Physical Therapy in Sport 35 (2019) 42–55

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Literature Review

Hold-relax and contract-relax stretching for hamstrings flexibility: A systematic review with meta-analysis

Christopher S. Cayco [a, *], Alma V. Labro [b], Edward James R. Gorgon [a]

[a] Department of Physical Therapy, University of the Philippines Manila, Manila, Philippines
[b] College of Allied Medical Professions, University of the Philippines Manila, Manila, Philippines

ARTICLE INFO

Article history:
Received 31 January 2018
Received in revised form
18 September 2018
Accepted 2 November 2018

Keywords:
Hamstring muscles
Muscle stretching exercises
Physical therapy modalities
Range of motion

ABSTRACT

Objective: To synthesize evidence on the effects of hold-relax and contract-relax stretching (HR and CR) on hamstrings flexibility compared with no intervention and other stretching techniques.
Design: Electronic databases (PubMed, PEDro, Cochrane CENTRAL, Scopus, LILACS) were searched from inception until March 31, 2014 and updated until May 31, 2017. Randomized controlled trials involving HR and CR to improve hamstrings flexibility in adults (aged $\geq$18 years old) with or without a pathological condition were included. Two reviewers independently searched literature, assessed risk of bias, and extracted data, while a third reviewer settled disagreements.
Results: Thirty-nine trials (n = 1770 healthy adults; median PEDro score = 4/10) were included. Meta-analysis showed large effects compared to control immediately after 1 session (6 trials, SMD = 1.02, 95% CI = 0.69 to 1.35, $I^2 = 2\%$) and multiple sessions (4 trials, SMD = 1.02, 95% CI = 0.64 to 1.40, $I^2 = 0\%$). Meta-analysis showed conflicting results compared to static stretching, while individual trials demonstrated conflicting results compared to other techniques.
Conclusions: The immediate effects of HR and CR on hamstrings flexibility in adults are better against control. The long-term effects against other stretching types, and optimal exercise prescription parameters require further research.

1. Introduction

Sufficient muscle flexibility is related to the muscle's ability to partially absorb lengthening and limit strain on the myofibrils (Croisier, 2004). Insufficient hamstrings flexibility is associated with adverse alterations in lower limb kinematics (Gaudreault, Fuentes, Mezghani, Gauthier, & Turcot, 2013). Various musculoskeletal injuries such as lower back (Radwan et al., 2014), hip, and knee joint impairments (Messier et al., 2008), and strains (Bahr & Holme, 2003; Hrysomallis, 2013) have been associated with hamstrings tightness in both athletes and non-athletes (van Beijsterveldt, van de Port, Vereijken, & Backx, 2013; van der Worp et al., 2015; Watsford et al., 2010).

Stretching exercises have been used in sports medicine and physical therapy to improve hamstrings flexibility and joint range of motion (ROM), and enhance outcomes of rehabilitation (Decoster, Cleland, Altieri, & Russell, 2005; Malliaropoulos, Papalexandris, Papalada, & Papacostas, 2004; McHugh & Cosgrave, 2010). The rationale behind how stretching increases flexibility remains unclear. Current explanations indicate that stretching improves flexibility through mechanisms including decrease in either muscle and tendon stiffness (Konrad, Stafilidis, & Tilp, 2017). Some studies suggest that stretching decreases viscosity of tendons to increase tissue elasticity (Kubo et al., 2001, 2002). This decrease in tendon stiffness however contradicts findings of other studies which found changes in muscle stiffness instead (Kay, Husbands-Beasley, & Blazevich, 2015). Aside from soft tissue changes, increased stretch tolerance after stretching showed a strong correlation with ROM changes (Kay et al., 2015). Stretching is also hypothesized to result in changes through structural adaptations of muscles and other soft tissues (Harvey, Herbert, & Crosbie, 2002). In practice, long-term changes translate into greater functional carry-over compared to acute effects (Shrier, 2004), and are therefore more important.

Several systematic reviews of randomized controlled trials (RCT)

* Corresponding author. Department of Physical Therapy, College of Allied Medical Professions, University of the Philippines Manila, Pedro Gil Street, Malate, Manila, 1004, Philippines.
E-mail address: cscayco1@up.edu.ph (C.S. Cayco).

https://doi.org/10.1016/j.ptsp.2018.11.001
1466-853X/© 2018 Elsevier Ltd. All rights reserved.

have previously attempted to synthesize direct evidence on the effects of stretching on hamstrings flexibility (Decoster et al., 2005; Harvey et al., 2002; Medeiros, Cini, Sbruzzi, & Lima, 2016). In two systematic reviews, positive immediate and short-term effects have been demonstrated (Harvey et al., 2002; Medeiros et al., 2016). However, the evidence pooled in these reviews focused primarily (Harvey et al., 2002) or solely (Medeiros et al., 2016) on static stretching. One systematic review examined the effects of various stretching techniques to decrease hamstrings tightness (Decoster et al., 2005). It covered only literature up to the year 2004 and concluded that data were insufficient to establish the superiority of stretching types and treatment parameters (Decoster et al., 2005). Therefore, the effects of stretching techniques other than static stretching and the comparative effects of different stretching techniques for hamstrings tightness are still not clear.

Hold-relax and contract-relax stretching (HR and CR, respectively), methods rooted in the proprioceptive neuromuscular facilitation (PNF) approach, have been applied with the intention of stimulating sensory receptors that provide information about body position and movement to facilitate a desired motion (Adler, Beckers, & Buck, 2008). Theoretically, CR involves an isotonic contraction resisted by the therapist, while HR requires a resisted isometric contraction (Adler et al., 2008). For either, the joint or body part is repositioned either actively or passively to the new limit of ROM following the contraction (Adler et al., 2008). In a review by Sharman, Cresswell, and Riek (2006), these techniques often have variations in their descriptions, and at times have been named to mean the same technique. Improvement in ROM attributed to HR and CR has been explained through autogenic or reciprocal inhibition depending on the muscle being contracted (i.e. autogenic inhibition, when the target muscle is contracted; reciprocal inhibition, when the opposing muscle is contracted), or through altered stretch tolerance (Sharman et al., 2006). HR and CR encourage active patient participation and do not require specialized instrumentation (Adler et al., 2008).

One systematic review with meta-analysis examined the effectiveness of CR over SS and found that both techniques were equally effective in producing immediate, short-term and long-term hamstrings flexibility changes (Borges, Medeiros, Minotto, & Lima, 2018). However, it included controlled clinical trials and cross-over trials. The inclusion of non-randomized and cross-over over groups increases risk for bias due to possible systematic differences of treatment groups (Sibbald & Roland, 1998) and carryover effects (Sedgwick, 2015), respectively. These limitations can preclude attribution of effects to the assigned interventions. Additionally, there is a need to assess HR and CR effectiveness compared with stretching techniques aside from SS. This study aimed to answer the following research questions: (1) Are HR and CR effective in developing immediate (effects present < 24 h after stretch), short-term (effects present 24 h–1 week after stretch), or long-term (effects present > 1 week after stretch) changes in hamstrings flexibility compared with control or no intervention? (2) What is the comparative effect of HR and CR and other stretching techniques on immediate, short-term, and long-term changes in hamstrings flexibility? To provide a strong basis for making practice recommendations, high-level evidence from clinical trials was required. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guided the design and reporting of this review (Liberati et al., 2009).

2. Materials and methods

2.1. Search strategy

Reviewers conducted a comprehensive search on the following electronic databases from inception until March 31, 2014: PubMed, Physiotherapy Evidence Database (PEDro), Cochrane Central Register of Controlled Trials (CENTRAL), Scopus, and Latin American and Caribbean Health Sciences Literature (LILACS). The search strategy comprised keywords and synonyms based on these key concepts: PNF, stretching, hamstrings, flexibility, and clinical trial (see Appendix 1 for detailed search strategy). Search terms were combined using Boolean terms as applicable. No restrictions were placed on publication date and language. Reviewers performed an updated search covering April 1, 2014 to May 31, 2017 in all the databases. Clinical trials investigating the effects of HR and CR on hamstrings flexibility underwent hand searching. The first author (CSC) and second author (AVL) independently conducted the literature search and screened articles for inclusion and exclusion. Reviewers resolved any disagreement by re-examining the article full text. Where a consensus was not achieved, the third author (EJRG) assisted in resolving disagreements.

2.2. Eligibility criteria

2.2.1. Types of studies and participants

Studies were included if they were randomized controlled trials published as full text articles. Studies should have included adults (aged ≥18 years) with hamstrings tightness with or without a pathological condition. Hamstrings tightness was defined as a limitation in full knee extension (hip in flexion) of at least 10–20° (Depino, Webright, & Arnold, 2000) or hip flexion ROM of <70–80° during a straight leg raise (Göeken & Hof, 1991). No restrictions were placed on the sex, socioeconomic background, lifestyle, and health status.

2.2.2. Interventions

Studies must have used HR or CR to improve hamstrings flexibility compared to either control conditions or another stretching intervention. No intervention was excluded based on dose and duration. Studies were excluded if HR and CR were combined with another intervention (e.g. heating agents) as such combination would affect attribution of effects. Studies not involving direct application of HR and CR to the knee muscles, or studies where participants received both experimental and control conditions such as cross-over designs were excluded.

2.2.3. Outcomes

The outcome of interest was change in hamstrings flexibility, defined operationally as change in range of motion of the hip joint with the knee extended or of the knee joint with the hip flexed. Any outcome measure that objectively assessed such change was included. Torque-controlled measures of joint mobility (e.g. torque controlled devices) were preferred as they have improved reliability (Harvey et al., 2003; Katalinic, Harvey, & Herbert, 2011). If torque-controlled measures were not reported, passive measures (e.g. passive knee extension test (PKE)) were prioritized followed by active measures (e.g. active knee extension test (AKE)). Adverse events were documented.

2.3. Methodological quality assessment

Risk of bias was estimated using the PEDro scale, a valid and reliable measure of internal validity specific to clinical trials (de Morton, 2009; Maher, Sherrington, Herbert, Moseley, & Elkins, 2003). The 11-item instrument contains one item on external validity (reporting of eligibility criteria) and 10 scored items assessing internal validity threats related to lack of randomization, allocation concealment, baseline comparability, blinding, adequate follow-up, intention-to-treat analysis, and statistical reporting. The authors (CSC and AVL) independently appraised risk of bias. Disagreements were resolved through consultation with the third author (EJRG) and re-examination of the article toward arriving at a consensus.

