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INFLUENCE OF CHRONIC STRETCHING ON MUSCLE PERFORMANCE: SYSTEMATIC REVIEW

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Trabalho de Conclusão de Curso apresentado ao curso de Fisioterapia da Escola de Educação Física, Fisioterapia e Dança da Universidade Federal do Rio Grande do Sul como requisito parcial para a obtenção do título de Bacharel em Fisioterapia.

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DEDICATÓRIA

Dedico esse trabalho a minha família que me deu condições de buscar o meu sonho.

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A minha família que tornou tudo isso possível.

À Universidade Federal do Rio Grande do Sul que oportunizou minha formação.

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RESUMO

Introdução: O alongamento é uma prática amplamente utilizada tanto no contexto de reabilitação quanto no âmbito esportivo. No entanto, a influência do aumento crônico de flexibilidade na performance muscular (PM) ainda é pouco compreendida. **Objetivo**: O objetivo do presente estudo foi avaliar a influência do aumento crônico de flexibilidade na PM por meio de uma revisão sistemática. **Métodos**: A estratégia de busca incluiu as plataformas MEDLINE (via Pubmed), PEDro, Cochrane Central e LILACS, além disso, uma minuciosa busca manual foi realizada por meio das referências dos artigos, do início a junho de 2016. Estudos Randomizados e não randomizados que analisaram a influência do treino de flexibilidade (qualquer técnica) na PM foram incluídos. Diferentemente, estudos com populações especiais (crianças, idosos, e pessoas com qualquer condição patológica), e artigos que utilizaram treinamentos inferiores a 3 semanas (ou 20 sessões) foram excluídos. A avalição da PM poderia ter sido avaliada por meio de testes funcionais (saltos, *Sprint*, tarefas de ciclo alongamento-encurtamento), contrações isométricas e isotônicas. **Resultados**: Vinte e cinco estudos foram incluídos de 509 selecionados. Cinco estudos avaliaram a PM por meio de tarefas envolvendo ciclo alongamento-encurtamento, 8 estudos avaliaram a PM através de contrações isométricas e 12 estudos avaliaram a PM por meio de contrações isotônicas. Devido a alta heterogeneidade entre os estudos incluídos, não foi possível a realização de metanálise. No entanto, em uma análise qualitativa dos estudos, nós identificamos que 16 estudos encontraram resultados positivos do aumento crônico de flexibilidade na PM. A maioria dos resultados positivos foram encontrados em testes funcionais e contrações isotônicas. **Conclusão**: Embora os mecanismos para o aumento na PM após um treinamento de flexibilidade não sejam claros, a presente revisão demonstrou que, cronicamente, o alongamento possui um papel importante na PM, especialmente em atividades dinâmicas.

SUMÁRIO

APRESENTAÇÃO

Desde 2010 faço parte do grupo de pesquisa em cinesiologia e cinesioterapia. Há algum tempo, concentramos boa parte dos seus esforços em entender melhor a prática do alongamento. Através de uma leitura aprofundada sobre o assunto, algumas lacunas ainda não preenchidas na literatura estão sendo percebidas. Esse trabalho foi idealizado a partir da identificação de uma carência da literatura em estabelecer a real relação entre o aumento crônico de flexibilidade e a performance muscular. Há evidências consistentes que o efeito agudo do alongamento pode gerar efeitos deletérios na produção de força. No entanto, o efeito crônico do alongamento no desempenho muscular é pouco compreendido.

No grupo, incentivamos a realização de revisões sistemáticas (com metanálise), pois estas, quando propriamente realizadas, se configuram como a evidência de maior poder no contexto científico. Além disso, elas permitem a localização de inconsistências na literatura, o que nos estimula a pensar criticamente a respeito da metodologia dos trabalhos, e elaborar projetos de pesquisa bem definidos. Portanto, fizemos a opção de organizar uma revisão sistemática para compreender melhor a relação das duas valências do condicionamento físico supracitadas. Vale salientar que o presente autor já teve experiência em trabalhos desse gênero, o que facilitou a escolha do tema e a realização do estudo.

