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SYSTEMATIC REVIEW

# REVISED Effects of stretching exercises on human gait: a systematic review and meta-analysis [version 2; peer review: 2 approved, 1 approved with reservations]

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## Abstract

**Background:** Stretching is commonly used in physical therapy as a rehabilitation tool to improve range of motion and motor function. However, is stretching an efficient method to improve gait, and if so, for which patient category?

**Methods:** A systematic review of randomized and non-randomized controlled trials with meta-analysis was conducted using relevant databases. Every patient category and every type of stretching programs were included without multicomponent programs. Data were meta-analysed where possible. Estimates of effect sizes (reported as standard mean difference (SMD)) with their respective 95% confidence interval (95% CI) were reported for each outcome. The PEDro scale was used for the quality assessment.

**Results:** Twelve studies were included in the analysis. Stretching improved gait performance as assessed by walking speed and stride length only in a study with a frail elderly population, with small effect sizes (both SMD= 0.49; 95% CI: 0.03, 0.96; PEDro score: 3/10). The total distance and the continuous walking distance of the six-minute walking test were also improved only in a study in an elderly population who had symptomatic peripheral artery disease, with large effect sizes (SMD= 1.56; 95% CI: 0.66, 2.45 and SMD= 3.05; 95% CI: 1.86, 4.23, respectively; PEDro score: 5/10). The results were conflicting in healthy older adults or no benefit was found for most of the performance, spatiotemporal, kinetic and angular related variables. Only one study (PEDro score: 6/10) showed improvements in stance phase duration (SMD=-1.92; 95% CI: -3.04, -0.81), swing phase duration (SMD=1.92; 95 CI: 0.81, 3.04), double support phase duration (SMD= -1.69; 95% CI: -2.76, -0.62) and step length (SMD=1.37; 95% CI: 0.36, 2.38) with large effect sizes.

**Conclusions:** There is no strong evidence supporting the beneficial

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effect of using stretching to improve gait. Further randomized controlled trials are needed to understand the impact of stretching on human gait.

**Keywords**
stretching, gait, performance, balance, physical therapy

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Any reports and responses or comments on the article can be found at the end of the article.

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**REVISED** **Amendments from Version 1**

We have added a whole paragraph at the beginning of the introduction section to specify how gait can be related to the different variables seen in the review.

No article in children with cerebral palsy fitted our inclusion criteria during the systematic search of the literature. We have added a whole paragraph in a specific section "limitations of the study" for explain it.

We have added some precisions in the discussion section (healthy older adults paragraph) to specify how we have limited the risk of bias.

We have added some precisions in the discussion section (young adults paragraph) to specify why stretching is less interesting to improve gait parameters in young healthy adults.

**Any further responses from the reviewers can be found at the end of the article**

## Introduction

Gait is the medical term used to describe the human whole body movement of walking[1]. Gait involves internal and external forces that act on the body to move the center of mass (COM) across a given distance[2]. It depends on many biomechanical features that can be observed during gait analysis such as center of mass shift, joint range of motion (ROM), forces, muscle activity, joint moments, and joint powers[3]. Spatiotemporal features (e.g. velocity, step length, stride length, step with, step variability) and kinematics parameters (ROM) can be observed subjectively with functional evaluations by clinicians (e.g. the Tinetti test[4] or the timed up and go test[5]), but, it can be further objectified with biomechanical analysis in a laboratory[2]. Kinetics variables (the forces that cause the body to move) must be collected in a laboratory environment with force plates (e.g. 6–9 for recent studies that used this technic).

Gait is a highly complex motor skill that is classically considered as an integrative measure and a predictor of health in older adults (e.g. 10; cf. 11 and also 12 for recent research topics on this matter). The loss of gait or its alteration with pathological conditions are known to be related to mortality, especially in the elderly (e.g. 13,14), stressing the importance of addressing gait disorders in physiotherapy. Gait requires body propulsion and balance control for safe progression, two "subtasks" that require the coordination of multiple skeletal muscles and the integration of sensory information arising from the vestibular, visual and somatosensory systems[15–17]. As such, gait may expose populations with sensory or motor deficits to the risk of falling with serious consequences for health and autonomy. For these reasons, improving gait is a major aim in rehabilitation for most neurological/orthopaedic disorders, such as stroke or Parkinson's disease, and for frail older adults. Various therapeutic methods have been used to improve gait, such as resistance training[18], endurance training[19], balance training[20], whole body vibrations (for a complete review, see Fischer *et al.*, 2019[21]), multi-component exercise programs[22] and stretching[23].

The successful completion of numerous daily life activities is conditioned by the ability to move efficiently through a sufficient ROM[24]. Recent studies on gait initiation[25–27] and seat-to-stand task[28,29] showed that the experimental restriction of postural chain ROM induced by orthosis wear in young healthy adults led to instability and lower motor performance. It is well established that ROM significantly decreases with aging[30–35] and more generally with reduced functional demand (e.g. sedentarity, immobilization, disease etc.)[24]. Consequently, stretching has become an important part of many sport and rehabilitation programs to maintain or improve ROM, reduce stiffness and promote physical activity. This method has been applied in older adults[36,37], patients with stroke[38], Parkinson's disease[39], multiple sclerosis[40], plantar fasciitis[41] and spastic paraplegia[42], for example. In sport programs, the influence of stretching on motor performance remains an issue of debate, although recent reviews conclude that maximal muscle performance (e.g. force, power, jump height, reaction time, etc.) is impaired primarily immediately after long durations of stretch (>90 seconds)[43,44]. To date, no review has collected results on the relationship between stretching and locomotor performance in rehabilitation programs.

Hence, the purpose of this article is to analyse the effects of a stretching program on gait in each patient category by means of a systematic literature review and meta-analysis, comparing the gait outcomes of the intervention groups with the control groups. It will contribute to provide evidence-based practice from scientific data in order to integrate stretching in rehabilitation programs in a reasoned manner.

## Methods

### Design and literature screening

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology was employed in this systematic review[45]. A completed PRISMA checklist was submitted to an online repository (*Reporting guidelines)*.

PubMed, Science Direct, Springer and Sage databases were used for a comprehensive systematic literature search for articles published prior to 28 April 2020 with no time limit. In addition, a manual search was conducted using the reference list of selected studies. The keywords used for the search strategy in PubMed were: "stretching" AND (gait OR walk). We included only articles published in English or French.

The selection procedure was conducted by two experts in rehabilitation (TV and AD). Disagreements were discussed with a third expert in a group until a mutual consensus was reached. First, a review was performed on all available titles obtained from the literature search with the selected keywords. All relevant or potentially relevant titles were included in the subsequent phase. Then, the abstracts were reviewed with all relevant or potential articles included in the following phase. Finally, full-text articles were reviewed to ensure that only relevant studies were included. In the same way, reference lists of all included articles were reviewed to possibly include articles through cross-referencing.

### Inclusion and exclusion criteria

We included randomized controlled trials (RCT) and controlled clinical trials (CCT) published in peer-reviewed journals that aimed to explore the effects of stretching on gait parameters.

We included all categories of subjects, all stretching techniques and different durations of treatment since standardized protocols are lacking in the purpose of the present study. Gait could be evaluated by functional tests, electromyographic (EMG) or biomechanical analysis. The following exclusion criteria were used: lack of gait assessment, non-application of muscle stretching, multimodal exercise programs, no control group, case report and review.

### Data extraction and main measurements examined
Data were extracted from the selected articles by one of the authors (TV). The extracted data were checked by another author (AD) and disagreements were resolved with a third (EY).

The following data were extracted for each selected article: (1) the names of the authors and the date of publication; (2) the number of subjects involved in the experiment with their characteristics and breakdown in each group; (3) stretching training details (in the following order: number of participants, stretching technique, muscle groups stretched, number of sets, duration of stretch, frequency, protocol duration); (4) control group details; and (5) the main outcomes related to gait with the main results. When information could not be provided, it was indicated by a "?".