2.4. Data analysis

Authors (CSC and AVL) independently extracted data using a tool developed based on the Data Extraction Template for Cochrane Reviews (Cochrane, 2011). The following were extracted from each included study: (1) participant characteristics (sample size, age, sex, and health condition); (2) details of interventions (specific HR and CR techniques, control conditions, or comparison interventions, including dose, frequency, and duration); (3) outcome measures used to assess hamstrings flexibility; and (4) results (summary data for intervention groups, any participant attrition, and any adverse event related to an intervention). Disagreements were settled with the third author (EJRG) and the article full text was re-examined to arrive at a consensus. For included studies in which data were presented only graphically or not reported, authors were contacted through email.

Bias-corrected standardized mean differences (SMD) using Hedges *g* (Higgins & Green, 2011) and 95% confidence intervals (95% CI) were computed to determine effect sizes (ES). Existing convention for ES interpretation was applied: 0.2 to <0.5, small effect; 0.5 to <0.8 = medium effect; and ≥0.8 = large effect (Rosenthal & Rosnow, 1991). All reviewers assessed clinical heterogeneity of included studies together and determined suitability for inclusion in the meta-analysis by consensus. Results of clinically homogenous studies (ie, similar interventions and outcomes) were pooled through meta-analysis using a random effects model. Statistical heterogeneity was assessed using the I^2 statistic, with a value of 50% and higher representing substantial heterogeneity (Higgins & Green, 2011). If the I^2 was greater than 50%, a sensitivity analysis was conducted to determine the cause of heterogeneity. Sensitivity analysis examined the effects of concealment of treatment allocation, blinding of outcome assessment, and handling of withdrawals (Jüni, Witschi, Bloch, & Egger, 1999). The reviewers analyzed effects of the comparability of groups at baseline. RevMan 5.3 software (The Cochrane Collaboration, 2014) was used in all quantitative analyses. Reviewers pre-planned to analyze and report separately for samples with physical injury or disability, and those without (i.e. "healthy" adults). Data not eligible for meta-analysis were analyzed descriptively.

3. Results

Flow of studies in the literature search is detailed in Fig. 1. All included studies are described in Table 1. Fifteen clinical trials published from 2004 through the early part of 2014 were included from the original literature search. From the updated search, 10 relevant articles published in 2014 and 2015 were added. Hand searching yielded 14 additional relevant records. In total, 39 trials met the inclusion criteria. Authors were contacted via email for additional data with two authors responding (Beltrão, Ritti-Dias, Pitangui, & De Araújo, 2014; Mallmann et al., 2011). The final sample involved 1770 adults with ages ranging from 19 to 65 years (670 females and 1012 males; sex not specified for 88 participants). Participants were reported as either healthy or active. No studies involving adults with hamstrings tightness resulting from physical injury or disability were located. All studies were RCT, with a median PEDro score of 4/10 and individual scores ranging from 2 to 7/10 (Table 1). Detailed PEDro ratings for included trials are found in Appendix 2.

3.1. Interventions

Of the 39 included trials, 15 investigated the effects of HR and CR against no intervention only, eight trials compared HR and CR against other stretching techniques only, and 16 trials compared HR and CR with both no intervention and another stretching technique. Only ten trials studied short-term effects of HR and CR against either control or another stretching intervention (Beltrão et al., 2014; Chebel, Galuppo, Cardoso de Sá, & Bertoncello, 2010; Eston, Rowlands, Coulton, Mckinney, & Gleeson, 2007; Hardy, 1985; Hardy & Jones, 1986; Hartley-O'Brien, 1980; Junker & Stöggl, 2015; Poor, Mohseni, Najafzadeh, Hemmati, & Najafi, 2014; Rowlands, Marginson, & Lee, 2003; Sady, Wortman, & Blanke, 1982), and only three trials studied its long-term effects at one week (Tanigawa, 1972), 15 days (Silva et al., 2012), and eight weeks (Moesch et al., 2014). Intervention durations ranged from one session to 10 weeks. Frequencies of sessions ranged from one to seven times per week. Applications of HR and CR varied: isometric contractions were held for 5–15 s; static stretch and relaxation components lasted for 6–32 s and 3–15 s, respectively; and stretches were repeated one to four times per session. No adverse events were reported in all trials.

3.2. Effects of HR and CR compared with control

Meta-analysis of six trials (median PEDro score = 6.5/10, range = 3–8/10) with a total of 168 participants was done. Studies using the AKE and PKE were analyzed separately. Each analysis demonstrated that HR and CR were better than control in immediately decreasing hamstrings tightness after one session using either AKE (SMD = 0.96, 95% CI = 0.48 to 1.44, I^2 = 33%) or PKE (SMD = 1.19, 95% CI = 0.58 to 1.80, I^2 = 0%) (Fig. 2). One trial (Gama, Medeiros, Dantas, & Souza, 2007) was excluded from the meta-analysis due to non-comparability of groups at baseline (I^2 = 57%). Meta-analysis of four trials (median PEDro score = 5/10, range = 4–5/10) with a total of 101 participants demonstrated that HR and CR were also better than control immediately after multiple sessions ranging from five days to six weeks of intervention using either AKE (SMD = 1.02, 95% CI = 0.44 to 1.59, I^2 = 0%) or SLR (SMD = 1.03, 95% CI = 0.51 to 1.54, I^2 = 1%) (Fig. 3). Three trials were excluded from the meta-analysis due to non-comparability of groups at baseline (Gama et al., 2007; Magalhães et al., 2015; Rowlands et al., 2003) and large number of dropouts (Magalhães et al., 2015) (I^2 = 67%). Two individual trials that measured short-term effects showed that changes lasted 24 h after cessation (SMD = 2.79, CI = 1.67 to 3.92; SMD = 1.04, CI = 0.23 to 1.86) (Junker & Stöggl, 2015; Rowlands et al., 2003) while one trial showed that effects were lost 15 days after cessation (SMD = −0.44, CI = −1.33 to 0.45) (Silva et al., 2012).

3.3. Effects of HR and CR compared with other stretching techniques

Five trials (median PEDro score = 6/10; range = 4–7/10) with 176 participants compared the immediate effects of HR and CR against SS after one session and found a small significant effect in favor of HR and CR on the AKE (SMD = 0.39, 95% CI = 0.02 to 0.76, I^2 = 0%) but no significant difference between the two techniques on the PKE (SMD = 0.15, 95% CI = −0.37 to 0.66, I^2 = 0%) (Fig. 4). Individual trials on the immediate effects of HR and CR against ballistic or dynamic stretching after multiple sessions exhibited inconsistent findings, with one trial showing no significant effects after six consecutive days (Hardy & Jones, 1986) (SMD = 0.08, 95% CI = −1.05 to 1.21) and another showing a large effect after eight weeks (Poor et al., 2014) (SMD = 1.58, 95% CI = 0.55 to 2.62). Other

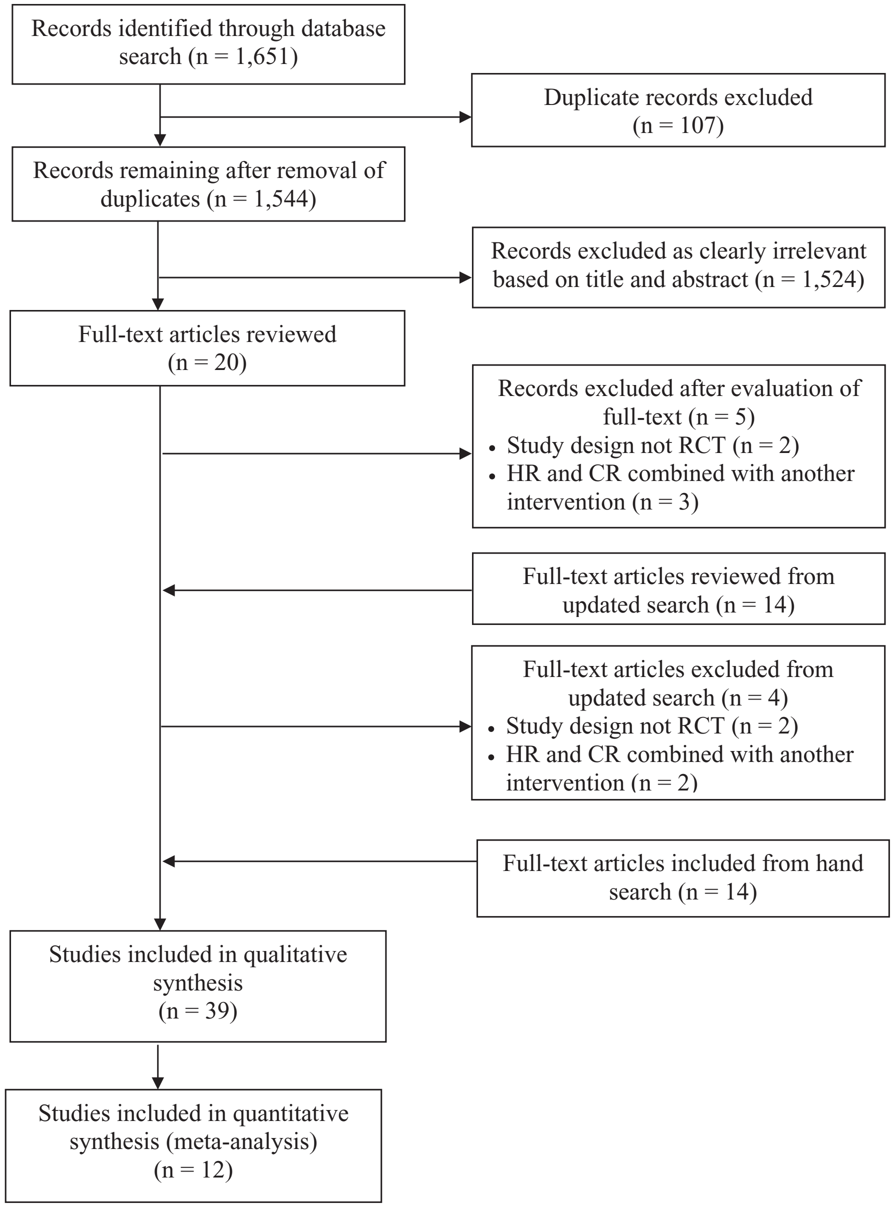

Fig. 1. Flow of studies through selection process.

individual trials showed that immediate effects of HR and CR were not superior to kinesiostretching (SMD = 0.55, 95% CI = −0.24 to 1.33), Mulligan stretching (SMD = −0.43, 95% CI = −1.50 to 0.65), and muscle energy technique (Alcântara, Firmino, & Lage, 2011; Moesch et al., 2014; Yildirim et al., 2016). Individual studies measuring short-term effects of HR and CR against SS showed conflicting results. One study showed a large effect in favor of HR and CR on the PKE (SMD = 2.40, 95% CI = 1.31 to 3.49) (Chebel et al., 2010) and two studies showed no significant differences on the PKE (SMD = −0.02, 95% CI = −0.76 to 0.72) (Mallmann et al., 2011) and AKE (SMD = 0.43, 95% CI = −0.05 to 0.90) (Beltrão et al., 2014). One trial found that the long-term effects of HR and CR after eight weeks were not superior to kinesiostretching (SMD = 0.16, 95% CI = −0.61 to 0.93) (Moesch et al., 2014).

