretch intensity						
Low intensity (reference group)	21	0.82 (0.47, 1.18)	< 0.001	Reference		Moderate
Moderate intensity	62	1.05 (0.86, 1.24)	< 0.001	0.22 (−0.17, 0.62)	0.26	Moderate
High intensity	34	0.84 (0.59, 1.09)	< 0.001	0.02 (−0.41, 0.45)	0.93	Moderate
Intensity not reported	31	1.01 (0.72, 1.31)	< 0.001	0.19 (−0.27, 0.65)	0.41	Low
Body region/muscle group						
Hamstrings (reference group)	84	1.06 (0.88, 1.24)	< 0.001	Reference		Moderate
Ankle plantar flexors	44	0.90 (0.69, 1.12)	< 0.001	−0.16 (−0.44, 0.12)	0.27	Moderate
Shoulder	10	0.92 (0.48, 1.36)	< 0.001	−0.14 (−0.62, 0.34)	0.56	Low
Hip	4	0.92 (0.24, 1.60)	0.01	−0.14 (−0.84, 0.56)	0.70	Low
Quadriceps	4	0.63 (−0.09, 1.35)	0.08	−0.43 (−1.17, 0.32)	0.26	Low
Spine	2	0.46 (−0.46, 1.39)	0.32	−0.60 (−1.54, 0.35)	0.21	Low
Age						
< 65 years (reference group)	133	0.99 (0.86, 1.13)	< 0.001	Reference		Moderate
65 years and older	10	0.92 (0.44, 1.39)	< 0.001	−0.08 (−0.57, 0.42)	0.76	Moderate
Sex						
Male (reference group)	37	1.16 (0.92, 1.39)	< 0.001	Reference		Moderate
Female	13	1.05 (0.67, 1.44)	< 0.001	−0.10 (−0.53, 0.32)	0.63	Moderate
Mixed	92	0.88 (0.72, 1.04)	< 0.001	−0.28 (−0.56, −0.01)	0.05	High
Training status						
Sedentary (reference group)	13	1.19 (0.79, 1.60)	< 0.001	Reference		Low
Recreationally active	40	0.85 (0.60, 1.10)	< 0.001	−0.34 (−0.82, 0.14)	0.16	Low
Trained	30	0.99 (0.72, 1.25)	< 0.001	−0.21 (−0.69, 0.28)	0.40	Moderate
Athlete	3	0.73 (−0.08, 1.54)	0.08	0.46 (−1.37, 0.44)	0.31	Very low
Baseline flexibility						
Poor (reference group)	57	1.19 (0.98, 1.40)	< 0.001	Reference		High
Average/not reported	91	0.86 (0.71, 1.00)	< 0.001	−0.33 (−0.59, −0.08)	0.01	Moderate
Intervention length						
< 4 weeks (reference group)	21	0.97 (0.67, 1.27)	< 0.001	Reference		Low
4–6 weeks	80	1.05 (0.86, 1.23)	< 0.001	0.07 (−0.28, 0.43)	0.68	Moderate
> 6 weeks	47	0.84 (0.63, 1.06)	< 0.001	−0.13 (−0.50, 0.24)	0.49	Moderate
Trial type						
RCT	122	0.99 (0.85, 1.14)	< 0.001	Reference		Moderate
CT	26	0.86 (0.60, 1.13)	< 0.001	−0.13 (−0.43, 0.17)	0.40	Moderate

CI confidence interval, *CT* controlled trial, *RCT* randomised controlled trial

physical activity that raises body temperature will increase flexibility [1, 239, 240], whereas we excluded such studies.