O presente estudo foi submetido à revista *Human Movement Science*, com fator de impacto de 1,606, no dia 16 de outubro de 2016, e atualmente encontra-se sob avaliação dos revisores. Dessa forma, o artigo resultante desse trabalho foi escrito com base nas normas e instruções de publicação dessa revista, as quais seguem em anexo ao final deste documento.

Influence of chronic stretching on muscle performance: Systematic review

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Palavras chave: flexibilidade; ciclo alongamento-encurtamento; força muscular; performance atlética

Keywords: flexibility; stretch-shortening cycle; muscle strength; athletic performance

RESUMO

Introdução: O alongamento é uma prática amplamente utilizada tanto no contexto de reabilitação quanto no âmbito esportivo. No entanto, a influência do aumento crônico de flexibilidade na performance muscular (PM) ainda é pouco compreendida. **Objetivo**: O objetivo do presente estudo foi avaliar a influência do aumento crônico de flexibilidade na PM por meio de uma revisão sistemática. **Métodos**: A estratégia de busca incluiu as plataformas MEDLINE (via Pubmed), PEDro, Cochrane Central e LILACS, além disso, uma minuciosa busca manual foi realizada por meio das referências dos artigos, do início a junho de 2016. Estudos Randomizados e não randomizados que analisaram a influência do treino de flexibilidade (qualquer técnica) na PM foram incluídos. Diferentemente, estudos com populações especiais (crianças, idosos, e pessoas com qualquer condição patológica), e artigos que utilizaram treinamentos inferiores que 3 semanas (ou 20 sessões) foram excluídos. A avalição da PM poderia ter sido avaliada por meio de testes funcionais (saltos, *Sprint*, tarefas de ciclo alongamento-encurtamento), contrações isométricas e isotônicas. **Resultados**: Vinte e cinco estudos foram incluídos de 509 selecionados. Cinco estudos avaliaram a PM por meio de tarefas envolvendo ciclo alongamento-encurtamento, 8 estudos avaliaram a PM através de contrações isométricas e 12 estudos avaliaram a PM por meio de contrações isotônicas. Devido a alta heterogeneidade entre os estudos incluídos, não foi possível a realização de metanálise. No entanto, em uma análise qualitativa dos estudos, nós identificamos que 16 estudos encontraram resultados positivos do aumento crônico de flexibilidade na PM. A maioria dos resultados positivos foram encontrados em testes funcionais e contrações isotônicas. **Conclusão**: Embora os mecanismos para o aumento na PM após um treinamento de flexibilidade não sejam claros, a presente revisão demonstrou que, cronicamente, o alongamento possui um papel importante na PM, especialmente em atividades dinâmicas.

Palavras chave: flexibilidade; ciclo alongamento-encurtamento; força muscular; performance atlética

ABSTRACT

Background: Stretching is strategy widely performed in both therapeutic and sport contexts. However the influence of chronic stretching on muscle performance (MP) remains unclear. **Objective**: The aim of the current study was to investigate the influence of chronic stretching on muscle performance by a systematic review. **Methods**: The search strategy included MEDLINE, PEDro, Cochrane CENTRAL, LILACS, and manual search from inception to June 2016. Randomized and controlled clinical trials, non-randomized, and single group studies that have analyzed the influence of a stretching training (any technique) on MP were included. Differently, studies with special populations (children, elderly, and people with any dysfunction/disease), and articles that have used stretching training protocols shorter than 3 weeks or twelve sessions were excluded. The MP assessment could have been performed by functional tests (e.g. jump, sprint, stretch-shortening cycle tasks), isometric contractions, and/or isotonic contractions. **Results**: Twenty-five studies were included out of 509. Five studies evaluated MP by stretch-shortening cycle tasks, 8 studies evaluated MP by isometric contractions, and 12 studies assessed MP by isotonic contractions. Due to the high heterogeneity among the included studies, we were unable to perform a meta-analysis. In an individual study level analysis, we identified that 16 studies found positive effects of chronic stretching on MP. Most of the improvements were observed in functional tests and isotonic contractions. **Conclusions**: Even though the mechanisms behind such improvements are unclear, this review demonstrated that chronic stretching seems to play an important role on MP, especially in dynamic activities.