4. Discussion

This systematic review of 39 RCT (n = 1770 participants) demonstrated that: (1) HR and CR were better than control in improving hamstrings flexibility immediately after intervention; (2) the effects of HR and CR can last for at least 24 h but may not be sustained for longer periods of time based on limited evidence; and (3) the superiority of HR and CR to other stretching techniques in terms of immediate, short-term and long-term effects is unclear based on limited evidence. No adverse events were reported. Findings should be interpreted in light of the methodological quality of the available evidence. The median PEDro score of the included trials was relatively low at 4/10, with only a small proportion having important methodological features including assessor blinding (11/39, 28%), allocation concealment (8/39, 21%), and intention-to-treat analysis (1/39, 3%). Clinicians must weigh the available evidence in light of potential threats to internal validity. Consequently, high-quality research is needed to generate definitive evidence for the effects of HR and CR against other techniques.

The large positive effects of HR and CR against control are

Table 1
Characteristics of included trials on HR and CR for hamstrings flexibility (n = 39).

Study	Participants	Experimental condition	Control condition	Comparison condition	Outcome measures	Results	PEDro score
Alcântara et al. (2011)	n = 90 **active adults** Age (*yr*) = 24 (SD 7) Gender = 60 M, 30 F	CR with 10s maximum isometric contraction of agonist against resistance followed by 30s active contraction of quadriceps until point of tissue resistance 1 × 1 session	No intervention	Muscle energy technique using 25% of maximum contraction held for 10s followed by 6s relaxation 3 × 1 session	SLR using goniometer	**CR > CG** **CR > muscle energy technique**	6/10
Azevedo, Melo, Alves Corrêa, and Chalmers (2011)	n = 60 **healthy students** Age (*yr*) = 23 (SD 2) Gender = 60 M, 0 F	CR with 6s isometric contraction at point of hamstrings stretch followed by relaxation and 10s stretch hold 2 × 1 session	No intervention	None	AKE using inclinometer	**CR > CG**	7/10
Beltrão et al. (2014)	n = 70 **young healthy adults** Age (Exp) (*yr*) = 23 (SD 4) Age (Com) (*yr*) = 22 (SD 3) Gender = 32 M, 38 F	CR with 30s stretch hold at point of hamstrings stretch followed by 6s maximal isometric contraction and relaxation 2 × 7 sessions on consecutive d	None	SS using pulley and rope system with 1min stretch hold using 7 kg load 1 × 7 sessions on consecutive d	AKE using goniometer	**CR = SS**	6/10
Brasileiro, Faria, and Queiroz (2007)	n = 40 **healthy students** Age (*yr*) = 22 (SD 3) Gender = 12 M, 28 F	CR with 15s isometric contraction at point of hamstrings stretch followed by 15s relaxation 4 × 10 sessions	No intervention	None	AKE using goniometer	**CR > CG**	5/10
Chebel et al. (2010)	n = 24 **sedentary students** Age range (*yr*) = 18–26 Gender = 0 M, 24 F	Exp = HR with 6s isometric contraction of hamstrings followed by 30s stretch hold 5 × 2/wk x 5 wk	None	SS for 30s 5 × 2/wk x 5 wk	PKE using goniometer	**HR = SS**	4/10
Cornelius, Ebrahim, Watson, and Hill (1992)	n = 120 **healthy students** Age (*yr*) = 22 (SD 3) Gender = 120 M, 0 F	Exp 1 = passive stretch of hip extensors, active stretch facilitated by concentric contraction of hip flexors, and passive stretch of hip extensors 3 × 1 session Exp 2 = passive stretch of hip extensors, 3s maximal isometric contraction of hip extensors, active stretch facilitated by concentric contraction of hip flexors, and passive stretch of hip extensors 3 × 1 session Exp 3 = passive stretch of hip extensors, 3s maximal isometric contraction of hip flexors, active stretch facilitated by concentric contraction of hip flexors, and passive stretch of hip extensors 3 × 1 session	None	SS in agonist pattern (hip flexion) 3 × 1 session	SLR using Leighton flexometer	**CR > SS**	4/10
Davis, Ashby, McCale, McQuain, and Wine (2005)	n = 19 **young healthy adults** Age range (*yr*) = 21–35 Age (*yr*) = 23 (SD 2) Gender = 11 M, 8 F	10s concentric contraction of quadriceps against resistance with hip passively flexed to 90° and knee passively extended, followed by 30s stretch hold 1 × 3/wk x 4 wk	No intervention	Com 1 = active self-stretching for 30s 1 × 3/wk x 4 wk Com 2 = manual SS for 30s 1 × 3/wk x 4 wk	PKE using inclinometer	**CR > CG** **CR < SS** **CR = active self-stretching**	3/10
Eston et al. (2007)	n = 14 **young active students** Age (*yr*) = 21 (SD 1) Gender = 14 M, 0 F	CR with 6s maximal isometric contraction followed by active movement to new range held for 5s 3 x 2x/wk x 5 wk	No intervention	None	Adapted sit-and-reach test using tape measure	**CR > CG**	3/10
Farquharson and Greig (2015)	n = 30 **active adults** Age (*yr*) = 21 (SD 0.1) Gender = 30 M, 0 F	CR with 10s stretch hold at point of hamstrings stretch, 10s contraction against 75% resistance, 3s relaxation, and 10s stretch hold 3 × 1 session	None	SS for 30s with 10s rest 3 × 1 session	AKE using goniometer	**CR = SS**	5/10
							3/10

Table 1 (*continued*)

Study	Participants	Experimental condition	Control condition	Comparison condition	Outcome measures	Results	PEDro score
Fasen et al. (2009)	n = 87 **healthy adults** Age range (*yr*) = 21–57 Age (*yr*) = 33 (SD 8) Age (Exp) (*yr*) = 32 (SD 8) Age (Com 1) (*yr*) = 31 (SD 6) Age (Com 2) (*yr*) = 37 (SD 9) Age (Com 3) (*yr*) = 31 (SD 6) Age (Con) (*yr*) = 36 (SD 10) Gender = 47 M, 40 F	Agonist contraction of quadriceps by actively extending knees with 30s stretch hold 3 × 1 session	No intervention	Com 1 = SS held for 30s 3 × 1 session Com 2 = active-assisted SLR stretch held for 30s 3 × 1 session Com 3 = passive SLR stretch held for 30s 3 × 1 session	PKE using goniometer	**CR > CG** **CR < SLR** **CR = SS**	
Feland and Marin (2004)	n = 72 **healthy students** Age (*yr*) = 23 (SD 2) Age range (*yr*) = 18–27 Gender = 72 M, 0 F	Exp 1 = CR with 6s contraction at 20% of MVIC followed by 10s relaxation and further passive extension 3 × 5d Exp 2 = CR with 6s contraction at 60% of MVIC followed by 10s relaxation and further passive extension 3 × 5d Exp 3 = CR with 6s contraction at 100% of MVIC followed by 10s relaxation and further passive extension 3 × 5d	No intervention	None	PKE using goniometer	**CR > CG**	4/10
Feland, Myrer, and Merrill (2001)	n = 97 **older athletes** Age range = 55–79 Age (*yr*) = 65 Gender = 66 M, 31 F	CR with 6s MVIC of hip extensors followed by 10s relaxation and stretch 2 × 1 session	No intervention	SS for 32s 1 × 1 session	PKE using goniometer	**CR > CG** **CR > SS**	4/10
Ford and McChesney (2007)	n = 32 **active adults** Age (*yr*) = 21 (SD 3) Gender = 18 M, 14 F	CR agonist contract with 6s stretch hold at point of hamstrings stretch followed by 6s isometric contraction and 6s relaxation 4 × 1 session	No intervention	Com 1 = SS using modified hurdler's stretch for 30s followed by 10s relaxation 5 × 1 session Com 2 = active control stretching with knee held in extended position while seated for 10s followed by 10s relaxation 10 × 1 session	AKE using inclinometer	**CR > CG** **CR = SS** **CR = active control stretching**	4/10
Gama et al. (2007)	n = 28 **young healthy adults** Age (*yr*) = 23 (SD 2) Age (Exp 1) (*yr*) = 22 (SD 3) Age (Exp 2) (*yr*) = 23 (SD 2) Age (Con) (*yr*) = 23 (SD 3) Gender = 0 M, 28 F	Exp 1 = HR with 5s contraction at point of hamstrings stretch followed by 30s stretch hold and 10s rest 3 × 3/wk x 10 sessions Exp 2 = HR with 5s contraction at point of hamstrings stretch followed by 30s stretch hold and 10s rest 3 × 5/wk x 10 sessions	No intervention	None	AKE using goniometer	**HR > CG**	5/10
Gama et al. (2007)	n = 36 **young healthy adults** Age (*yr*) = 22 (SD 2) Age (Exp 1) (*yr*) = 22 (SD 1) Age (Exp 2) (*yr*) = 20 (SD 1) Age (Exp 3) (*yr*) = 22 (SD 2) Age (Con)	Exp 1 = HR with 5s contraction at point of hamstrings stretch followed by relaxation and 30s stretch hold 1 × 5/wk x 2 consecutive wk Exp 2 = HR with 5s contraction at point of hamstrings stretch followed by relaxation and 30s stretch hold 3 × 5/wk x 2 consecutive wk Exp 3 = HR with 5s contraction at point of hamstrings stretch followed	No intervention	None	AKE using photometric analysis	**HR > CG**	5/10

(*continued on next page*)

Table 1 (*continued*)