### Quality and risk of bias assessment
The PEDro scale was used to assess the risk of bias, and thus the methodological quality of the selected studies[46]. This scale was chosen for its ability to provide an overview of the external (criterion 1), internal (criteria 2–9) and statistical (criteria 9 and 10) validity of clinical trials. The scale is divided into 11 criteria, but the first is not calculated in the total score. The output of each criterion could be either "yes" (y), "no" (n) or "do not know" (?). A "y" was given a score of one point, while an "n" or "?" was assigned zero points. Studies with a total score of 5–10/10 (≥ 50%) were considered to be of high quality, and scores of 0–4/10 (<50%) of low quality[47]. Two evaluators independently assessed the quality of the included studies. In the event of disagreement, a group discussion was held with a third expert to reach a consensus.

### Statistical analysis
Estimates of effect sizes (comparing the intervention group and the control group) accompanied with a measure of statistical uncertainty (95% confidence interval [95% CI]) were calculated for each outcome when sufficient data were reported. Estimates of effect sizes were reported by standard mean difference (SMD) and their respective 95% CI. In this way, the magnitude of the overall effect can be quantified as trivial (<0.2), small (0.2–0.49), moderate (0.5–0.79) or large (≥0.8)[48,49]. When data were lacking to calculate estimates of effect sizes, exact p values were reported.

When at least two studies used the same outcome, meta-analysis was performed, comparing the intervention groups with the control groups. When outcomes were identified in only one study, no meta-analysis could be performed but the effect of intervention was still calculated, reporting the estimate of effect size and its 95% confidence interval. Statistical analysis and figures (i.e. forest plot to facilitate the visualization of values) were produced using a random-effect model in Review Manager software (RevMan, v 5.3, Cochrane Collaboration, Oxford UK). A random-effect model was used to take into account heterogeneity between study effects. Statistical heterogeneity was calculated using the $I^2$ and Cochrane Q statistic tests[48]. Statistical significance was set at $p<0.05$.

### Level of evidence
The strength of evidence of primary outcomes was established as described by Van Tulder *et al.* 2003[50] based on effect size estimates with a measure of statistical uncertainty (SMD; 95% CI), statistical heterogeneity ($I^2$) when applicable (multiple studies) and risk of bias (PEDro scale). The level of evidence was considered strong with consistent findings among multiple high-quality RCT (at least two RCT with a PEDro score ≥5/10 that were statistically homogenous: $I^2$ p≥0.05). The level of evidence was considered moderate with consistent findings among multiple low-quality RCT and/or CCT (two trials with a PEDro score <5/10 that were statistically homogenous) and/or one high quality RCT. The level of evidence was considered limited when only one low quality RCT and/or CCT was identified. The level of evidence was conflicting when there was inconsistency among multiple trials ($I^2$ $p < 0.05$).

## Results
### Included studies
A total of 821 titles were screened in the first search stage, one more was included through cross-referencing, and 671 were excluded because they did not concern our research question. Following exclusion, 150 studies were considered for an abstract review. A further 105 were excluded in this second stage because they did not meet the inclusion criteria. Finally, 45 full-text articles were assessed for eligibility with 33 not accepted (Figure 1).

Thus, 12 articles were ultimately included in this systematic review. Six studies evaluated the effects of stretching in healthy older adults[23,51–55], one in a frail elderly population[56], one study in an elderly population with stable symptomatic peripheral artery disease[57], one in stroke patients[58], one study in adults with limited ankle ROM associated with a history of lower limb overuses injury[59], one study in healthy adults with limited ankle dorsiflexion[60] and one in healthy young adults[61]. A summary of the studies selected is provided in Table 1, and their quality assessment is reported in Table 2. The results in different patient categories are reported below.

### Results in different patient categories
***Healthy older adults***

**Description of the studies and quality assessment**

Six studies examined the effects of stretching on healthy elderly subjects[23,51–55]. Regarding the characteristics of the subjects, the average sample size was 46.6±33.9 subjects (ranging from 19[23] to 96 subjects[53]) and the mean age was 70.1±3.6 years (ranging from 65.40[52] to 75.30 years[23]). Regarding the characteristics of the training programs, the average training duration was 8.6±2.7 weeks (ranging from 4[52] to 12 weeks[54]), with an average frequency of 8.3±6.2 sessions per week (ranging from 2[54] to 14 sessions[51,53,55]). The average number of sets per

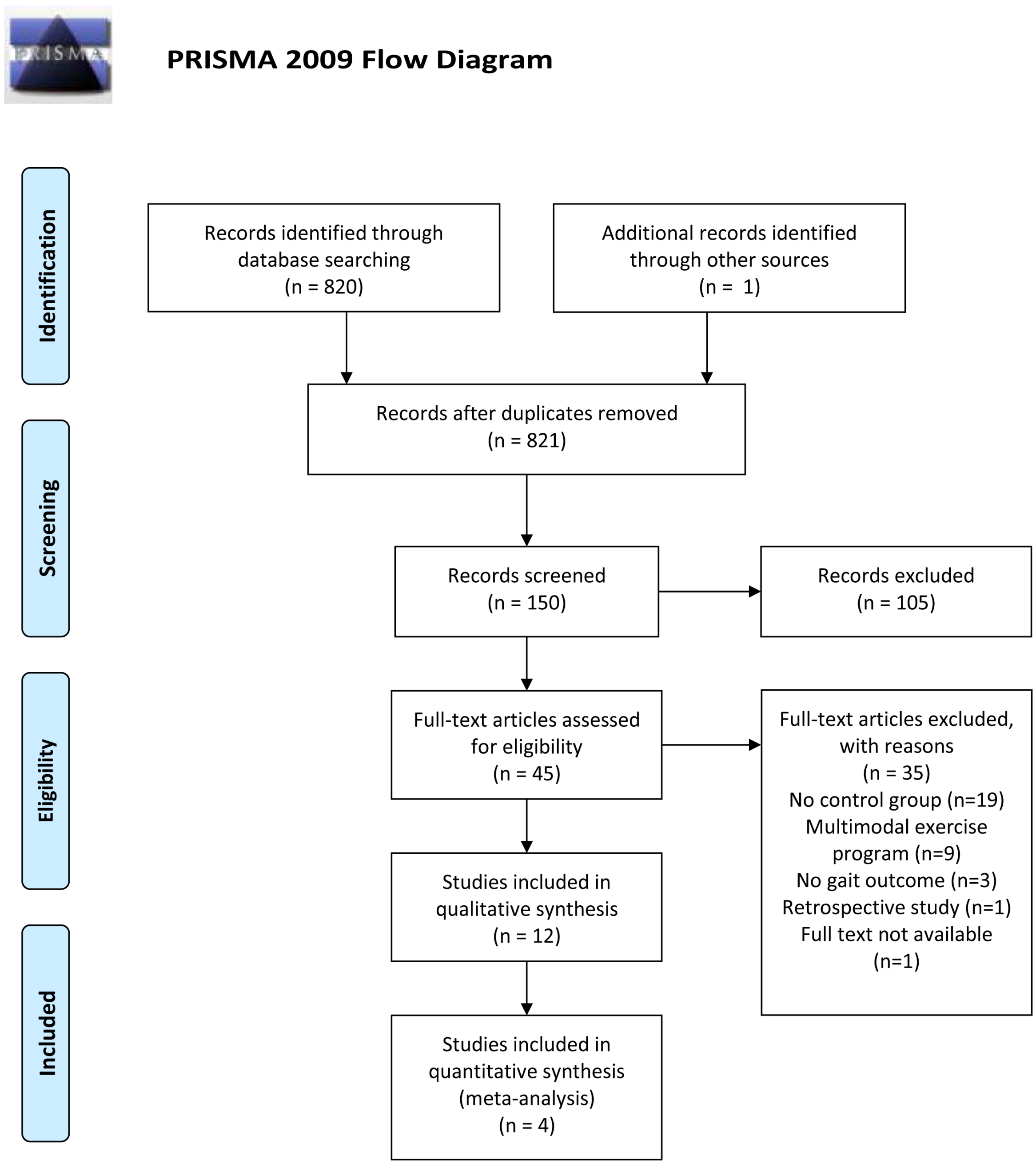


**Figure 1. PRISMA flow chart of study selection process.**

session was 4.5±2.8 sets (ranging from 2[55] to 10 sets[23]), with an average stretching time of 45.0±18.9 seconds (ranging from 15[23] to 60 seconds[52,54,55]). Static stretching was provided in all studies. The muscle groups stretched were the hip flexors[51–55], ankle plantar flexors[23,51,52,54], ankle dorsiflexors[54], hip extensors[52], knee extensors and flexors[54]. There was great heterogeneity in gait outcomes. Angular variables during gait included peak hip extension[51,53,55], ankle plantar flexion during gait[53], ankle ROM during gait[52], anterior pelvis tilt[52,55], knee ROM, pelvic rotation, lateral pelvic tilt and hip ROM[52]. Spatiotemporal variables were: gait speed[51,52,55], stance and swing duration, double support phases, step length[52] and stride length[52,55]. Kinetic variables were hip torque and ankle plantar flexion power[53]. Finally, two functional tests were used: the 10-meter walk test (10MWT)[23] and the 6-minute walk test (6MWT)[54]. Regarding the quality of the studies, the average PEDro score was 4.6±1.6 and one study was identified as a non-randomized trial[54]. The range of score varied from 3[54,55] to 7[23].