Keywords: flexibility; stretch-shortening cycle; muscle strength; athletic performance

1. Introduction

Stretching is a fundamental component of most training routines, and it is a strategy generally employed when the goal is to enhance muscle flexibility (Ayala, Sainz de Baranda, De Ste Croix, & Santonja, 2013; Marshall, Cashman, & Cheema, 2011). Flexibility, which refers to the ability of a muscle (group) to elongate (Magnusson, Simonsen, Aagaard, Sørensen, & Kjaer, 1996), is an important component of physical fitness, and it has intimate relation with muscle performance (MP).

Stretching can affect MP in different ways depending on how it is executed. The acute effects of stretching have been widely investigated in the last decade. A considerable amount of original studies (Costa, Herda, Herda, & Cramer, 2014; Cramer et al., 2007), and reviews (Behm & Chaouachi, 2011; Kay & Blazevich, 2012) have evidenced that a bout of stretching may provoke deleterious effects on MP. With respect to the chronic effects of stretching, it is well documented its effectiveness in increasing muscle flexibility (Medeiros, Cini, Sbruzzi, & Lima, 2016). However, the influence of such flexibility improvement on MP remains an issue of debate.

The theories that seek to explain the role of flexibility on MP are suggestive. It is believed that stretching training can decrease muscle stiffness (Wilson, Elliott, & Wood, 1992), induce an increase in Ca^{+} within the neuromuscular junction (Yamashita, Ishii, & Oota, 1992), and promote sarcomerogenesis (De Deyne, 2001). All these factors may contribute to a possible enhancement in MP after stretching training. Nonetheless, the literature is scarce on this topic.

To the best of the authors' knowledge, there are only two review studies

(Rubini, Costa, & Gomes, 2007; Stone et al., 2006) that attempted to elucidate the role of chronic stretching on MP. However, both studies employed a narrative approach and provided insufficient information on the topic. Besides, we are aware of a number of studies that have been published in the last decade. So then, a review study with more appropriate methodology would contribute to better understand the relationship between chronic stretching and MP. Hence, the purpose of the current investigation is to analyze the influence of chronic stretching on MP by means of a systematic literature review.

2. Methods

The current study utilized PRISMA (Preferred Reporting Items for Systematic Review and Meta-analyses) guidelines for Systematic Reviews and Meta-analysis (Shamseer et al., 2015).

2.1. Data sources and searches

We searched the following electronic databases (from inception to June 2016): MEDLINE (accessed by PubMed), Physiotherapy Evidence Database (PEDro), The Cochrane Central Register of Controlled Trials (Cochrane CENTRAL), and *Centro Latino-Americano e do Caribe de Informação em Ciências da Saúde* (LILACS). In addition, we searched the references of published studies. The search comprised the following terms: “Flexibility”, “Range of Motion”, “Joint Range of Motion”, “Joint Flexibility”, “Muscle Strength”, “Strength, muscle”, “Muscle Strength Dynamometer”, “Performance, Athletic”, “Static Stretching”, “PNF stretching”, “Muscle Stretching Exercises” combined with a high sensitivity combination of words used in the search for randomized clinical trials (Robinson & Dickersin, 2002). We included publications in English, Spanish, and Portuguese. For the combination of the keywords, we utilized the Boolean terms AND and OR. The complete search strategy used for the MEDLINE database is shown in Appendix A.

2.2. Eligibility criteria

We included randomized clinical trials (RCT), controlled clinical trials (CCT), single group, and nonrandomized studies. We opted for including all types of studies since high-quality articles are scarce in the matter investigated in the present review. We included studies that evaluated the effects of stretching training (any technique) on MP, which could have been evaluated by isokinetic dynamometry (isotonic or isometric contraction), repetition-maximum (RM) testing, or functional tests that follow the stretch-shortening cycle (SSC) principle. The following exclusion criteria were used: (1) samples comprised of people with any disease/dysfunction; (2) stretching training shorter than three weeks; (3) samples with mean age under 18 or over 40 years old; (4) non-application of muscle stretching; (5) no assessment of MP.

2.3. Studies selection and data extraction

Two investigators, in duplicate, independently evaluated titles and abstracts of all articles identified by the search strategy. All abstracts that did not provide sufficient information regarding the inclusion and exclusion criteria were selected for full-text evaluation. In the second phase, the same reviewers independently evaluated the full-text articles and made their selection in accordance with the eligibility criteria. Disagreements between reviewers were solved by consensus or through a third person review. Using standardized forms, the same two reviewers independently conducted data extraction with regard to the methodological characteristics of the studies, number of participants, age, interventions, muscle group evaluated, assessment protocol, and conclusions. Disagreements were also solved by consensus. The main outcome extracted was MP.