Study	Participants	Experimental condition	Control condition	Comparison condition	Outcome measures	Results	PEDro score
	(*yr*) = 23 (SD 2) Gender = 0 M, 36 F	by relaxation and 30s stretch hold 6 × 5/wk x 2 consecutive wk					
Gribble, Guskiewicz, Prentice, and Shields (1999)	n = 42 **college students** Age (*yr*) = 20 (SD 2) Gender = not specified	HR with 8s stretch hold at point of hamstrings stretch followed by 7s isometric contraction, 5s rest, and 10s stretch hold 4 × 4/wk x 6 wk	No intervention	SS for 30s 4 × 4/wk x 6 wk	AKE and SLR using goniometer	**HR > CG** **HR = SS**	5/10
Hardy (1985)	n = 42 **healthy students** Age range (*yr*) = 18–22 Gender = 0 M, 42 F	Exp 1 = 3s maximal isometric contraction of hip extensors followed by 10s stretch hold 3 × 3 sets x 6 consecutive d Exp 2 = 6s maximal isometric contraction of hip extensors followed by 10s stretch hold 3 × 3 sets x 6 consecutive d Exp 3 = 3s maximal isometric contraction of hip extensor followed by 10s concentric contraction of hip flexors 3 × 3 sets x 6 consecutive d Exp 4 = 6s maximal isometric contraction of hip extensor followed by 10s concentric contraction of hip flexors 3 × 3 sets x 6 consecutive d	No intervention	Com 1 = SS for 30s 3 × 6 consecutive d Com 2 = passive lift, active hold with leg taken to endpoint followed by concentric contraction of hip flexors for 10s 3 × 3 sets x 6 consecutive d	SLR using Leighton flexometer	**CR > CG** **CR > SS**	3/10
Hardy and Jones (1986)	n = 24 **healthy students** Age range (*yr*) = 18–22 Gender = 0 M, 24 F	Passive leg raise to endpoint, 6s MVIC of antagonist, active concentric contraction of agonist, followed by another passive maneuver 3 × 3 sets (30s rest between sets) x 7 daily sessions	No intervention	Com 1 = ballistic stretching as many times as possible in 30s with emphasis on speed 3 (30s rest between rep) x 7 daily sessions Com 2 = ballistic stretching as many times as possible in 30s with emphasis on range 3 (30s rest between rep) x 7 daily sessions	Sproboscopic photography	**CR > CG** **CR = ballistic stretching**	4/10
Hartley-O'Brien (1980)	n = 119 **healthy students** Age (*yr*) = 20 Gender = 0 M, 119 F	Exp 1 = active hip flexion in 6s followed by 6s maximum isometric contraction against resistance 5 × 9 sessions Exp 2 = passive movement to end-point in 6s followed by 6s maximum isometric contraction against resistance 5 × 9 sessions	No intervention	Com 1 = SS for 6s followed by 6s active contraction of hip flexors 5 × 9 sessions Com 2 = dynamic stretch and hold with 4 leg swings starting at 45° angle with 6s hold at endpoint of fourth swing 6 × 9 sessions Com 3 = prolonged stretch for 1min 1 × 9 sessions Com 4 = relaxation method with prolonged stretching at endpoint for 1min with addition of mental relaxation and mind-set technique 1 × 9 sessions	SLR using Leighton flexometer	**CR > CG** **CR = SS** **CR = dynamic stretch**	4/10
Junker and Stöggl (2015)	n = 40 **active adults** Age (*yr*) = 31 (SD 9) Age (Exp) (*yr*) = 33 (SD 11) Age (Con) (*yr*) = 30 (SD 9) Gender = 40 M, 0 F	CR with 6s contraction at 25% MVIC at point of hamstrings stretch followed by 10s stretch 3 × 3 sets x 3/wk x 4 wk	No intervention	None	Stand-and-reach test	**CR > CG**	5/10
Lim, Nam, and Jung (2014)	n = 48 **healthy adults** Age (Exp) (*yr*) = 24 (SD 2) Age (Com) (*yr*) = 22 (SD 2) Age (Con) (*yr*) = 22 (SD 2) Gender = 48 M, 0 F	HR with 6s contraction at point of hamstrings stretch followed by 5s relaxation, 6s contraction, 5s relaxation, and 6s contraction 1 × 1 session	No intervention	SS for 30s 1 × 1 session	AKE using goniometer	**HR > CG** **HR = SS**	6/10
Magalhães et al. (2015)	n = 32 **healthy adults**		No intervention	None	AKE using goniometer	**CR > CG**	3/10

Table 1 (*continued*)

Study	Participants	Experimental condition	Control condition	Comparison condition	Outcome measures	Results	PEDro score
	Age range = 20–25 Age (*yr*) = 22 Gender = 14 M, 18 F	CR with 5s submaximal isometric contraction followed by relaxation and 30s stretch hold					
Mallmann et al. (2011)	n = 41 **healthy adults** Age (*yr*) = 20 (SD 3) Gender = 5 M, 36 F	5s maximum contraction at point of hamstrings stretch followed by 32s stretch hold	None	Com 1 = SS for 32s 1 × 1 session Com 2 = kinesiostretching for 8s 3 × 1 session	PKE using goniometer	**CR = SS** **CR = kinesiostretching**	6/10
Markos (1979)	n = 30 **healthy adults** Age range (*yr*) = 19–34 Age (*yr*) = 22 Gender = 0 M, 30 F	Exp 1 = HR with 9s isometric contraction followed by 3s relaxation 2 × 1 session Exp 2 = CR with 9s maximal contraction followed by 3s relaxation 2 × 1 session	9s isometric contraction against gravity only	None	SLR using plumbline	**HR > CG**	4/10
Minshull, Eston, Bailey, Rees, and Gleeson (2014)	n = 18 **active adults** Age (Exp) (*yr*) = 20 (SD 2) Age (Com) (*yr*) = 21 (SD 2) Gender = 18 M, 0 F	CR agonist contraction with 10s maximal contraction of knee flexors and hip extensors followed by 5s relaxation and 10s stretch hold 3 × 3/wk x 8 wk	None	SS with 10s passive motion at endpoint followed by 5s relaxation 3 × 3/wk x 8 wk	SLR using Leighton flexometer	**CR = SS**	4/10
Moesch et al. (2014)	n = 40 **healthy adults** Age (*yr*) = 20 (SD 3) Gender = 5 M, 35 F	5s maximal contraction at point of hamstrings stretch, followed by relaxation and 32s stretch hold 1 × 3/wk x 6 wk	None	Com 1 = SS for 32s 1 × 3/wk x 6 wk Com 2 = kinesiostretching in sittting, 8s extension of dominant lower limb with flexion and external rotation of contralateral limb, followed by moving torso forward, and performing ankle dorsiflexion and head flexion 3 × 3/wk x 6 wk	PKE using goniometer	**CR = SS** **CR = kinesiostretching**	6/10
O'Hora, Cartwright, Wade, Hough, and Shum (2011)	n = 45 **healthy students** Age (Exp) (*yr*) = 27 (SD 4) Age (Com) (*yr*) = 24 (SD 2) Age (Con) (*yr*) = 26 (SD 3) Gender = 22 M, 23 F	6s contraction of hamstrings against resistance followed by passive movement of knee to full extension 1 x 1 session	No intervention	SS for 30s 1 × 1 session	PKE using goniometer	**CR > CG** **CR > SS**	7/10
Poor et al. (2014)	n = 30 **healthy students** Age range (*yr*) = 18–24 Gender = 30 M, 0 F	Exp 1 = 10s stretch hold followed by 5s contraction, 10s relaxation, and another 10s stretch hold 2 × 5/wk x 8 wk Exp 2 = 10s stretch hold followed by 10s contraction, 10s relaxation, and another 10s stretch hold 2 × 5/wk x 8 wk	None	Dynamic stretching 1 × 5/wk x 8 wk	AKE (unspecified instrument)	**CR = dynamic stretching**	4/10
Prentice (1983)	n = 46 **healthy students** Age range (*yr*) = 18–34 Gender = not specified	10s isometric contraction of hamstrings at endpoint followed by relaxation and contraction of quadriceps until further stretch was felt in hamstrings 3 × 3/wk x 10 wk	None	SS for 10 s at endpoint followed by 10s relaxation 3 × 3/wk x 10 wk	SLR using goniometer	**CR > SS**	2/10
Rezaeeshirizi, Zanganeh and Beiki (2012)	n = 60 **healthy students** Age (Exp) (*yr*) = 22 (SD 7) Age (Con) (*yr*) = 22 (SD 5) Gender = 60 M, 0 F	HR with 10s stretch hold followed by 3s rest 3 × 3/wk x 4 wk	No intervention	None	SLR (unspecified instrument)	**HR > CG**	4/10
Rowlands et al. (2003)	n = 37 **healthy students** Age (*yr*) = 20 (SD	Exp 1 = CR agonist contract with 5s maximal isometric contraction of hamstrings followed by 5s relaxation and 10s stretch hold	No intervention	None	SLR using Leighton flexometer	**CR > CG**	3/10

(*continued on next page*)

Table 1 (*continued*)