4.2 Frequency and Duration

To our knowledge, this is the first review to present dose–response thresholds for static stretching. Specifically, our multi-variate meta-regression suggests that stretching a single muscle group beyond 4 min within a single session or beyond 10 min over the course of a week leads to no further meaningful improvements in ROM. This is similar to other meta-analyses investigating the relationship between static stretching volume and flexibility improvements. Compared to less (< 5 min) training, Thomas et al. [12] found larger (albeit similar) improvements in flexibility for 5–10 min and 10 + minutes of static stretching per muscle group per week. Similarly, Arntz et al. [27] concluded that a longer static stretching duration was associated with larger improvements in flexibility. In contrast, Konrad et al. [28] found no association between flexibility outcomes and stretch duration. Unlike Thomas et al. [12], who found improved flexibility for longer (5 days) versus shorter (< 5 days) weekly session

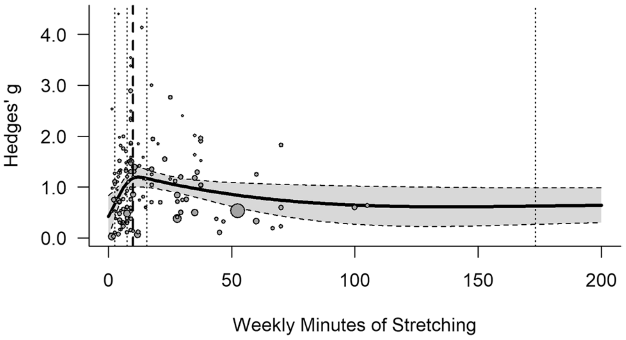

Fig. 3 Cubic spline regression model depicting the non-linear relationship between stretching volume (minutes per session) and acute increases in flexibility. The thin dashed vertical lines depict the knot placements of 3, 8, 16 and 173 min. The thick dashed vertical line represents the threshold at which chronic increases in flexibility are maximised. The shaded area depicts the 95% confidence interval

frequencies, both the current meta-analysis and the Konrad et al. [28] study found weekly session frequency was not associated with improved flexibility. This difference may be because Thomas et al. [12] examined weekly session frequency but did not consider the potential confounding effect of total stretching volume. Indeed, one of our included studies [49] found evidence that static stretching appears to be equally effective, whether performed daily or three times per week, provided individuals stretch at least twice a day. Similarly, Cipriani et al. [49] found that 7 min of static stretching per week was as beneficial as 14 min, both of which were more effective than 3.5 min/week. This is consistent with the 10 min/week (per muscle group) we identified as the optimal stretching dosage in this meta-analysis.

However, whether this optimal stretching dosage reflects a true physiological saturation point or merely reflects the current literature's bias towards studies with short stretching durations is unclear. Indeed, the median stretch duration of the included studies was 2.5 min per session and 12.5 min/week. Only recently have studies begun investigating the effect of extremely long stretching durations of up to 60 min/day on improvements in flexibility [64–68, 241]. Warneke et al. [68] found that statically stretching the ankle plantar flexors with an extended knee for 60 min/day led to significantly greater improvements in ankle dorsiflexion ROM when assessed in knee extension compared with 30 min and 10 min/day over a 6-week period. It has been proposed that such high-volume long-duration static stretching is necessary to elicit the morphological adaptations in the muscle–tendon unit that were elusive in earlier reviews [5, 15]. More studies investigating the effects of longer duration static stretching on flexibility are needed to increase the confidence in the dose–response relationship suggested by the current review and to identify the physiological mechanisms underpinning these improvements in flexibility.

4.3 Intensity

Like Arntz et al. [27] and Konrad et al. [28], we found that stretch intensity did not influence the magnitude of the improvement in flexibility. While this suggests that stretching beyond the point of discomfort or pain is unnecessary to improve flexibility, stretching at higher intensities may be required to elicit morphological changes within the muscle itself [15]. This is supported by evidence from a recent meta-analysis [15], which found that compared with low-intensity stretching, high-intensity chronic static stretching led to significant 'trivial' and 'small' increases in muscle fascicle length at rest and while stretching, respectively. Furthermore, four of the included studies specifically compared the effect of different stretching intensities, all reporting larger improvements for higher intensities [54, 57, 59, 60]. Nakumura et al. [59] found a significantly larger increase in dorsiflexion ROM when stretching the ankle plantar flexors at very high intensities over 4 weeks compared with very low intensities. Likewise, Melo et al. [57] reported significantly greater improvements in hamstring flexibility when stretching into 'mild discomfort' and 'pain' compared with 'comfort-level' stretching. Interestingly, there was no difference between 'mild discomfort' and 'pain', suggesting that stretching into pain may not be necessary. Oba et al. [60] quantified intensity by setting it at a specific percentage of each participant's maximum tolerable passive resistive torque (measured at baseline), finding the largest improvements following the 100% condition. Hatano et al. [54] reported greater increases in hamstring flexibility when stretching beyond the onset of pain compared with at the onset of pain.