**Table 1. Summary of the included studies.**

| Studies | Population | Stretching group | Control group | Outcomes and main results |
|---|---|---|---|---|
| Kerrigan *et al.*, 2003[53] | 96 healthy older adults, ? (≥65 years) | n= 47, static stretching, hip flexors, 4 sets, 30 seconds, twice daily, 10 weeks | n=49, static shoulder deltoid-stretching, same protocol | No significant difference between groups for hip extension (SMD= 0.22; 95% CI: -0.18, 0.62), hip torque (SMD= 0.35; 95% CI: -0.06, 0.75), anterior pelvic tilt (SMD= -0.35 ; 95% CI : -0.76, 0.05), ankle plantar flexion ROM (SMD= -0.05, 95% CI : -0.45, 0.35), ankle plantar flexion power (SMD= 0.00 ; 95% CI : -0.40, 0.40), hip extension (SMD= 0.22 ; 95% CI : -0.19, 0.62) and hip torque (SMD= 0.35; 95% CI: -0.06, 0.75) |
| Gajdosik *et al.*, 2005[23] | 19 community dwelling older women, ? (65–89 years) | n=10, static stretching, ankle plantar flexors, 10 sets, 15 seconds,<br>3 times per week, 8 weeks | n=9, no exercise. | No significant difference between groups for 10MWT (SMD= -0.76; 95% CI: -1.70, 0.18) |
| Christiansen, 2008[51] | 40 healthy older adults, 72.10±4.70 years | N= 20, static stretching, hip flexors, 3 sets, 45 seconds, twice daily, 8 weeks | n=20, maintain their current level of physical activity | No significant difference between groups for gait speed (SMD= -0.32; 95% CI: -0.97, 0.33), hip extension (SMD= 0.22; 95% CI: -0.43, 0.86), stride length (SMD= - 0.14 ; 95% CI : -0.79, 0.50), ankle dorsiflexion (SMD= 0.29 ; 95% CI : -0.36, 0.94) |
| Cristopoliski *et al.*, 2009[52] | 20 healthy elderly women, 65.90±4.20 years | n=12, static stretching, hip flexors and extensors, ankle plantar flexors, 4 sets, 60 seconds, 3 sessions per week,<br>12 sessions | n=8, no specific activity in this period | Significant improvement in favor of stretching group for gait speed (SMD= 1.32 ; 95% CI : 0.32, 2.32), anterior pelvic tilt (SMD= -2.52 ; 95% CI : -3.77, -1.27), stand phase duration (SMD= -1.92; 95% CI: -3.04, -0.81), swing phase duration (SMD= 1.92 ; 95% CI : 0.81, 3.04), double support phase duration (SMD= -1.69; 95% CI: -2.76, -0.62), step length (SMD= 1.37 ; 95% CI : 0.36, 2.38) and pelvic rotation (SMD= 1.37 ; 95% CI : 0.36, 2.38)<br>No significant difference between groups for cycle duration (SMD= - 0.24 ; 95% CI : -1.14, 0.66), heel-contact velocity (SMD= -0.46 ; 95% CI : -1.37, 0.45), toe clearance (SMD= 0.91 ; 95% CI : -0.04, 1.86), lateral pelvic tilt (SMD= 0.93 ; 95% CI : -0.02, 1.88) and knee ROM (SMD= 0.23 ; 95% CI : -0.67, 1.12) |
| Watt *et al.*, 2011[55] | 82 healthy elderly subjects, 72,6±6 years | n= 43, static stretching, hip flexors, 2 sets, 60 seconds, 2 sessions daily stretching, 10 weeks | N= 39, shoulder abductor static stretching, same protocol | Significant improvement in favor of stretching group for gait speed (SMD= 0.47; 95% CI: 0.03, 0.91)<br>No significant difference between groups for hip extension (SMD= 0.18; 95% CI: -0.25, 0.62), anterior pelvic tilt (SMD=0.07 ; 95% CI : -0.36, 0.51), stride length (SMD= 0.54 ; 95% CI : -0.01, 1.08) |
| Locks *et al.*, 2012[54] | 23 healthy older individuals, 67.5±2.12 years | n=10, static stretching, knee extensors, ankle dorsiflexor, knee flexors, ankle plantar flexors, 4 sets, 60 seconds, twice a week ,12 weeks | n=13 a one-hour seminar on healthy living every four weeks and did not perform any physical or therapeutic exercise. | No significant difference between groups for 6MWT (SMD= -0.04; 95% CI : -0.86, 0.79) |
| Watt *et al.*, 2011[56] | 74 frail elderly subjects, 77.00±8.00 years | n=33, static stretching, hip flexors, 2 sets, 60 seconds, 2 sessions per day, 10 weeks | n=41, shoulder abductor stretching program, same protocol | No significant difference between groups in peak hip extension, (SMD= 0.22; 95% CI: -0.24, 0.68), anterior pelvic tilt (SMD= -0.05; 95% CI: -0.51, 0.41) and cadence (SMD= 0.13; 95% CI: -0.33, 0.59) Significant improvements in favor of the stretching group in walking speed and stride length (both SMD= 0.49; 95% CI: 0.03, 0.96) |

| Studies | Population | Stretching group | Control group | Outcomes and main results |
|---|---|---|---|---|
| Hotta *et al.*, 2019[57] | 13 elderly patients with symptomatic peripheral artery disease, ? | n= 13, static stretching, ankle plantar flexor stretching, 1 set, 30 minutes, 5 sessions per week, 4 weeks | n= 13, no stretching intervention (cross-over intervention) | Significant improvements in favor of the stretching group for both total walking distance and continuous walking distance with large effect sizes (SMD= 1.56; 95% CI: 0.66, 2.45 and SMD= 3.05; 95% CI: 1.86, 4.23 respectively) |
| Kim *et al.*, 2013[58] | 24 patients with stroke, 53.30±3.16 years | n=12, static stretching, ankle plantar flexors, 1 set, 20 minutes, 4 times a week, 4 times a week, 6 weeks | n= 12, conventional physical therapy as in in the stretching group | No significant difference between groups in sway of the center of pressure (SMD=0.75; 95% CI: -0.09, 1.58) |
| Johanson *et al.*, 2006[59] | 19 adults with limited passive ankle-dorsiflexion ROM (less than 8 degrees) and a history of lower limb overuse injury, 30.30± 9.80 years | n=11, static stretching, ankle plantar flexors, 5 sets, 30 seconds, 2 times daily, 3 weeks | n= 8, continue all of their usual activities | No significant difference between groups in ankle dorsiflexion during gait in both right and left ankle (SMD= 0.50; 95% CI: -0.42, 1.43 and SMD= 0.41; 95% CI: -0.52, 1.33 respectively) and for time-to-heel-off during the stance phase of gait in both right and left ankle (SMD= -0.50; 95% CI: -1.43, 0.43 and SMD= -0.48; 95% CI: -1.41, 0.45 respectively) |
| Johanson *et al.*, 2009[60] | 16 healthy adults with limited passive ankle-dorsiflexion ROM (less than 5 degrees), 27.40±8.20 years | n=8, static stretching, ankle plantar flexors, 4 sets, 30 seconds, 2 times daily, 3 weeks | n=8, no physical activity or stretching programs involving the lower extremities for 3 weeks | No significant difference between groups in ankle dorsiflexion (SMD= 0.53; 95% CI: -0.48, 1.53), maximum knee extension (SMD= -0.07; 95% CI: -1.05, 0.91), medial and lateral gastrocnemius activities (SMD= 0.37; 95% CI: -0.62, 1.36 and SMD= 0.00; 95% CI=: -0.98, 0.98 respectively) |
| Godges *et al.*, 1993[61] | 16 healthy, athletic, male college students, 21.00±l.00 years | n=9, static stretching, hip flexors, 3 sets, 2 minutes, 2 sessions per week, 3 weeks | n=7, continue their current activity levels | No significant difference between groups in gait economy (SMD= 0.83; 95% CI: -0.21, 1.87) |

SMD: standard mean difference, CI: confidence interval, 10MWT: 10-meter walk test, 6MWT: 6-minute walk test, ROM: ROM, ?: information not provided.