Study	Participants	Experimental condition	Control condition	Comparison condition	Outcome measures	Results	PEDro score
	1) Gender = 0 M, 37 F	3 × 2/wk x 6 wk Exp 2 = CR agonist contract with 10s MVIC followed by 5s relaxation and 10s stretch hold 3 × 2/wk x 6 wk					
Sady et al. (1982)	n = 43 **healthy students** Age (*yr*) = 23 (SD 3) Gender = 43 M, 0 F	6s contraction followed by relaxation and further stretch 3 × 3/wk x 6 wk	No intervention	Com 1 = ballistic stretching through full range of motion 20 × 3/wk x 6 wk Com 2 = SS for 6s followed by relaxation 3 × 3/wk x 6 wk	SLR using Leighton flexometer	**CR > CG** **CR > SS** **CR > ballistic stretching**	3/10
Schuback, Hooper, and Salisbury (2004)	n = 40 **healthy students** Age (Exp 1) (*yr*) = 34 (SD 10) Age (Exp 2) (*yr*) = 35 (SD 11) Age (Con) (*yr*) = 38 (SD 13) Gender = 20 M, 20 F	Exp 1 = active SLR followed by 15s isometric contraction against self-induced resistance through the hands followed by 15s relaxation; leg straightened after each repetition 4 × 1 session Exp 2 = 15s contraction against therapist resistance at point of hamstrings tightness followed by 15s relaxation 4 × 1 session	No intervention	None	SLR using goniometer	**CR > CG**	7/10
Silva et al. (2012)	n = 30 **healthy students** Age range (*yr*) = 19–40 Age (*yr*) = 24 Gender = 30 M, 0 F	Exp 1 = HR in sagittal plane with 5s isometric contraction followed by 15s relaxation 6 × 5d Exp 2 = HR in diagonal plane with 5s isometric contraction followed by 15s relaxation 6 (3 in medial plane and 3 in lateral plane) x 5d	No intervention	None	SLR using Flexis fleximeter	**HR > CG**	4/10
Spernoga, Uhl, Arnold, and Gansneder (2001)	n = 30 **military cadets** Age (*yr*) = 19 (SD 1) Gender = 30 M, 0 F	Modified HR with no hip rotation with 7s stretch hold, followed by 7s maximal isometric contraction of hamstrings and 5s relaxation 5 × 1 session	No intervention	None	AKE using goniometer	**HR > CG**	3/10
Tanigawa (1972)	n = 30 **healthy adults** Age range (*yr*) = 20–48 Age (Exp) (*yr*) = 26 Age (Com) (*yr*) = 24 Age (Con) (*yr*) = 27 Gender = 30 M, 0 F	HR using 2 diagonal patterns with 7s isometric contraction followed by 5s rest 2 for each pattern x 2/wk x 4 wk	No intervention	Passive mobilization stretch (limb elevated until pulling sensation in posterior knee, with further elevation at moderate rate of 2s followed by 5s hold and 5s rest) 4 × 2/wk x 4 wk	SLR using plumb line	**HR > CG** **HR > passive mobilization**	4/10
Trampas, Kitsios, Sykaras, Symeonidis, and Lazarou (2010)	n = 30 **healthy students** Age (Exp) (*yr*) = 21 (SD 1) Age (Con) (*yr*) = 21 (SD 1) Gender = 30 M, 0 F	Modified CR without hip rotation with 15s stretch hold at point of hamstrings stretch, followed by 6s maximal isometric contraction, relaxation, and 10s stretch hold with 30s rest period between each repetition 3 × 1 session	No intervention	None	PKE using goniometer	**CR > CG**	7/10
Yıldırım, Ozyurek, Tosun, Uzer, and Gelecek (2016)	n = 26 **young healthy adults** Age (*yr*) = 22 (SD 1) Gender = 17 M, 9 F	HR with isometric contraction for 10s, relaxation for 10s, followed by straightening of leg 1 x 3x/wk x 4 wk	No intervention	Com 1 = SS for 30s 10 x 3x/wk x 4 wk Com 2 = traction applied to leg while lifting limb through pain-free range of SLR until onset of discomfort (Mulligan stretching) 3 x 3x/wk x 4 wk	SLR using digital goniometer	**HR > CG** **HR = Mulligan stretching** **HR > SS**	5/10
Yuktasir and Kaya (2009)	n = 28 **healthy students** Age (*yr*) = 22 (SD 2) Gender = 28 M, 0 F	CR with 10s stretch followed by 5s contraction, 5s relaxation, and 15s stretch hold with 10s rest period between repetitions 4 × 4/wk x 6 wk	No intervention	SS for 30s with 10s rest period between repetitions 4 × 4/wk x 6 wk	PKE using goniometer	**CR > CG** **CR = SS**	5/10

Abbreviations: AKE, active knee extension test; Com, comparator stretching group; CG, control group; CR, contract-relax; Exp, experimental group; HR, hold-relax; MVIC, maximum voluntary isometric contraction; PKE, passive knee extension test; SLR, straight leg raise.

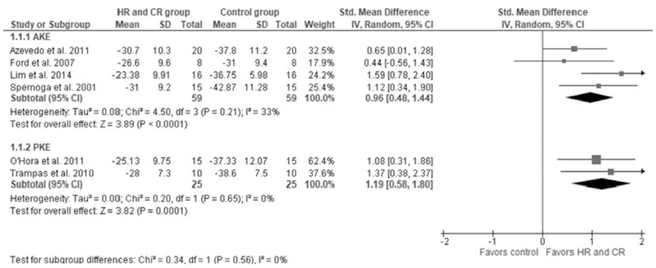

Fig. 2. Pooled SMD (95% CI) of effect of HR and CR stretching compared with control on hamstrings flexibility: immediately after one session, six trials (n = 168). Abbreviations: AKE, active knee extension test; IV, inverse variance analysis; PKE, passive knee extension test; Std., standard.

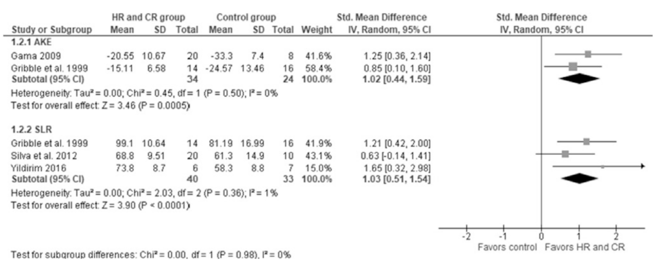

Fig. 3. Pooled SMD (95% CI) of effect of HR and CR stretching compared with control on hamstrings flexibility immediately after multiple sessions, four trials (n = 101). Abbreviations: AKE, active knee extension test; IV, inverse variance analysis; SLR, straight leg raise; Std., standard.

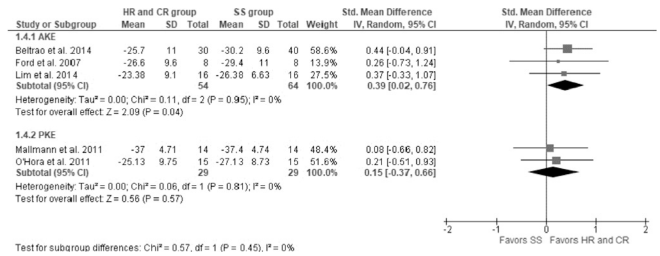

Fig. 4. Pooled SMD (95% CI) of effect of HR and CR compared with SS on hamstrings flexibility immediately after one session, five trials (n = 176). Abbreviations: AKE, active knee extension test; IV, inverse variance analysis; PKE, passive knee extension test; Std., standard.

consistent with literature that theoretically predicts HR and CR to be effective in enhancing immediate and short-term flexibility (Hindle, Whitcomb, Briggs, & Hong, 2012; Smedes, Heidmann, Schäfer, Fischer, & Stępień, 2016; Westwater-Wood, Adams, & Kerry, 2010). Exact mechanisms underpinning such flexibility gains are not well established although there appears to be both mechanical and neural factors involved (Guissard & Duchateau, 2006). Adding muscle contractions, regardless of intensity and duration, prior to stretching decreases muscle stiffness and transiently inhibits spinal reflexes long enough to be advantageous for subsequent stretching (Guissard & Duchateau, 2006). These changes in neural excitability need to be investigated further as originally proposed mechanisms, such as reciprocal and autogenic inhibition, lack convincing empirical evidence (Chalmers, 2004; Ferber, Osternig, & Gravelle, 2002; Mitchell et al., 2009; Olivo & Magee, 2006; Sharman et al., 2006; Smedes et al., 2016). The positive large effects that lasted for more than 24 h in individual trials (Junker and Stoggl, 2015; Rowlands et al., 2003) suggest that HR and CR may induce structural adaptations in soft tissues but this hypothesis warrants further study. Alteration in stretch tolerance is suggested as a more plausible explanation for HR- and CR-related gains (Behm, Blazevich, Kay, & McHugh, 2016; Laessøe & Voigt, 2004; Sharman et al., 2006; Smedes et al., 2016), with progressive increases in stretch tolerance observed after repeated procedures (Mitchell et al., 2007). It is worth exploring the mechanisms of HR and CR that can explain immediate and short-term effects. Regardless, this systematic review informs clinicians that they can expect large effects on hamstrings flexibility when applying the technique in practice.

Evidence from one trial suggests that gains from HR and CR may be lost days after cessation (Silva et al., 2012). This finding is important to consider since transient effects have little clinical usefulness (Katalinic et al., 2011). Systematic review evidence indicates that acute bouts of stretching may not translate to functional gains, while regular stretching does (Shrier, 2004). Wallin, Ekblom, Grahn, and Nordenborg (1985) found that continuation of CR at least once a week was necessary to maintain gains. Therefore, if the goal is to induce functional changes to minimize injury risk, stretching must be administered routinely. A potential challenge is that HR and CR procedures require several steps, making it difficult for some clients to carry out unsupervised (Schuback et al., 2004) or unassisted (Behm et al., 2016). Clinicians need to consider this dimension when planning routine use among clients outside of therapist-supervised sessions.

This study found small immediate effects in favor of HR and CR compared to SS using the AKE, in contrast to the findings of a recent systematic review (Borges et al., 2018). However, the finding of this study that CR was not superior to SS in inducing long-term changes was in agreement with that of this earlier systematic review. Nonetheless, this study parallels previous systematic reviews in that HR and CR stretching is effective in immediately improving hamstrings flexibility (Borges et al., 2018; Decoster et al., 2005; Harvey et al., 2002; Medeiros et al., 2016). Further, the current study highlights the lack of available published studies that makes it difficult to ascertain the superiority of HR and CR over other types of stretching techniques apart from SS. Limited evidence from individual trials showed either conflicting or no evidence of the superiority of HR and CR to other stretching techniques. Musculotendinous unit changes attributed to HR and CR, and other stretching techniques are underpinned by similar theories such as stress relaxation, creep, post-stretch decreases in motor neuron excitability, and increased stretch tolerance (Behm et al., 2016; Magnusson et al., 1996; Weppler & Magnusson, 2010). A possible reason for the inability of trials to clarify any difference of HR and CR against other stretching techniques may be the insufficiency of stretching exercise prescription parameters applied in the interventions. HR and CR techniques are recommended to be repeated until no more range is gained (Adler et al., 2008), although the included trials only used 1–4 repetitions. Although isometric contractions used across trials concurred with recommended parameters (Adler et al., 2008; Kwak & Ryu, 2015), the stretching component varied in duration from 6 to 32 s and was generally sub-optimal based on recommendations (Ryan et al., 2008). Stretching intensity is an important consideration in potentially influencing changes in joint flexibility (Apostolopoulos, Metsios, Flouris, Koutedakis, & Wyon, 2015), however none of the included trials examined its effects. Overall, this systematic review provides additional knowledge on the comparative effects of HR and CR against various other stretching techniques for improving hamstrings flexibility and builds on previous systematic reviews. It highlights gaps in the knowledge on the comparative long-term effects of stretching techniques and optimal exercise prescription parameters for stretching.