A key limitation in understanding the influence of intensity on improvements in flexibility is that few studies have objectively quantified the force exerted on the stretched muscle. Most studies subjectively measure intensity based on perceived discomfort or pain [15]. Furthermore, terminology and definitions of intensity differed between studies, making it challenging to categorise with certainty. Like Arntz et al. [27], we categorised stretch intensity as low (below the level of discomfort), moderate (discomfort but below the level of pain) and high (stretching into pain). However, not all included studies operationalised intensity as perceived discomfort or pain; instead, they used vague terminology such as 'maximal range of motion' without further context. Moreover, ~ 20% of our included studies failed to mention stretch intensity. Future studies on static stretching should quantify intensity and report it with relevant descriptive terminology. While objective measures of intensity are desirable in the research setting [15], the clinical utility of such measures must be considered. Future studies should explore the association between objective measures of intensity, such as the percentage of maximal torque measured at baseline, with validated subjective scales of perceived exertion adapted for stretching, such as the Borg CR-10 scale [242, 243], the Scale of Perceived Exertion in Flexibility (PERFLEX) [57, 244], the Stretching Intensity Scale (SIS) [245] or the Verbal Numerical Scale (VNS) [246].

4.4 Other Moderators for Static Stretching

4.4.1 Baseline Flexibility

The subgroup analysis suggests that less flexible adults are more responsive to static stretching compared with adults with average flexibility. This is not surprising presuming that those who are more flexible are likely to be closer to their hypothetical "upper limit" of ROM, and therefore less likely to see large improvements. Although intuitive, the only included study that directly compared the chronic effects of static stretching between participants with 'limited' and 'normal' flexibility reported similar increases in passive straight leg raise following a 12-week intervention consisting of 9 min of hamstring stretching per week [48]. Given that there was no plateau observed in either group over the course of the 12 weeks, it is plausible that those in the 'normal' hamstring flexibility group had yet to reach their hypothetical upper limit. Importantly, it is unclear whether intensity was controlled for across both groups.

4.4.2 Training Status

In contrast, consistent with an earlier review [28], our subgroup analysis revealed no effect of training status on improvements in ROM following acute and chronic static stretching. Given the diverse flexibility requirements across different sports and activities, this is not surprising. For example, an elite gymnast and an elite distance runner could both be considered tier 5 'athletes' according to the Participant Classification Framework [236], but would likely display large discrepancies in flexibility given the contrasting physical demands of each sport. As such, it is more likely that stretching responses will differ by sporting demands, rather than competition level.

4.4.3 Muscle Groups

Although our subgroup analysis revealed a significantly larger effect for acute static stretching of the hamstrings compared with the muscles of the spinal column, there was no difference in effect size between the remaining muscle groups following acute and chronic static stretching. However, this acute response in the muscles of the spinal column may reflect a methodological limitation of the current review, in that our categorisation of 'spine' included three studies that stretched the cervical region and two studies that stretched the lumbar region—two anatomically distinct regions of the spine. Furthermore, the outcome measure used in both lumbar studies was the sit-and-reach test, which itself has questionable validity as a measure of lumbar spine ROM [247]. This is noteworthy as inspection of the forest plots (see Appendix S6 of the ESM) revealed that the summary effect was notably reduced by these two studies, suggesting that our finding may have been influenced by the choice of outcome measure. Indeed, we anticipated that some muscle groups would be more responsive to stretch-induced increases in flexibility because of differences in both the relative composition of structural properties that make up the muscle–tendon unit itself (i.e. higher collagen content in tendons should mean that muscles with longer tendons, such as the ankle plantar flexors, are less compliant than muscles with shorter tendons, such as the hamstrings) and the absolute physiological range available at the specific joint. The lack of a significant difference in responses between different muscle groups suggests that mechanisms underlying increased ROM following static stretching are not exclusively dependent on the mechanical and structural properties of the muscle–tendon unit and joints. Our findings are consistent with Konrad et al. [28] and Coratella et al. [50] who reported similar improvements in hip flexion, hip extension, ankle dorsiflexion and ankle plantar flexion ROM following a combined 3 min and 45 s of static stretching in each of the four muscle groups. Last, given that the hamstrings and ankle plantar flexors accounted for 80% ($n=151$) of the studies included in our review, further research on other muscle groups is needed to better understand muscle-specific adaptations to acute and chronic static stretching.