**Table 2.** **Quality assessment of the included studies.**

| Study | Eligibility criteria specified | Random allocation | Concealed allocation | Groups similar at baseline | Participant blinding | Therapist blinding | Assessor blinding | <15% dropouts | Intention-to-treat analysis | Between-group difference reported | Point estimate and variability reported | Total score | Patient category |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kerrigan *et al.*, 2003 | y | y | n | y | n | n | y | y | n | y | y | 6 | Healthy older adults |
| Gajdosik *et al.*, 2005 | y | y | y | y | n | n | n | y | y | y | y | 7 | |
| Christiansen, 2008 | y | y | n | y | n | n | n | y | n | y | y | 5 | |
| Cristopoliski *et al.*,, 2009 | y | y | n | y | n | n | n | y | y | y | y | 6 | |
| Watt *et al.*, 2011 | y | y | n | n | n | n | y | n | n | n | y | 3 | |
| Locks *et al.*, 2012 | y | n | n | y | n | n | n | n | n | y | y | 3 | |
| Watt *et al.*, 2011 | y | y | n | ? | n | n | y | n | n | n | y | 3 | Frail older adults |
| Hotta *et al.*, 2009 | y | y | n | y | n | n | n | y | n | y | y | 5 | Peripheral artery disease |
| Kim *et al.*, 2013 | n | n | n | y | n | n | n | n | n | y | y | 3 | Stroke |
| Johanson *et al.*, 2006 | y | y | n | n | n | n | n | y | y | y | y | 5 | Lower limb overuse injury |
| Johanson *et al.*, 2009 | y | y | n | y | n | n | n | y | y | y | y | 6 | Limited ankle ROM |
| Godges *et al.*, 1993 | y | y | n | ? | n | n | n | y | y | y | y | 5 | Healthy adults |

n: criterion not fulfilled; y: criterion fulfilled; ?: criterion not mentioned; total score: each item (except the first) contributes 1 point to the total score, yielding a PEDro scale score that can range from 0 to 10.

**Meta-analyses**

Four meta-analysis were conducted for the following outcomes (Figure 2): gait speed, stride length, hip extension during gait and anterior pelvic tilt.

*Gait speed:* For gait speed (Figure 2A), two studies were included in the meta-analysis[51,52]. One study was excluded because intervention and control groups were not similar at baseline[55]. Statistical analysis showed no significant difference between groups (SMD= 0.45; 95% CI: -1.15, 2.06), with heterogeneous results ($I^2$=86%, p=0.007). Thus, the level of evidence was conflicting.

*Stride length:* For stride length (Figure 2B), two studies were included in the meta-analysis[51,55]. Statistical analysis showed no significant difference between groups (SMD= 0.22; 95% CI: -0.44, 0.88), with consistent results ($I^2$=59%, p=0.12). Only one study was of high quality[51], thus a moderate level of evidence supports the lack of beneficial effect of stretching to improve stride length in the elderly.

*Hip extension:* For hip extension during gait (kinematic data) (Figure 2C), three studies were included in the meta-analysis[51,53,55]. Statistical analysis showed no significant difference between groups (SMD= 0.20; 95% CI: -0.06, 0.47), with consistent results ($I^2$=0%, p=0.99). Two studies were of high quality[51,53], thus a strong level of evidence supports the lack of beneficial effect of stretching to improve hip ROM during gait in the elderly.

*Anterior pelvic tilt:* For anterior pelvic tilt (Figure 2D), three studies were included in the meta-analysis[52,53,55]. Statistical analysis showed no significant difference between groups (SMD= -0.70; 95% CI: -1.60, 0.21), with heterogeneous results ($I^2$=87%, p<0.01). Thus, the level of evidence was conflicting.

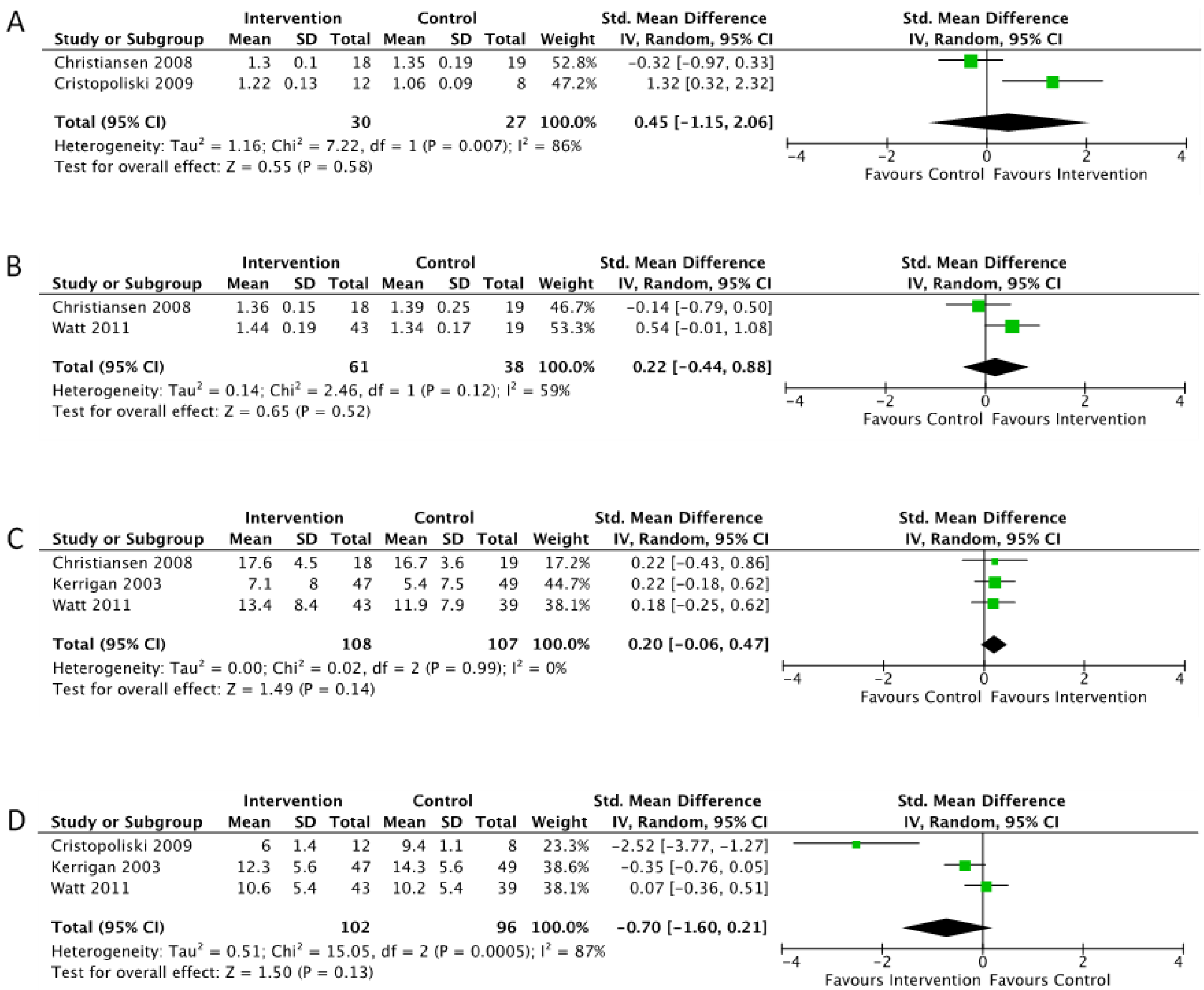


**Figure 2.** Comparisons between intervention and control groups for gait speed (**A**), stride length (**B**), hip extension (**C**) and anterior pelvic tilt (**D**) in healthy older adults.