Several methodological strengths underpin the present findings. Only trials that used HR and CR without being combined with other treatments were included, allowing the research questions to be answered directly. Comprehensiveness of the literature search was enhanced by using multiple electronic databases, keyword searching without restrictions on publication language and date, contacting authors for additional data, hand searching included and relevant studies, and conducting an updated search up to May 31, 2017. Risk of bias in included studies was assessed using widely used criteria. All included studies were RCT and results were pooled through meta-analysis, which represented highest-level evidence for treatment effects. Finally, use of bias-corrected ES diminished the possibility of overestimating the effects of HR and CR stretching.

4.1. Study limitations

Findings need to be interpreted considering several limitations. Exclusion of unpublished literature might have introduced publication bias. Differences in outcome measures and incomplete data reporting in some included trials precluded further quantitative synthesis. Limited conclusions could be made regarding comparative effects of HR and CR versus other stretching techniques due to insufficient available evidence. Conclusions were based on relatively low quality data (median PEDro score = 4/10) and therefore high risk of bias. Key methodological issues such as lack of allocation concealment, baseline participant group comparability, assessor blinding, and intention-to-treat analysis limited the strength of conclusions of the included trials. Most trials did not carry out power calculation in determining sample size, which could negatively impact statistical conclusions.

5. Conclusion

Current best evidence from multiple RCT with generally low-to moderate-quality trials in adults demonstrates that HR and CR are safe and effective in increasing hamstrings flexibility immediately within-session and after repeated administration (ie, it is better than control/nothing). Conflicting or limited evidence from generally low-to moderate-quality trials demonstrates that HR and CR have long-term effects and are superior to other stretching techniques. Long-term effects of HR and CR and superiority to other stretching techniques require further examination. Further research to test effects of HR and CR should use rigorous trial designs, and apply optimal exercise prescription parameters. Although clinicians can expect large gains following administration of HR and CR, a regular stretching routine is needed to maintain gains and for such gains to be clinically useful.

Conflicts of interest

None.

Ethical statements

None declared.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements

We are grateful to Aila Nica Bandong, Maria Eliza Aguila, Maricar Maandal, and Lenin Grajo for providing assistance in locating key literature used in this review, and Marina De Barros Pinheiro for providing mentoring for the meta-analysis.

Appendix 1. PubMed search strategy

1. Muscle stretching exercises [MeSH]
2. Proprioceptive neuromuscular facilitation
3. Hamstrings
4. Stretch*
5. Flexib*
6. PNF
7. Neuromuscular facilitation
8. PNF stretch*
9. Proprioceptive
10. Proprioceptive neuromuscular facilitation patterns
11. Randomized controlled trial
12. RCT
13. Quasi-randomized study
14. Quasi-randomized controlled trial
15. Controlled clinical trial
16. Proprioceptive neuromuscular facilitation techniques
17. Knee flexors
18. Hip extensors
19. Connective tissue
20. Tissue manipulation
21. Soft tissue mobilization
22. Therapeutic exercise
23. Dynamic stretching
24. Isometric stretching
25. Active stretching
26. Passive stretching
27. Muscle length
28. ROM
29. Range of motion
30. Joint range of motion
31. Joint flexibility
32. Extensib*
33. Flex*
34. Adapt*
35. Pliab*
36. Tight*
37. Contracture
38. Muscle tightness
39. Muscular tension
40. Muscle tone
41. Shorten*
42. Straight leg raise
43. SLR
44. Active knee extension test
45. Manual therapy
46. Neurofacilitation
47. (#1 OR #2 OR # 6 OR # 7 OR #8 OR #9 #10 OR #16 OR #45 OR #46)
48. (#3 OR #17 OR #18 OR #19)
49. (#4 OR #20 OR #21 OR #22 OR #23 OR #24 OR #25 OR #26)
50. (#5 OR #27 OR #28 OR #29 OR #30 OR #31 OR #32 OR #33 OR #34 OR #35 OR #36 OR #37 OR #38 OR #39 OR #40 OR #41 OR #42 OR #43 OR #44)
51. (#11 OR #12 OR #13 OR #14 OR #15)
52. (#47 AND #48 AND #49 AND #50 AND #51)

Appendix 2. Methodological quality assessment of included trials using PEDro scale (n = 39)

Study	1	2	3	4	5	6	7	8	9	10	11	Total
Alcântara et al. (2011)	Y	Y	Y	N	N	N	Y	Y	N	Y	Y	6
Azevedo et al. (2011)	N	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Beltrão et al. (2014)	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Brasileiro et al. (2007)	Y	Y	Y	N	N	N	N	Y	N	Y	Y	5
Chebel et al. (2010)	Y	Y	N	Y	N	N	N	N	N	Y	Y	4
Cornelius et al. (1992)	Y	Y	N	N	N	N	N	Y	N	Y	Y	4
Davis et al. (2005)	N	Y	N	N	N	N	Y	N	N	Y	N	3
Eston et al. (2007)	N	Y	N	N	N	N	N	N	N	Y	Y	3
Farquharson and Greig (2015)	Y	Y	N	Y	N	N	N	Y	N	Y	Y	5
Fasen et al. (2009)	N	Y	N	N	N	N	N	Y	N	Y	N	3
Feland and Marin (2004)	N	Y	N	N	N	N	N	Y	N	Y	Y	4
Feland et al. (2001)	Y	Y	N	N	N	N	N	Y	N	Y	Y	4
Ford and McChesney (2007)	Y	Y	N	Y	N	N	N	Y	N	Y	Y	4
Gama et al. (2007)	N	Y	N	N	N	N	Y	Y	N	Y	Y	5
Gama et al. (2007)	Y	Y	N	Y	N	N	N	Y	N	Y	Y	5
Gribble et al. (1999)	Y	Y	N	Y	N	N	N	Y	N	Y	Y	5
Hardy (1985)	Y	Y	N	N	N	N	N	N	N	Y	Y	3
Hardy and Jones (1986)	N	Y	N	Y	N	N	N	N	N	Y	Y	4
Hartley-O'Brien (1980)	Y	Y	N	Y	N	N	N	N	N	Y	N	4
Junker and Stöggl (2015)	Y	Y	N	Y	N	N	N	Y	N	Y	Y	5
Lim et al. (2014)	Y	Y	Y	Y	N	N	N	Y	N	Y	Y	6
Magalhães et al. (2015)	N	Y	N	N	N	N	N	N	N	Y	Y	3
Mallmann et al. (2011)	N	Y	Y	Y	N	N	Y	Y	N	Y	Y	6
Markos (1979)	Y	Y	N	N	N	N	N	Y	N	Y	Y	4
Minshull et al. (2014)	N	Y	N	Y	N	N	N	N	N	Y	Y	4
Moesch et al. (2014)	Y	Y	Y	Y	N	N	Y	N	N	Y	Y	6
O'Hora et al. (2011)	Y	Y	N	Y	N	N	Y	Y	N	Y	Y	7
Poor et al. (2014)	Y	Y	N	N	N	N	N	N	N	Y	Y	4
Prentice (1983)	Y	Y	N	N	N	N	N	N	N	Y	N	2
Rezaeeshirizi et al. (2012)	Y	Y	N	Y	N	N	N	N	N	Y	Y	4
Rowlands et al. (2003)	Y	Y	N	N	N	N	N	N	N	Y	Y	3
Sady et al. (1982)	N	Y	N	Y	N	N	N	N	N	Y	Y	3
Schuback et al. (2004)	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Silva et al. (2012)	Y	Y	N	Y	N	N	N	N	N	Y	Y	4
Spernoga et al. (2001)	Y	Y	N	N	N	N	N	N	N	Y	Y	3
Tanigawa (1972)	Y	Y	N	Y	N	N	N	Y	N	Y	N	4
Trampas et al. (2010)	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Yildirim et al. (2016)	N	Y	N	Y	N	N	Y	N	N	Y	Y	5
Yuktasir and Kaya (2009)	Y	Y	N	N	N	N	Y	Y	N	Y	Y	5
Studies that satisfied each criterion	27 (69%)	39 (100%)	8 (21%)	22 (56%)	0 (0%)	0 (0%)	11 (28%)	22 (56%)	1 (3%)	39 (100%)	34 (87%)	

References

Adler, S., Beckers, D., & Buck, M. (2008). *PNF in practice* (3rd ed.). Heidelberg, Germany: Springer-Verlag.

Alcântara, M., Firmino, F., & Lage, R. (2011). Efeitos agudos do alongamento: uma comparação entre as técnicas de facilitação neuromuscular. *Revista Brasileira de Ciência e Movimento, 18*(3), 35–42.

Apostolopoulos, N., Metsios, G. S., Flouris, A. D., Koutedakis, Y., & Wyon, M. A. (2015). The relevance of stretch intensity and position-a systematic review. *Frontiers in Psychology, 6*, 1128. https://doi.org/10.3389/fpsyg.2015.01128.

Azevedo, D. C., Melo, R. M., Alves Corrêa, R. V., & Chalmers, G. (2011). Uninvolved versus target muscle contraction during contract: Relax proprioceptive neuromuscular facilitation stretching. *Physical Therapy in Sport, 12*(3), 117–121. https://doi.org/10.1016/j.ptsp.2011.04.003.

Bahr, R., & Holme, I. (2003). Risk factors for sports injuries–a methodological approach. *British Journal of Sports Medicine, 37*(5), 384–392.

Behm, D. G., Blazevich, A. J., Kay, A. D., & McHugh, M. (2016). Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: A systematic review. *Applied Physiology Nutrition and Metabolism, 41*(1), 1–11. https://doi.org/10.1139/apnm-2015-0235.

van Beijsterveldt, A. M. C., van de Port, I. G. L., Vereijken, A. J., & Backx, F. J. G. (2013). Risk factors for hamstring injuries in male soccer players: A systematic review of prospective studies. *Scandinavian Journal of Medicine & Science in Sports, 23*(3), 253–262. https://doi.org/10.1111/j.1600-0838.2012.01487.x.

Beltrão, N. B., Ritti-Dias, R. M., Pitangui, A. C. R., & De Araújo, R. C. (2014). Correlation between acute and short-term changes in flexibility using two stretching techniques. *International Journal of Sports Medicine, 35*(14), 1151–1154. https://doi.org/10.1055/s-0034-1382018.

Borges, M. O., Medeiros, D. M., Minotto, B. B., & Lima, C. S. (2018). Comparison between static stretching and proprioceptive neuromuscular facilitation on hamstring flexibility: Systematic review and meta-analysis. *European Journal of Physiotherapy, 20*(1), 12–19. https://doi.org/10.1080/21679169.2017.1347708.

Brasileiro, J. S., Faria, A. F., & Queiroz, L. L. (2007). Influence of local cooling and warming on the flexibility of the hamstring muscles. *Brazilian Journal of Physical Therapy, 11*(1), 57–61. https://doi.org/10.1590/S1413-35552007000100010.