4.4.4 Sex

Although just falling short of significance, studies consisting of male-only cohorts demonstrated larger improvements in ROM following chronic static stretching compared with studies with mixed-sex cohorts. Given that female individuals on average are more flexible than male individuals [248–251], their presence in mixed-sex studies may bring the overall cohort closer to their hypothetical upper limit. Such sex differences have traditionally been attributed to musculoskeletal factors including differences in muscle mass, the shape of specific joints and the relative proportion of collagen within the muscle–tendon unit [1, 252], while more recent research has focused on the influence of the menstrual cycle [253, 254]. Interestingly, despite a smaller effect, there was no significant difference in response to long-term static stretching in female-only cohorts compared to male-only cohorts. This may, however, reflect the broader issue of female under-representation in medical research with more than three times as many male-only cohort studies included in the current review. Furthermore, the female-only studies contained a disproportionally higher number of participants with limited flexibility compared with the male-only studies, potentially negating any inherent sex-specific baseline differences. Surprisingly, Konrad et al. [28] reported significantly larger effect sizes in female-only studies compared with male-only studies. However, their review also included ballistic, dynamic and proprioceptive neuromuscular facilitation stretching with static stretching. It is possible that female individuals are more responsive than male individuals to these other stretching techniques. Nevertheless, the only included study directly comparing responses between sexes found significantly larger increases in ankle dorsiflexion ROM in male individuals than female individuals following 60 min of daily high-intensity static stretching of the ankle plantar flexors over 6 weeks [66].

4.4.5 Age

Subgroup analyses failed to show any difference in response to chronic static stretching between younger adults (aged $<$ 65 years) and older adults (aged $\geq$ 65 years). This was surprising given that older adults tend to be less flexible because of age-related increases in connective tissue, particularly collagen [72, 255]. However, the extent to which this decline in flexibility associated with aging is confounded by the more sedentary lifestyle often observed in older adults remains controversial. It is possible that the older adults who participated in the studies included in our review were, on average, more physically active than others of similar age. However, any inferences as to whether this may be the case are limited given that three out of the seven included studies investigating chronic static stretching in older adults failed to report any information regarding their level of physical activity. Furthermore, we were unable to perform a subgroup analysis for age for acute static stretching as only two studies included participants aged 65 years and over. This underscores the need for further research in older adults.

4.4.6 Intervention Length

Interestingly, we found no difference in the magnitude of response between chronic static stretching interventions of different lengths. One of the main reasons people stretch is to increase their flexibility [5]. Indeed, flexibility is the most ubiquitous outcome measure used to determine the effectiveness of stretching interventions [10–13]. However, the mechanisms underpinning improvements in flexibility following static stretching remain controversial. Responses to acute static stretching have been attributed to transient changes in neuromuscular factors, such as muscle spindle sensitivity [1, 256, 257], musculotendinous compliance [258–260] and an increased stretch tolerance [5, 14, 261], whereas chronic stretching is thought to elicit morphological adaptations such as sarcomerogenesis [262] and changes in fascicle length [15]. It could be that these purported acute responses account for a relatively larger proportion of the flexibility improvements from static stretching, while the latter morphological changes contribute to a lesser extent. More research is needed to identify the mechanisms by which short-term and long-term stretching improves flexibility.

4.5 Call for Action for Future Research

Throughout this systematic review process, we identified several common inconsistencies in reporting standards. To facilitate between-study comparisons and future data pooling efforts, we propose a checklist for prospective authors and reviewers to consult prior to publishing future flexibility-focused research in Table 3.