**Effects of interventions in other outcomes**

For the outcomes below, no meta-analysis could be performed because only one study was identified. Nevertheless, for each outcome, effect size estimates with a measure of statistical uncertainty (95% CI) were provided.

*Angular variables during gait initiation:* The study of Christiansen *et al.* (2008) showed no significant difference between stretching and control groups for ankle dorsiflexion during gait (SMD=0.29; 95% CI: -0.36, 0.94) with a moderate level of confidence (PEDro score: 5/10). The study of Kerrigan *et al.* (2003) showed no significant difference between groups for ankle plantar flexion (SMD=-0.05; 95% CI: -0.45, 0.35), with a moderate level of confidence (PEDro score: 6/10). The study of Cristopoliski *et al.* (2009) showed no significant difference between groups for lateral pelvic tilt (SMD= 0.93; 95% CI: -0.02, 1.88) and knee ROM (SMD= 0.23; 95% CI: -0.67, 1.12), with a moderate level of confidence (PEDro score: 6/10).

*Kinetic variables:* The study of Kerrigan *et al.* (2003) showed no significant difference between groups for hip torque (SMD= 0.35; 95% CI: -0.06, 0.75) and ankle plantar flexion power (SMD=0.00; 95% CI: -0.40, 0.40), with a moderate level of confidence (PEDro score: 6/10).

*Spatiotemporal variables:* The study of Cristopoliski *et al.* (2009) showed no significant difference between groups for cycle duration (SMD= -0.24; 95% CI: -1.14, 0.66), heel contact velocity (SMD= -0.46; 95% CI: -1.37, 0.45) and toe clearance (SMD= 0.91; 95% CI: -0.04, 1.86). However, the study showed significant decreases with large effect sizes in stance phase duration (SMD=-1.92; 95% CI: -3.04, -0.81), double support phase duration (SMD= -1.69; 95% CI: -2.76, -0.62) in favour of the stretching group as compared to the control group. Additionally, the authors found significant increases with large effect sizes of swing phase duration (SMD=1.92; 95 CI: 0.81, 3.04) and step length (SMD=1.37; 95% CI: 0.36, 2.38) in favour of the stretching group as compared to the control group. The study obtained a PEDro score of 6/10, thus, the level of evidence for these outcomes was moderate.

*Functional tests:* The study of Gajdosik *et al.* (2005) showed no significant difference between groups for the 10MWT (SMD= -0.76; 95% CI= -1.70, 0.18), with a moderate level of confidence (PEDro score: 7/10). The study of Locks *et al.* (2012) showed no significant improvement of the 6MWT in favour of the stretching group as compared to the control group (SMD= -0.04; 95% CI:-0.86, 0.79) with a limited level of confidence (low quality CCT with a PEDro score of 3/10).

***Frail elderly***

**Description of the study and quality assessment**

The study of Watt *et al.* 2011 examined the effects of stretching on frail elderly subjects[56]. Regarding the characteristics of the subjects, 74 subjects were included, and the mean age was 77.0±8.0 years. Regarding the characteristics of the training programs, the stretching program lasted ten weeks, with a frequency of 14 sessions per week (two sessions per day). Participants performed two sets per session, holding the stretch for 60 seconds (static stretching), alternating the right and left limb (four minutes in total). The muscle group stretched was the hip flexors. The outcomes were cadence (steps/minute), walking speed (meters/second), stride length (meters) peak hip extension (degree) and peak anterior pelvic tilt (degree). Regarding the quality assessment, the study was identified as RCT and had an average PEDro score of 3 (low level of evidence).

**Effects of intervention**

The study of Watt *et al.* (2011) showed no significant difference between groups in angular variables, i.e. peak hip extension and anterior pelvic tilt (SMD= 0.22; 95% CI: -0.24, 0.68 and SMD= -0.05; 95% CI: -0.51, 0.41 respectively). There was also no significant difference for cadence (SMD= 0.13; 95% CI: -0.33, 0.59). However, the study showed significant improvements in favour of the stretching group with small effect sizes in some performance-related variables, i.e. walking speed and stride length (both SMD= 0.49; 95% CI: 0.03, 0.96).

***Elderly with symptomatic peripheral artery disease***

**Description of the study and quality assessment**

The study of Hotta *et al.* (2019) examined the effects of stretching in elderly with symptomatic peripheral artery disease[57]. Regarding the characteristics of the subjects, 13 subjects were included and the mean age was not mentioned. Regarding the characteristics of the training programs, the stretching program lasted four weeks, with a frequency of five sessions per week. Participants performed one set daily, holding the stretch for 30 minutes (static stretching with splints). The muscle group stretched was ankle plantar flexors. The gait outcome was 6MWT. Regarding the quality assessment, the study was identified as RCT and had an average PEDro score of 5 (moderate level of evidence).

**Effects of intervention**

The study of Hotta *et al.* (2019) showed significant improvements in favour of the stretching group for both total walking distance and continuous walking distance with large effect sizes (SMD= 1.56; 95% CI: 0.66, 2.45 and SMD= 3.05; 95% CI: 1.86, 4.23 respectively).

***Stroke***

**Description of the study and quality assessment**

The study of Kim *et al.* (2013) examined the effects of stretching on stroke patients[58]. Only a static muscle stretching training group and control group were included in the analysis. Regarding the characteristics of the subjects, 24 subjects were included, and the mean age was 53.3±3.1 years. Regarding the characteristics of the training programs, the stretching program lasted six weeks, with a frequency of four sessions per week. Participants performed one set per session, holding the stretch for 20 minutes (static stretching). The muscle group stretched was ankle plantar flexors. The outcome was the sway of the centre of pressure during the stance phase.

Regarding the quality assessment, the study was identified as CCT and had an average PEDro score of 3 (low level of evidence).

**Effects of intervention**
The study of Kim *et al.* (2013) showed no significant difference between groups in the sway of the centre of pressure (SMD=0.75; 95% CI: -0.09, 1.58).

***Young adults with limited ankle ROM and a history of lower limb overuse injury***
**Description of the study and quality assessment**
The study of Johanson *et al.* (2006) examined the effects of stretching on healthy adults with limited passive ankle-dorsiflexion ROM (less than eight degrees) and a history of lower limb overuse injury[59]. Regarding the characteristics of the subjects, 19 subjects were included and the mean age was 30.3±9.8 years. Regarding the characteristics of the training programs, the stretching program lasted three weeks, with a frequency of two sessions per day. Participants performed five sets per session, holding the stretch for 30 seconds (static stretching). The muscle group stretched was ankle plantar flexors. The outcomes were ankle dorsiflexion and time-to-heel-off during the stance phase of gait. Regarding the quality assessment, the study was identified as RCT and had an average PEDro score of 5 (moderate level of evidence).

**Effects of intervention**
The study of Johanson *et al.* (2006) showed no significant difference between groups in ankle dorsiflexion during gait in both the right and left ankle (SMD= 0.50; 95% CI: -0.42, 1.43 and SMD= 0.41; 95% CI: -0.52, 1.33 respectively). There was also no significant difference between groups for time-to-heel-off during the stance phase of gait in both the right and left ankle (SMD= -0.50; 95% CI: -1.43, 0.43 and SMD= -0.48; 95% CI: -1.41, 0.45 respectively).

***Young adults with limited ankle ROM***
**Description of the study and quality assessment**
The study of Johanson *et al.* (2009) examined the effects of stretching on young adults with limited passive ankle-dorsiflexion ROM (less than 5 degrees)[60]. It is worth noticed that these participants were not the same than in the study of Johanson *et al*. (2006). In contrast, the characteristics of the training programs were the same as in Johanson *et al*. (2006). In the current study, 16 subjects were included, and the mean age was 27.4±8.2 years. The muscle group stretched was the ankle plantar flexors. The outcomes were maximum ankle dorsiflexion, maximum knee extension and EMG amplitude of the gastrocnemius during the stance phase of gait. Regarding the quality assessment, the study was identified as RCT and had an average PEDro score of 6 (moderate level of evidence).