Chalmers, G. (2004). Re-examination of the possible role of Golgi tendon organ and muscle spindle reflexes in proprioceptive neuromuscular facilitation muscle stretching. *Sports Biomechanics, 3*, 159–183.

Chebel, K. J., Galuppo, D. F., Cardoso de Sá, C. dos S., & Bertoncello, D. (2010). Comparative study about two types of muscle stretching with gain on joint movement. *Revista de Atenção à Saúde, 5*(14), 27–31. https://doi.org/10.13037/rbcs.vol5n14.387.

Cochrane. (2011). *Cochrane training*. http://training.cochrane.org/resource/data-collection-forms-intervention-reviews. (Accessed 13 December 2016).

Cornelius, W. L., Ebrahim, K., Watson, J., & Hill, D. W. (1992). The effects of cold application and modified PNF stretching techniques on hip joint flexibility in college males. *Research Quarterly for Exercise & Sport, 63*(3), 311–314. https://doi.org/10.1080/02701367.1992.10608747.

Croisier, J.-L. (2004). Factors associated with recurrent hamstring injuries. *Sports Medicine (Auckland, N.Z.), 34*(10), 681–695.

Davis, D. S., Ashby, P. E., McCale, K. L., McQuain, J. A., & Wine, J. M. (2005). The effectiveness of 3 stretching techniques on hamstring flexibility using consistent stretching parameters. *The Journal of Strength & Conditioning Research, 19*(1), 27–32. https://doi.org/10.1519/14273.1.

Decoster, L. C., Cleland, J., Altieri, C., & Russell, P. (2005). The effects of hamstring stretching on range of motion: A systematic literature review. *Journal of Orthopaedic & Sports Physical Therapy, 35*(6), 377–387. https://doi.org/10.2519/jospt.2005.35.6.377.

Depino, G. M., Webright, W. G., & Arnold, B. L. (2000). Duration of maintained hamstring flexibility after cessation of an acute static stretching protocol. *Journal of Athletic Training, 35*(1), 56–59.
Eston, R., Rowlands, A. V., Coulton, D., Mckinney, J., & Gleeson, N. (2007). Effect of flexibility training on symptoms of exercise-induced muscle damage: A preliminary study. *Journal of Exercise Science and Fitness, 5*(1), 33–39.
Farquharson, C., & Greig, M. (2015). Temporal efficacy of kinesiology tape vs. Traditional stretching methods on hamstring extensibility. *International Journal of Sports Physical Therapy, 10*(1), 45–51.
Fasen, J. M., O'Connor, A. M., Schwartz, S. L., Watson, J. O., Plastaras, C. T., Garvan, C. W., … Akuthota, V. (2009). A randomized controlled trial of hamstring stretching: Comparison of four techniques. *The Journal of Strength & Conditioning Research, 23*(2), 660–667. https://doi.org/10.1519/JSC.0b013e318198fbd1.
Feland, J. B., & Marin, H. N. (2004). Effect of submaximal contraction intensity in contract-relax proprioceptive neuromuscular facilitation stretching. *British Journal of Sports Medicine, 38*(4), E18. https://doi.org/10.1136/bjsm.2003.010967.
Feland, J. B., Myrer, J. W., & Merrill, R. M. (2001). Acute changes in hamstring flexibility: PNF versus static stretch in senior athletes. *Physical Therapy in Sport, 2*(4), 186–193. https://doi.org/10.1054/ptsp.2001.0076.
Ferber, R., Osternig, L., & Gravelle, D. (2002). Effect of PNF stretch techniques on knee flexor muscle EMG activity in older adults. *Journal of Electromyography and Kinesiology, 12*(5), 391–397.
Ford, P., & McChesney, J. (2007). Duration of maintained hamstring ROM following termination of three stretching protocols. *Journal of Sport Rehabilitation, 16*(1), 18–27.
Gama, Z. A. da S., Medeiros, C. A. de S., Dantas, A. V. R., & Souza, T. O. de (2007). Influence of the stretching frequency using proprioceptive neuromuscular facilitation in the flexibility of the hamstring muscles. *Revista Brasileira de Medicina do Esporte, 13*(1), 33–38. https://doi.org/10.1590/S1517-86922007000100008.
Gaudreault, N., Fuentes, A., Mezghani, N., Gauthier, V. O., & Turcot, K. (2013). Relationship between knee walking kinematics and muscle flexibility in runners. *Journal of Sport Rehabilitation, 22*(4), 279–287.
Göeken, L. N., & Hof, A. L. (1991). Instrumental straight-leg raising: A new approach to Lasègue's test. *Archives of Physical Medicine and Rehabilitation, 72*(12), 959–966.
Gribble, P. A., Guskiewicz, K. M., Prentice, W. E., & Shields, E. W. (1999). Effects of static and hold-relax stretching on hamstring range of motion using the FlexAbility LE1000. *Journal of Sport Rehabilitation, 8*(3), 195–208. https://doi.org/10.1123/jsr.8.3.195.
Guissard, N., & Duchateau, J. (2006). Neural aspects of muscle stretching. *Exercise and Sport Sciences Reviews, 34*(4), 154–158. https://doi.org/10.1249/01.jes.0000240023.30373.eb.
Hardy, L. (1985). Improving active range of hip flexion. *Research Quarterly for Exercise & Sport, 56*(2), 111–114. https://doi.org/10.1080/02701367.1985.10608444.
Hardy, L., & Jones, D. (1986). Dynamic flexibility and proprioceptive neuromuscular facilitation. *Research Quarterly for Exercise & Sport, 57*(2), 150–153. https://doi.org/10.1080/02701367.1986.10762191.
Hartley-O'Brien, S. J. (1980). Six mobilization exercises for active range of hip flexion. *Research Quarterly for Exercise & Sport, 51*(4), 625–635. https://doi.org/10.1080/02701367.1980.10609323.
Harvey, L. A., Byak, A. J., Ostrovskaya, M., Glinsky, J., Katte, L., & Herbert, R. D. (2003). Randomised trial of the effects of four weeks of daily stretch on extensibility of hamstring muscles in people with spinal cord injuries. *Australian Journal of Physiotherapy, 49*(3), 176–181.
Harvey, L., Herbert, R., & Crosbie, J. (2002). Does stretching induce lasting increases in joint ROM? A systematic review. *Physiotherapy Research International, 7*(1), 1–13.
Higgins, J. P. T., & Green, S. (Eds.). (2011). *Cochrane handbook for systematic reviews of interventions*. The Cochrane Collaboration.
Hindle, K. B., Whitcomb, T. J., Briggs, W. O., & Hong, J. (2012). Proprioceptive Neuromuscular Facilitation (PNF): Its mechanisms and effects on range of motion and muscular function. *Journal of Human Kinetics, 31*, 105–113. https://doi.org/10.2478/v10078-012-0011-y.
Hrysomallis, C. (2013). Injury incidence, risk factors and prevention in Australian rules football. *Sports Medicine, 43*(5), 339–354. https://doi.org/10.1007/s40279-013-0034-0.
Jüni, P., Witschi, A., Bloch, R., & Egger, M. (1999). The hazards of scoring the quality of clinical trials for meta-analysis. *Journal of the American Medical Association, 282*(11), 1054–1060.
Junker, D. H., & Stöggl, T. L. (2015). The foam roll as a tool to improve hamstring flexibility. *The Journal of Strength & Conditioning Research, 29*(12), 3480–3485. https://doi.org/10.1519/JSC.0000000000001007.
Katalinic, O. M., Harvey, L. A., & Herbert, R. D. (2011). Effectiveness of stretch for the treatment and prevention of contractures in people with neurological conditions: A systematic review. *Physical Therapy, 91*(1), 11–24. https://doi.org/10.2522/ptj.20100265.
Kay, A. D., Husbands-Beasley, J., & Blazevich, A. J. (2015). Effects of contract-relax, static stretching, and isometric contractions on muscle-tendon mechanics. *Medicine & Science in Sports & Exercise, 47*(10), 2181–2190. https://doi.org/10.1249/MSS.0000000000000632.
Konrad, A., Stafilidis, S., & Tilp, M. (2017). Effects of acute static, ballistic, and PNF stretching exercise on the muscle and tendon tissue properties. *Scandinavian Journal of Medicine & Science in Sports, 27*(10), 1070–1080. https://doi.org/10.1111/sms.12725.
Kubo, K., Kanehisa, H., & Fukunaga, T. (2002). Effect of stretching training on the viscoelastic properties of human tendon structures in vivo. *Journal of Applied Physiology, 92*(2), 595–601. https://doi.org/10.1152/japplphysiol.00658.2001.
Kubo, K., Kanehisa, H., Kawakami, Y., & Fukunaga, T. (2001). Influence of static stretching on viscoelastic properties of human tendon structures in vivo. *Journal of Applied Physiology, 90*(2), 520–527.
Kwak, D. H., & Ryu, Y. U. (2015). Applying proprioceptive neuromuscular facilitation stretching: Optimal contraction intensity to attain the maximum increase in range of motion in young males. *Journal of Physical Therapy Science, 27*(7), 2129–2132. https://doi.org/10.1589/jpts.27.2129.
Laessøe, U., & Voigt, M. (2004). Modification of stretch tolerance in a stooping position. *Scandinavian Journal of Medicine & Science in Sports, 14*(4), 239–244. https://doi.org/10.1111/j.1600-0838.2003.00332.x.
Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., … Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. *Journal of Clinical Epidemiology, 62*(10), e1–e34. https://doi.org/10.1016/j.jclinepi.2009.06.006.
Lim, K.-I., Nam, H.-C., & Jung, K.-S. (2014). Effects on hamstring muscle extensibility, muscle activity, and balance of different stretching techniques. *Journal of Physical Therapy Science, 26*(2), 209–213. https://doi.org/10.1589/jpts.26.209.
Magalhães, F. E. X., Junior, A. R. de M., Meneses, H. T. de S., Moreira Dos Santos, R. P., Rodrigues, E. C., Gouveia, S. S. V., … Machado, D.de C. D. (2015). Comparison of the effects of hamstring stretching using proprioceptive neuromuscular facilitation with prior application of cryotherapy or ultrasound therapy. *Journal of Physical Therapy Science, 27*(5), 1549–1553. https://doi.org/10.1589/jpts.27.1549.
Magnusson, S. P., Simonsen, E. B., Aagaard, P., Dyhre-Poulsen, P., McHugh, M. P., & Kjaer, M. (1996). Mechanical and physical responses to stretching with and without preisometric contraction in human skeletal muscle. *Archives of Physical Medicine and Rehabilitation, 77*(4), 373–378.
Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M., & Elkins, M. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. *Physical Therapy, 83*(8), 713–721.
Malliaropoulos, N., Papalexandris, S., Papalada, A., & Papacostas, E. (2004). The role of stretching in rehabilitation of hamstring injuries: 80 athletes follow-up. *Medicine & Science in Sports & Exercise, 36*(5), 756–759.
Mallmann, J. S., Moesch, J., Tomé, F., Vieira, L., Ciqueleiro, R. T., & Bertolini, G. R. F. (2011). Comparison between the immediate and acute effect of three stretching protocols of hamstrings and paravertebral muscles. *Revista da Sociedade Brasileira de Clínica Médica, 9*(5), 354–359.
Markos, P. D. (1979). Ipsilateral and contralateral effects of proprioceptive neuromuscular facilitation techniques on hip motion and electromyographic activity. *Physical Therapy, 59*(11), 1366–1373.
McHugh, M. P., & Cosgrave, C. H. (2010). To stretch or not to stretch: The role of stretching in injury prevention and performance. *Scandinavian Journal of Medicine & Science in Sports, 20*(2), 169–181. https://doi.org/10.1111/j.1600-0838.2009.01058.x.
Medeiros, D. M., Cini, A., Sbruzzi, G., & Lima, C. S. (2016). Influence of static stretching on hamstring flexibility in healthy young adults: Systematic review and meta-analysis. *Physiotherapy Theory and Practice, 32*(6), 438–445. https://doi.org/10.1080/09593985.2016.1204401.
Messier, S. P., Legault, C., Schoenlank, C. R., Newman, J. J., Martin, D. F., & DeVita, P. (2008). Risk factors and mechanisms of knee injury in runners. *Medicine & Science in Sports & Exercise, 40*(11), 1873–1879. https://doi.org/10.1249/MSS.0b013e31817ed272.
Minshull, C., Eston, R., Bailey, A., Rees, D., & Gleeson, N. (2014). The differential effects of PNF versus passive stretch conditioning on neuromuscular performance. *European Journal of Sport Science, 14*(3), 233–241. https://doi.org/10.1080/17461391.2013.799716.
Mitchell, U. H., Myrer, J. W., Hopkins, J. T., Hunter, I., Feland, J. B., & Hilton, S. C. (2007). Acute stretch perception alteration contributes to the success of the PNF "contract-relax" stretch. *Journal of Sport Rehabilitation, 16*(2), 85–92.
Mitchell, U. H., Myrer, J. W., Hopkins, J. T., Hunter, I., Feland, J. B., & Hilton, S. C. (2009). Neurophysiological reflex mechanisms' lack of contribution to the success of PNF stretches. *Journal of Sport Rehabilitation, 18*(3), 343–357.
Moesch, J., Mallmann, J. S., Tomé, F., Vieira, L., Ciqueleiro, R. T., & Bertolini, G. R. F. (2014). Effects of three protocols of hamstring muscle stretching and paravertebral lumbar. *Fisioterapia Em Movimento, 27*(1), 85–92. https://doi.org/10.1590/0103-5150.027.001.AO09.
de Morton, N. A. (2009). The PEDro scale is a valid measure of the methodological quality of clinical trials: A demographic study. *Australian Journal of Physiotherapy, 55*(2), 129–133.
O'Hora, J., Cartwright, A., Wade, C. D., Hough, A. D., & Shum, G. L. K. (2011). Efficacy of static stretching and proprioceptive neuromuscular facilitation stretch on hamstrings length after a single session. *The Journal of Strength & Conditioning Research, 25*(6), 1586–1591. https://doi.org/10.1519/JSC.0b013e3181df7f98.
Poor, A. S., Mohseni, H., Najafzadeh, N., Hemmati, M., & Najafi, A. (2014). Comparing the effectiveness of an eight-week period stretching PNF, and dynamic stretching on hamstring muscle flexibility. *Research Journal of Pharmaceutical, Biological and Chemical Sciences, 5*(6), 1246–1252.
Prentice, W. E. (1983). A comparison of static stretching and PNF stretching for improving hip joint flexibility. *Athletic Training, 18*(1), 56–59.
Radwan, A., Bigney, K. A., Buonomo, H. N., Jarmak, M. W., Moats, S. M., Ross, J. K., … Tomko, M. A. (2014). Evaluation of intra-subject difference in