2.4. Quality assessment

Study quality assessment included adequate sequence generation, allocation concealment, blinding of outcome assessors, description of losses and exclusions, and intention-to-treat analysis. Use of intention-to-treat analysis was considered as a confirmation on study assessment that the number of participants randomized and the number analyzed were identical, except for patients lost to follow-up or who withdrew consent for study participation. Studies without a clear description of these characteristics were considered as unclear or not reporting the latter. The same two reviewers independently performed the quality assessment.

3. Results

3.1. Description of studies

The search strategy yielded 509 articles, of which 32 studies were considered as potentially relevant and retrieved for detailed analysis. In the full-text analysis, seven studies were excluded. Hence, twenty-five studies met the eligibility criteria and were included in the systematic review (n = 773). Figure 1 shows the flow diagram of the studies included in this review.

3.2. Risk of Bias

Of the studies included in this systematic review, 12% presented an adequate sequence generation, 16% reported allocation concealment; 24% had blinded assessment of outcomes, 28% described losses to follow-up and exclusions, and 36% of the studies used the intention-to-treat principle for statistical analyses (Appendix B).

3.3. Effects of interventions

We were unable to perform statistical analyses due to the high heterogeneity among the included studies. Tables 1, 2, and 3 summarize the studies' characteristics and its conclusions.

3.3.1. Flexibility training on functional tasks

Five studies assessed MP using a functional test that followed the SSC principle. Four studies (Abdel-aziem & Mohammad, 2012; Caplan, Rogers, Parr, & Hayes, 2009; Hunter & Marshall, 2002; Wilson et al., 1992) found that an increase in flexibility promotes an increase in MP, and only one study (Yuktasir & Kaya, 2009) found no significant difference when compared to a control group (Table 1).

3.3.2. Flexibility training on isometric contraction

Isometric contraction, which was evaluated by isokinetic dynamometry, was utilized in 8 studies. Two of them (Handel, Horstmann, Dickhuth, & Gülch, 1997; Rees, Murphy, Watsford, McLachlan, & Coutts, 2007) found that flexibility training improves MP whereas 6 studies (Blazevich et al., 2014; Guissard & Duchateau, 2004; Konrad, Gad, & Tilp, 2015; Konrad & Tilp, 2014a, 2014b; Minshull, Eston, Bailey, Rees, & Gleeson, 2014) found no significant difference when compared to a control group (Table 2).

3.3.3. Flexibility training on isotonic contractions

Of the twenty-five studies included in the present review, twelve of them evaluated MP through isotonic contractions. All of them assessed concentric contraction whereas only three studies evaluated eccentric contraction.

Regarding concentric contractions, 7 studies (Abdel-aziem & Mohammad, 2012; Chen et al., 2009, 2011; Handel et al., 1997; Leite et al., 2015; Nelson et al., 2012; Worrell, Smith, & Winegardner, 1994) showed that flexibility training improves MP, whereas 5 studies (Ferreira, Teixeira-Salmela, & Guimarães, 2007; LaRoche, Lussier, & Roy, 2008; Marshall et al., 2011; Morton, Whitehead, Brinkert, & Caine, 2011; Wilson et al., 1992) did not found any significant changes when compared either to a control group or a pre moment. All three studies (Abdel-aziem & Mohammad, 2012; Handel et al., 1997; Worrell et al., 1994) that evaluated eccentric contractions showed that flexibility training enhances MP when compared either to a control group or a pre moment.

4. Discussion

The evidence presented in this review suggests that chronic stretching is able to enhance MP since 16 out of 25 articles showed positive results. Moreover, it is worth pointing out in this context that, differently from what is been observed in the literature for acute bouts of stretching, chronic stretching does not impair MP. We state that based on the fact that all included studies showed improvements in muscle flexibility, and none of them found any impairments in MP after such event.