4.6 Limitations

A limitation of the current study is that while the muscle group was considered when examining the effects of static stretching on flexibility, data on the stretching exercises used were not considered because of high between-study variability. While it is possible that certain stretching exercises were more effective at increasing the flexibility of specific muscle groups than others, we were unable to examine this. Similarly, though it is possible that some tests were more responsive to intervention than others, we did not account for test specificity in our meta-analysis. Additionally, although every effort was made to classify stretching intensity, poor reporting among the included studies made this challenging. As such, the intensity subgroup analysis may not truly reflect the impact of stretch intensity on flexibility. Our inclusion of only English language studies may have meant that we missed relevant studies published in other languages. However, limiting systematic reviews to English language studies appears to minimally impact effect estimates and conclusions [31, 263]. Last, it is important to reiterate that these recommendations apply only to improving flexibility. Whether static stretching improves performance or mitigates injury risk remains controversial and is beyond the scope of the current review.

Table 3 Proposed checklist for prospective authors and reviewers to consult prior to publishing flexibility-focused research

Population	Intervention	Comparison	Outcome
Sufficiently describe relevant participant characteristics:	Sufficiently describe:	Sufficiently describe any specific protocol(s) followed by any comparison group(s):	Sufficiently describe the device, protocol and reporting metric used for the flexibility outcome:
The number of participants, sex and mean (± SD) age for each study (intervention/control) group Their training status (i.e. sedentary, recreationally active or trained), baseline level of flexibility (i.e. limited, normal) and health status	Whether the intervention was unilateral or bilateral. If unilateral, identify the side stretched Whether a warm-up preceded any stretching interventions Stretching intensity using unambiguous terminology Whether constant-angle or constant-torque static stretching was used For chronic studies, whether stretching sessions were supervised or unsupervised For chronic studies, participant compliance	Refer to the criteria outlined for under 'intervention'	The make and model of the measurement device, testing procedure and the test–retest reliability of the procedure The number of trials performed, whether the maximum or average score was calculated How maximal range of motion was determined (i.e. was it defined as the first sensation of stretch, the onset of discomfort, or at the onset of pain?) Whether the flexibility assessment was performed actively by the participant or passively by the assessor Descriptive statistics for both the right and left sides independently and collectively Whether a warm-up preceded any measurements The duration between the final stretch (acute studies) or stretching session (chronic studies) and the post-intervention flexibility assessment

SD standard deviation

4.7 Practical Applications

Our meta-analysis indicates that acute and chronic static stretching resulted in moderate and large increases in flexibility, respectively. Results of our meta-regression analysis suggest that for immediate short-term improvements in flexibility, coaches and therapists should prescribe a cumulative total of 4 min of static stretching per muscle group. For long-term improvements in flexibility, 10 min per muscle group per week are needed to maximise the benefits, irrespective of the number of weekly sessions. Furthermore, stretching beyond the point of discomfort or pain is unnecessary for increased flexibility. These guidelines can be applied broadly as they do not appear to be moderated by participant age, sex or training status. Although these guidelines are based on the best evidence that is currently available, it is anticipated that these may change in response to future higher quality research that considers the shortcomings listed in Table 3.

5 Conclusions

Static stretching exercise leads to moderate immediate improvements in flexibility, while static stretch training leads to large longer term improvements. To maximise improvements in flexibility, 4 min per muscle group within a single session and 10 min per muscle accumulated over a week are recommended. It appears that these recommendations are not moderated by stretch frequency, intensity, age, sex or participant training status, while less flexible individuals show greater immediate and longer term improvements in ROM than those with average levels of flexibility. These general guidelines can be used by coaches and therapists to prescribe static stretching exercise or training for improving flexibility.

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Declarations

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Consent to participate Not applicable.

Consent for publication Not applicable.

Availability of data and material The data and materials necessary to reproduce the findings reported in this article are available at https://osf.io/eh537/.

Code availability Not applicable.

Authors' contributions LI, GT and HB contributed to the conception and design of the review and meta-analysis. LI and HB performed the initial search of databases. LI, GT, ND, BG, SG and HB screened and selected the eligible studies. LI performed the data extraction, which was verified by ND. LI and ND assessed the risk of bias of the included studies. LI and HB performed the GRADE analysis. HB performed the statistical analysis, which was verified by TB. LI, GT and HB drafted the manuscript. All authors reviewed, provided critical revisions, refined and approved the final manuscript.

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