**Effects of intervention**
The study of Johanson *et al.* (2009) showed no significant difference between groups in angular variables during gait, i.e. maximum ankle dorsiflexion and maximum knee extension (SMD= 0.53; 95% CI: -0.48, 1.53 and SMD= -0.07; 95% CI: -1.05, 0.91 respectively). There was also no significant difference between groups for EMG variables, i.e. medial and lateral gastrocnemius activity (SMD= 0.37; 95% CI: -0.62, 1.36 and SMD= 0.00; 95% CI=: -0.98, 0.98 respectively).

***Healthy young adults***
**Description of the study and quality assessment**
The study of Godges *et al.* (1993) examined the effects of stretching on healthy young adults[61]. Only a static hip extension stretching group and control group were included in the analysis. Regarding the characteristics of the subjects, 16 subjects were included, and the mean age was 21.0±1.0 years. Regarding the characteristics of the training programs, the stretching program lasted three weeks, with a frequency of two sessions per week. Participants performed three sets per session, holding the stretch for two minutes (static stretching). The muscle group stretched was the hip flexors. The outcome was walking economy (ml/kg/min). Regarding the quality assessment, the study was identified as RCT and had an average PEDro score of 5 (moderate level of evidence).

**Effects of intervention**
The study of Godges *et al.* (1993) showed no significant difference between groups in gait economy in terms of oxygen consumption (SMD= 0.83; 95% CI: -0.21, 1.87).

## Discussion
The aim of this systematic review was to determine the effects of a stretching program on human gait by means of a systematic literature review and meta-analysis. Twelves studies were identified in six different patient categories. Statistical analyses showed no strong level of evidence supporting the beneficial effect of a stretching program to improve any gait outcome. The major issue in conducting meta-analyses and establishing strong level of evidences was the great heterogeneity in gait variables. The results obtained in the different patient categories are discussed in detail below.

### Healthy older adults
The healthy older adult population was the most studied. Two muscle groups were systematically stretched in the six identified studies: hip flexors[23,51–53,55] and ankle plantar flexors[23,51–53]. Hip flexor stiffness, associated with reduced hip extension during gait has been demonstrated in the elderly and may alter gait[62,63]. In the same way, decreased calf muscle length associated with restricted dorsiflexion ROM is well documented in older adults[35,64]. A decreased ankle dorsiflexion ROM has been correlated with poorer balance test scores in the elderly[65] and may contribute to an increased risk of falls[66]. All the studies included in the present analysis showed that specific stretching programs were efficient to improve passive ROM of the targeted joints, but results are more heterogeneous regarding gait performance and dynamic ROM. This led to inconsistency in the results or the impossibility to conclude with a strong level of evidence that a stretching program improves gait in healthy older adults. Moreover, when improvement in ROM or gait performance occurred, it was not associated with a significant increase in dynamic hip extension or ankle dorsiflexion. Only trends toward increased dynamic ROM after stretching interventions were

observed[51,53,55]. This observation was consistent in young adults.

When data were meta-analyzed, we ensured that the groups and the training characteristics were similar to limit the risk of bias. This explains that a limited number of studies was included in the meta-analysis. It is worth noticed that the stretching technic was the same (i.e. static stretching), but that details of interventions varied across these studies. For example, both studies selected for the meta-analysis of gait speed included hip flexors and plantar flexors stretching, but, one study included hip extensor stretching[52] whereas the other did not[51]. This difference may partially explain the heterogenous results in the meta-analysis ($I^2$=86%, p=0.007). In the same way, the heterogenous results observed in the meta-analysis of anterior pelvic tilt ($I^2$=87%, p<0.01) may be explained by the stretching of additional muscle groups (hip extensors and plantar flexors) in the study of Cristopoliski *et al*. (2009) compared to the other studies (in which only hip flexors were stretched)[53,55]. Nevertheless, heterogeneity in the results was not systematically observed between studies that used slight different protocols, as showed by the consistent results int the meta-analyses of stride length ($I^2$=59%, p=0.12) and hip extension ($I^2$=0%, p=0.99). Thus, we assume that we have limited the risk of bias in the meta-analyses.

### Stroke patients

In stroke patients, ankle plantar flexor stretching has been successfully used to improve ankle stiffness[67–70]. Decreased plantar flexors stiffness may have a beneficial effect on postural control during gait because *triceps surae* is known to play an important role during gait[71–73] and an increase in muscle stiffness might alter synergistic muscle activities during human gait. However, only one non-randomized study[58] was identified and included in the current systematic review. Other studies that used stretching in multicomponent programs[74–76] or in control groups[77,78] were identified but excluded because of the addition of resistance training or the lack of a control group. Nevertheless, it should be noted that some studies showed improvements between pre- and post-stretching conditions. Forrester *et al.* (2014) showed that both robotic ankle mobilizations and manual ankle stretching improved gait velocity in stroke patients at hospital discharge compared to baseline. Similarly, Park *et al.* (2018) showed that both static ankle stretching and ankle mobilizations improved gait speed after four weeks of treatment compared to baseline. Other authors showed that one week of immobilization in dorsiflexed position (casting) followed by one week of plantar flexor stretching and gait training improved gait performances in 10MWT and 6MWT[74]. Hence, these encouraging results suggest that further randomized controlled trials of good quality are needed to explore the ability of ankle stretching to improve gait parameters in stroke or in other neurological diseases exposing patients to joint stiffness, e.g. Parkinson's disease[79].

### Young adults

In healthy adults, the interest of practicing stretching to improve gait seems limited as they are assumed to have sufficient mobility for walking. Moreover, the included study involved athletic males[61], a population that is known to be more flexible than inactive persons[80]. Stretching should be more indicated when ROM is limited[24]. However, even in young adults with limited ankle ROM, stretching did not improve dynamic dorsiflexion during gait[59,60]. Stretching programs in apparently healthy adults should be more indicated after a prolonged period of reduced functional demand (e.g. immobilization, sedentarity), when ROM is insufficient to practice a specific activity or when high levels of flexibility are required for sport performance (e.g. gymnastics or dance) and in sports that involve stretch-shortening cycles (e.g. basketball, volleyball)[24].

### Limitations of the study

Some patient categories were not included in the present review, although muscle stretching is commonly indicated in their clinical care to reduce spasticity[81]. This is for example the case for children with cerebral palsy[82]. In fact, we were able to identify studies in the literature focusing on the effects of stretching on gait in this population during the first phase of the present review, but the protocol of these studies combined stretching with another form of training (e.g. 83,84) or there was no control group (e.g. 85). These studies therefore did not fit with the inclusion criteria of the present systematic review and were consequently excluded. Now, it should be stressed that the effectiveness of static stretching to improve motor function in children with cerebral palsy is still controversial[86], although some authors showed that functional stretching exercises may be effective to improve gait[85]. Further randomized controlled trials are needed to explore the impact of stretching on gait in this population.

To reduce the risk of bias, data were meta-analyzed when at least 2 studies with similar populations and training characteristics were found. Considering these constraints and the great heterogeneity in the gait outcomes, we only performed meta-analyses in healthy older adults for 4 outcomes. The Cochrane Qualitative and Implementation Methods Group recommends the application of Grades of Recommendation, Assessment, Development, and Evaluation (GRADE) in the Evidence from Qualitative Reviews to assess the level of confidence in systematic review with meta-analyses[87]. However, the GRADE necessitates assessing the risk of publication bias with a funnel plot, determining its asymmetry, which can be performed with at least 10 studies[88]. In the present study, the meta-analyses included less that 10 randomized controlled trials, so, we chose to implement other guidelines described by a Cochrane collaboration group to assess the level of evidence[50]. Because this method includes fewer criteria, our confidence in the results must be taken with caution

## Conclusion

Twelve studies were identified, involving a total of 442 subjects. Despite some improvements in isolated studies, statistical analyses showed no strong level of evidence supporting the beneficial effect of using stretching alone to improve gait outcomes in rehabilitation programs. The major obstacle in conducting meta-analyses and establishing strong levels of evidence were the great heterogeneity in gait variables and the low quality of the included studies. Because the effects of stretching are not clear, further randomized controlled trials of good quality are needed to understand the impact of stretching on human gait. Currently, stretching is more recommended to maintain and improve ROM rather than improve gait parameters and should be integrated in multicomponent programs.