hamstring flexibility in patients with low back pain: An exploratory study. *Journal of Back and Musculoskeletal Rehabilitation, 28*(1), 61–66. https://doi.org/10.3233/BMR-140490.
Rezaeeshirizi, R., Zanganeh, F., & Beiki, Y. (2012). The effect of proprioceptive neuromuscular facilitation training on hamstring muscles flexibility and agility. *International Journal of Sport Studies, 2*, 9–16.
Rosenthal, R., & Rosnow, R. L. (1991). *Essentials of behavioral research: Methods and data analysis*. McGraw-Hill Humanities Social.
Rowlands, A. V., Marginson, V. F., & Lee, J. (2003). Chronic flexibility gains: Effect of isometric contraction duration during proprioceptive neuromuscular facilitation stretching techniques. *Research Quarterly for Exercise & Sport, 74*(1), 47–51. https://doi.org/10.1080/02701367.2003.10609063.
Ryan, E. D., Beck, T. W., Herda, T. J., Hull, H. R., Hartman, M. J., Costa, P. B., … Cramer, J. T. (2008). The time course of musculotendinous stiffness responses following different durations of passive stretching. *Journal of Orthopaedic & Sports Physical Therapy, 38*(10), 632–639. https://doi.org/10.2519/jospt.2008.2843.
Sady, S. P., Wortman, M. V., & Blanke, D. (1982). Flexibility training: Ballistic, static or proprioceptive neuromuscular facilitation? *Archives of Physical Medicine and Rehabilitation, 63*(6), 261–263.
Schuback, B., Hooper, J., & Salisbury, L. (2004). A comparison of a self-stretch incorporating proprioceptive neuromuscular facilitation components and a therapist-applied PNF-technique on hamstring flexibility. *Physiotherapy, 90*(3), 151–157. https://doi.org/10.1016/j.physio.2004.02.009.
Sedgwick, P. (2015). Bias in randomised controlled trials: Comparison of crossover group and parallel group designs. *BMJ (Clinical Research Ed.), 351*, h4283.
Sharman, M. J., Cresswell, A. G., & Riek, S. (2006). Proprioceptive neuromuscular facilitation stretching : Mechanisms and clinical implications. *Sports Medicine, 36*(11), 929–939.
Shrier, I. (2004). Does stretching improve performance? A systematic and critical review of the literature. *Clinical Journal of Sport Medicine, 14*(5), 267–273.
Sibbald, B., & Roland, M. (1998). Understanding controlled trials: Why are randomised controlled trials important? *BMJ, 316*(7126), 201. https://doi.org/10.1136/bmj.316.7126.201.
Silva, S. B., de Faria, E. M., Almeida, J. B., Bernardes, R. C., Valenti, V. E., Vanderlei, L. C. M., et al. (2012). Effects of two proprioceptive neuromuscular facilitation techniques in different planes on hamstrings muscles of health subjects. *HealthMED, 6*(7), 2332–2338.
Smedes, F., Heidmann, M., Schäfer, C., Fischer, N., & Stępień, A. (2016). The proprioceptive neuromuscular facilitation-concept; the state of the evidence, a narrative review. *Physical Therapy Reviews, 21*(1), 17–31. https://doi.org/10.1080/10833196.2016.1216764.
Spernoga, S. G., Uhl, T. L., Arnold, B. L., & Gansneder, B. M. (2001). Duration of maintained hamstring flexibility after a one-time, modified hold-relax stretching protocol. *Journal of Athletic Training, 36*(1), 44–48.
Tanigawa, M. C. (1972). Comparison of the hold-relax procedure and passive mobilization on increasing muscle length. *Physical Therapy, 52*(7), 725–735.
The Cochrane Collaboration. (2014). *Review manager (Version 5.3)*. Copenhagen: The Nordic Cochrane Centre.
Trampas, A., Kitsios, A., Sykaras, E., Symeonidis, S., & Lazarou, L. (2010). Clinical massage and modified Proprioceptive Neuromuscular Facilitation stretching in males with latent myofascial trigger points. *Physical Therapy in Sport, 11*(3), 91–98. https://doi.org/10.1016/j.ptsp.2010.02.003.
Wallin, D., Ekblom, B., Grahn, R., & Nordenborg, T. (1985). Improvement of muscle flexibility. A comparison between two techniques. *The American Journal of Sports Medicine, 13*(4), 263–268. https://doi.org/10.1177/036354658501300409.
Watsford, M. L., Murphy, A. J., McLachlan, K. A., Bryant, A. L., Cameron, M. L., Crossley, K. M., et al. (2010). A prospective study of the relationship between lower body stiffness and hamstring injury in professional Australian rules footballers. *The American Journal of Sports Medicine, 38*(10), 2058–2064. https://doi.org/10.1177/0363546510370197.
Weppler, C. H., & Magnusson, S. P. (2010). Increasing muscle extensibility: A matter of increasing length or modifying sensation? *Physical Therapy, 90*(3), 438–449. https://doi.org/10.2522/ptj.20090012.
Westwater-Wood, S., Adams, N., & Kerry, R. (2010). The use of proprioceptive neuromuscular facilitation in physiotherapy practice. *Physical Therapy Reviews, 15*(1), 23–28. https://doi.org/10.1179/174328810X12647087218677.
van der Worp, M. P., Haaf, D. S. M. ten, van Cingel, R., de Wijer, A., Nijhuis-van der Sanden, M. W. G., & Staal, J. B. (2015). Injuries in runners; a systematic review on risk factors and sex differences. *PLoS One, 10*(2). https://doi.org/10.1371/journal.pone.0114937.
Yuktasir, B., & Kaya, F. (2009). Investigation into the long-term effects of static and PNF stretching exercises on range of motion and jump performance. *Journal of Bodywork and Movement Therapies, 13*(1), 11–21. https://doi.org/10.1016/j.jbmt.2007.10.001.
Yıldırım, M. S., Ozyurek, S., Tosun, O., Uzer, S., & Gelecek, N. (2016). Comparison of effects of static, proprioceptive neuromuscular facilitation and mulligan stretching on hip flexion range of motion: A randomized controlled trial. *Biology of Sport, 33*(1), 89–94. https://doi.org/10.5604/20831862.1194126.