## Data availability

### Underlying data

All data underlying the results are available as part of the article and no additional source data are required.

### Reporting guidelines

Harvard Dataverse: PRISMA checklist and PRISMA flow diagram for 'Effects of stretching exercises on human gait: a systematic review and meta-analysis', https://doi.org/10.7910/DVN/N8ZXNB[89].



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# Open Peer Review

## Current Peer Review Status: ✓ ? ✓

**Version 2**

Reviewer Report 26 February 2021

https://doi.org/10.5256/f1000research.30366.r79222



✓

**Maria Garcia Escudero**
School of Medicine and Health Sciencies, Universidad Católica de Valencia San Vicente Mártir, Valencia, Spain

I believe that the idea of this research study was necessary to carry it out because of the need to clarify stretch treatments and clear protocols to improve the progress of patients.

I think the methodology used is appropriate although after reviewing the results it is concluded that further randomized controlled trials of good quality are necessary even to offer this line of research to carry out new studies and improve the cohort of patients by categories and sample number.

**Are the rationale for, and objectives of, the Systematic Review clearly stated?**
Yes

**Are sufficient details of the methods and analysis provided to allow replication by others?**
Yes

**Is the statistical analysis and its interpretation appropriate?**
Yes

**Are the conclusions drawn adequately supported by the results presented in the review?**
Yes

***Competing Interests:*** No competing interests were disclosed.

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.**

Reviewer Report 09 November 2020

https://doi.org/10.5256/f1000research.30366.r74039



**Fabrice Mégrot**
[1] Unité Clinique d'Analyse de la Marche et du Mouvement, Centre de Médecine Physique et de Réadaptation pour Enfants Bois-Larris, Croix-rouge française, Lamorlaye, France
[2] BioMécanique et BioIngénierie (BMBI) - UMR 7338, Université de Technologie de Compiègne, Sorbonnes Université, Compiègne, France

Thanks for the corrections. That works.

**Are the rationale for, and objectives of, the Systematic Review clearly stated?**
Yes

**Are sufficient details of the methods and analysis provided to allow replication by others?**
Yes

**Is the statistical analysis and its interpretation appropriate?**
Yes

**Are the conclusions drawn adequately supported by the results presented in the review?**
Yes

***Competing Interests:*** No competing interests were disclosed.

***Reviewer Expertise:*** motor control, biomechanics, neurosciences, nonlinear dynamics, clinical gait/movement analysis and gross motor function of children with cerebral palsy

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.**

## Version 1

Reviewer Report 09 October 2020

https://doi.org/10.5256/f1000research.28219.r69875



**Xu Wei**

Department of Orthopaedic Surgery, Tongren Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai, China
**Guoning Zhang**
Department of Orthopaedic Surgery, Tongren Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai, China

1. The purpose of this article is to analyse the effects of a stretching program on gait in each patient category by means of a systematic literature review and meta-analysis, comparing the gait outcomes of the intervention groups with the control groups. This is a very interesting research direction and it has good innovation. But different ages and diseases have different gait results and different stretching training modes and intervention methods. How to eliminate the bias caused by these differences in meta-analysis and comparison?

2. Four meta-analysis were conducted for the following outcomes (Figure 2): gait speed, stride length, hip extension during gait and anterior pelvic tilt. Why choose these four dimensions? Is there any theoretical basis?

3. Kinetic variables: The study of Kerrigan et al. (2003)44 showed no significant difference between groups for hip torque (SMD= 0.35; 95% CI: -0.06, 0.75) and ankle plantar flexion power (SMD=0.00; 95% CI: -0.40, 0.40), with a moderate level of confidence (PEDro score: 6/10).: It seems that gait analysis cannot directly measure muscle power. sEMG can only evaluate muscle recruitment signals to evaluate muscle fiber contraction. Therefore, how is ankle flexion power measured by gait analysis?

4. Twelve studies were included in the analysis. Stretching improved gait performance as assessed by walking speed and stride length only in a study with a frail elderly population, with small effect sizes. There is no strong evidence supporting the beneficial effect of using stretching to improve gait. I think that since stretching can improve gait parameters for adults with special weakness, the effect of stretching on gait is significant, although it has little effect on healthy adults or young adults. Should it be explained? In general, this study made a meta-analysis on the effect of stretching on gait, which has good innovation. However, whether gait analysis has guiding significance for different groups of rehabilitation training is still controversial especially for healthy adults, so the research conclusion of this paper has practical significance in clinical guidance.

**Are the rationale for, and objectives of, the Systematic Review clearly stated?**
Yes

**Are sufficient details of the methods and analysis provided to allow replication by others?**
Yes

**Is the statistical analysis and its interpretation appropriate?**
Partly

**Are the conclusions drawn adequately supported by the results presented in the review?**

Partly

***Competing Interests:*** No competing interests were disclosed.

***Reviewer Expertise:*** Sports medicine; osteoporosis; osteosarcoma; Spine surgery; Scoliosis

**We confirm that we have read this submission and believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however we have significant reservations, as outlined above.**

Author Response 20 Oct 2020

**ARNAUD DELAFONTAINE**, Univ. Paris-Sud., Université Paris-Saclay, Orsay, France

Dear Reviewer
We greatly you for scrutinizing our manuscript and for his relevant comments. We feel that the manuscript has improved.

Comment 1. Different ages and diseases have different gait results and different stretching training modes and intervention methods. How to eliminate the bias caused by these differences in meta-analysis and comparison?

**Reply:** We add some precisions in the discussion section (healthy older adults paragraph) to specify how we have limited the risk of bias:
Please see L353-366: When data were meta-analyzed, we ensured that the groups and the training characteristics were similar to limit the risk of bias. This explains that a limited number of studies was included in the meta-analysis. It is worth noticing that the stretching technic was the same (i.e. static stretching), but that details of interventions varied across these studies. For example, both studies selected for the meta-analysis of gait speed included hip flexors and plantar flexors stretching, but, one study included hip extensor stretching[52] whereas the other did not[51]. This difference may partially explain the heterogenous results in the meta-analysis ($I^2$=86%, p=0.007). In the same way, the heterogenous results observed in the meta-analysis of anterior pelvic tilt ($I^2$=87%, p<0.01) may be explained by the stretching of additional muscle groups (hip extensors and plantar flexors) in the study of Cristopoliski et al. (2009) compared to the other studies (in which only hip flexors were stretched)[53,55]. Nevertheless, heterogeneity in the results was not systematically observed between studies that used slight different protocols, as showed by the consistent results in the meta-analyses of stride length ($I^2$=59%, p=0.12) and hip extension ($I^2$=0%, p=0.99). Thus, we assume that we have limited the risk of bias in the meta-analyses.

Comment 2. Four meta-analysis were conducted for the following outcomes (Figure 2): gait speed, stride length, hip extension during gait and anterior pelvic tilt. Why choose these four dimensions? Is there any theoretical basis?

**Reply:** Only these four outcomes fitted with the inclusion criteria for meta-analysis. Meta-analyses were performed only when more than one trial was identified for each outcome. Additionally, to reduce the risk of bias, we ensured that the groups were similar. For example, in the study of Watt et al. (2011), the intervention group had a significantly higher gait speed than the control group, so the trial was excluded of the meta-analysis.

Comment 3. Kinetic variables: The study of Kerrigan et al. (2003)44 showed no significant difference between groups for hip torque (SMD= 0.35; 95% CI: -0.06, 0.75) and ankle plantar flexion power (SMD=0.00; 95% CI: -0.40, 0.40), with a moderate level of confidence (PEDro score: 6/10).: It seems that gait analysis cannot directly measure muscle power. sEMG can only evaluate muscle recruitment signals to evaluate muscle fiber contraction. Therefore, how is ankle flexion power measured by gait analysis?

**Reply:** In the study of Kerrigan et al. (2003), "joint torque and power calculations were based on the mass and inertial characteristics of each lower-extremity segment, the derived linear and angular velocities and accelerations of each lower-extremity segment, and the ground reaction force and joint center position estimates. Joint torques and powers were normalized for body weight and height and were reported as external in newton meters per kilogram meters (N.m/kg.m) and watts per kilogram meters (W/kg.m), respectively".
Unless special recommendation of the reviewer or the Editor, we feel it is not necessary to add how the ankle flexion power was measured in the study of Kerrigan et al. (2003).

Comment 4. I think that since stretching can improve gait parameters for adults with special weakness, the effect of stretching on gait is significant, although it has little effect on healthy adults or young adults. Should it be explained?

**Reply:** We add some precisions in the discussion section (young adults paragraph) to specify why stretching is less interesting to improve gait parameters in young healthy adults:

Please see L387-390: In healthy adults, the interest of practicing stretching to improve gait seems limited as they are assumed to have sufficient mobility for walking. Moreover, the included study involved athletic males [61], a population that is known to be more flexible than inactive persons [81]. Stretching should be more indicated when range of motion is limited[24].

Best regards
Arnaud Delafontaine
on behalf of all the authors

***Competing Interests:*** None

Reviewer Report 14 September 2020

https://doi.org/10.5256/f1000research.28219.r69874

?

**Fabrice Mégrot**

[1] Unité Clinique d'Analyse de la Marche et du Mouvement, Centre de Médecine Physique et de Réadaptation pour Enfants Bois-Larris, Croix-rouge française, Lamorlaye, France

[2] BioMécanique et BioIngénierie (BMBI) - UMR 7338, Université de Technologie de Compiègne, Sorbonnes Université, Compiègne, France

Authors propose a systematic review and meta-analysis to investigate the effects of stretching programs on gait and to determine how stretching might be valuable for rehabilitation. From 150 studies identified through systematic searches and critical appraisal of the literature, 12 articles were considered by the authors.

The various demographics of the participants in the reported studies implied a mixed range of age and aetiology, even if old persons, either with an asymptomatic or a pathological health status, were the most represented individuals.

In young adults, two studies by Johanson are reported. Is it not clear if both groups of young adults with limited range of motion were identical in both studies and had the same characteristics? If yes, merging the two studies should make the deal, if not please provide specification about the second group.

Overall, the methodology is correct, and the meta-analysis well described. The results show weak effects of stretching on gait parameters.

The main issue arises from the various parameters which are considered in all the studies, both during gait initiation and straight walking (spatiotemporal parameters, kinematics, joint strength and dynamics, muscle activity, etc…). Therefore, in the results and the discussion, grouping the types of parameters according to their role in the process of walking would add value to this manuscript. The effects, demonstrated or not, have not all the same meaning depending on whether functional parameters or kinematics angles or even muscle strength and activity are considered.

Gait should be defined in a better way, especially how it is related to the different measures in terms of processes, even if there is anyway no real benefit demonstrated by stretching used as a unique therapy. Surprisingly, no article in children with cerebral palsy has been uncovered, while the clinical care of these children is mostly based on muscle stretching.

**Are the rationale for, and objectives of, the Systematic Review clearly stated?**

Yes

**Are sufficient details of the methods and analysis provided to allow replication by others?**

Yes

**Is the statistical analysis and its interpretation appropriate?**

Yes

**Are the conclusions drawn adequately supported by the results presented in the review?**

Partly

***Competing Interests:*** No competing interests were disclosed.

***Reviewer Expertise:*** motor control, biomechanics, neurosciences, nonlinear dynamics, clinical gait/movement analysis and gross motor function of children with cerebral palsy

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.**

Author Response 20 Oct 2020

**ARNAUD DELAFONTAINE**, Univ. Paris-Sud., Université Paris-Saclay, Orsay, France

Reviewer 1 :

Dear Reviewer
We greatly you for scrutinizing our manuscript and for his relevant comments. We feel that the manuscript has improved.

Comment 1. In young adults, two studies by Johanson are reported. Is it not clear if both groups of young adults with limited range of motion were identical in both studies and had the same characteristics? If yes, merging the two studies should make the deal, if not please provide specification about the second group.The participants in both studies were different. In the study of Johanson et al. (2006), the participants were healthy adults with limited passive ankle-dorsiflexion range of motion (less than 8 degrees) **and a history of lower limb overuse injury**. In the study Johanson et al. (2009), the characteristics of the stretching program were the same as in Joahnson et al. (2006), but the participants did not have any history of lower limb overuse injury.

**Reply:** To make this difference clearer, precisions were added in the "included studies" and "results" sections:
Please see L158-163 Thus, 12 articles were ultimately included in this systematic review. Six studies evaluated the effects of stretching in healthy older adults [23,51–55], one in a frail elderly population [56], one study in an elderly population with stable symptomatic peripheral artery disease[57], one in stroke patients [58], one study in adults with limited ankle range of motion (less than 8 degrees) associated with a history of lower limb overuse injury [59], one study in healthy adults with limited ankle dorsiflexion range of motion (less than 5 degrees) [60] and one in healthy young adults [61]

Please see L285-288: "The study of Johanson et al. (2006) examined the effects of stretching on healthy adults with limited passive ankle-dorsiflexion range of motion (less than 8 degrees) and a history of lower limb overuse injury[50]. Regarding the characteristics of the subjects, 19 subjects were included and the mean age was 30.3±9.8 years."

Please see L302-306: "The study of Johanson et al. (2009) examined the effects of stretching on young adults with limited passive ankle-dorsiflexion range of motion (less than 5 degrees) [51]. It is worth noticed that these participants were not the same than in the study of Johanson et al. (2006). In contrast, the characteristics of the training programs were the same as in Johanson et al. (2006)".

Comment 2. In the results and the discussion, grouping the types of parameters according to their role in the process of walking would add value to this manuscript. The effects, demonstrated or not, have not all the same meaning depending on whether functional parameters or kinematics angles or even muscle strength and activity are considered.

**Reply:** In the results and the discussion, we chose to group the participants by patient categories because differences in ages and health parameters may result in different training effects. However, in each patient category, each variable was considered separately in an organized way.

Comment 3. Gait should be defined in a better way, especially how it is related to the different measures in terms of processes, even if there is anyway no real benefit demonstrated by stretching used as a unique therapy.

**Reply:** We agree. We add a whole paragraph at the beginning of the introduction section to specify how gait can be related to the different variables seen in the review:

Please see L35-44: "Gait is the medical term used to describe the human whole body movement of walking[1]. Gait involves internal and external forces that act on the body to move the center of mass (COM) across a given distance[2]. It depends on many biomechanical features that can be observed during gait analysis such as center of mass shifts, joint range of motion, forces, muscle activity, joint moments, and joint powers[3]. Spatiotemporal features (e.g. velocity, step length, stride length, step with, step variability) and kinematics parameters (range of motion) can be observed subjectively with functional evaluations by clinicians(e.g. the Tinetti test[4] or the timed up and go test[5]), but, it can be further objectified with biomechanical analysis in a laboratory[2]. Kinetics variables (the forces that cause the body to move) must be collected in a laboratory environment with force plates (e.g.[6–9] for recent studies that used this technic)".

Comment 4. Surprisingly, no article in children with cerebral palsy has been uncovered, while the clinical care of these children is mostly based on muscle stretching.

**Reply:** We agree. However, no article in children with cerebral palsy fitted our inclusion criteria during the systematic search of the literature. We add a whole paragraph in a specific section "limitations of the study":

Please see L397-406: Some patient categories were not included in the present review, although muscle stretching is commonly indicated in their clinical care to reduce spasticity[82]. This is for example the case for children with cerebral palsy[83]. In fact, we were able to identify studies in the literature focusing on the effects of stretching on gait in this population during the first phase of the present review, but the protocol of these studies combined stretching with another form of training (e.g.[84,85]) or there was no control group (e.g.[86]). These studies therefore did not fit with the inclusion criteria of the present systematic review and were consequently excluded. Now, it should be stressed that the effectiveness of static stretching to improve motor function in children with cerebral palsy is still controversial[87], although some authors showed that functional stretching exercises may be effective to improve gait[86]. Further randomized controlled trials are needed to explore the impact of stretching on gait in this population.

Best regards
Arnaud Delafontaine
on behalf of all the authors

***Competing Interests:*** None