In order to understand the mechanisms responsible for the enhancement in MP after chronic stretching, it is crucial that we clarify the mechanisms involved in muscle flexibility increase itself. The hypotheses normally used to explain improvements in chronic flexibility are: increase in stretch tolerance (Konrad et al., 2015), viscoelastic adaptations (Kubo, Kanehisa, Kawakami, & Fukunaga, 2001; Reid & McNair, 2004), and addition of sarcomeres in series (Zöllner, Abilez, Böl, & Kuhl, 2012).

Increase in stretch tolerance is a widely accepted theory. It states that an increase in range of motion (ROM) without structural changes in the muscle-tendon unit (MTU) can only be explained by a modification in the perception of the discomfort associated with stretch (Halbertsma, Van Bolhuis, & Goeken, 1996). And this may be related to a nociceptive adaptation (Magnusson et al., 1996).

The fact that neural adaptations are present during regular stretching does not exclude the possibility of viscoelastic adaptations within the MTU. Viscoelastic materials have an elastic ability, which enables it to store and release energy (Böhm, Cole, Brüggemann, & Ruder, 2006), but they also have a viscous component since their response to tensile force is rate and time-dependent (Peltonen, Cronin, Stenroth, Finni, & Avela, 2013). The viscoelastic variable most evaluated among the studies in this field is passive stiffness, which is the change in passive tension per unit change in length of the muscle (Ryan et al., 2008). And the literature has demonstrated that decreased passive stiffness contributes to flexibility improvements after stretching training (Guissard & Duchateau, 2004).

Another factor that may contribute to the increase in muscle flexibility after chronic stretching is the addition of sarcomeres in series. Sarcomerogenesis has been confirmed in mathematical models (Zöllner et al., 2012), animal models studies (De Jaeger, Joumaa, & Herzog, 2015), and tendon transfer approaches (Boakes, Foran, Ward, & Lieber, 2006). However, there is a lack of studies analyzing sarcomerogenesis after chronic stretching in vivo. Evaluations of muscle optimum angle have been performed in an attempt to verify possible adaptations within the sarcomeres (Chen, Lin, Chen, Lin, & Nosaka, 2011). It is believed that a shift of the optimum angle toward a longer muscle length may be caused by increase in sarcomeres in series.

The enhancements in MP after stretching training are directly related to those adaptations above-mentioned. However, the impact of such adaptations on MP may be distinct depending on the type of movement involved in the task (Butterfield, Leonard, Herzog, & Butterfield, 2005). As of this date, there is no information about any relationship between modification in stretch tolerance and MP. On the other hand, the literature has hypothesized that modifications in muscle stiffness and the addition in sarcomeres in series within the muscle may have positive influence on MP (Butterfield et al., 2005; Wilson et al., 1992).

The major elastic component of MTU is the tendon (Zuurbier, Everard, van der Wees, & Huijing, 1994). Hence, the tendinous tissue is able to store potential energy during eccentric contractions, and release this energy during the subsequent concentric contraction (Ishikawa, Pakaslahti, & Komi, 2007). This phenomenon is known as stretch-shortening cycle (SSC). Activities involving SSC are highly influenced by muscle stiffness. It is believed that an increased MTU compliance improves its storage capacity, enhancing performance (Wilson et al., 1992). Another viscoelastic characteristic that has a great impact on SSC movements, and can be modified by chronic stretching is hysteresis (Kubo, 2005). Hysteresis refers to the energy lost as heat during stretching of viscoelastic materials (Kubo, 2005). So then, a decrease in hysteresis, provoked by chronic stretching, suggests a reduction in energy dissipation in the MTU, which would increment MP. In the present review, only one study (Yuktasir & Kaya, 2009) that evaluated MP by a functional test involving SSC (drop jump) did not find improvements in MP after chronic stretching. A reasonable explanation for that result might be related to the fact that their training protocol did not include knee extensors stretching. It is known that Rectus Femoris plays an essential role on drop jumps, especially from 60 cm height (Peng, Kernozek, & Song, 2011), the exact test employed in the above-mentioned study. So then, the non-utilization of knee extensors stretching may have limited the observation of positive results.

Another hypothesis utilized in an attempt to elucidate the increase in MP after regular stretching is the addition of sarcomeres in series. It is speculated that sarcomerogenesis potentiates the force-length relationship, which improves MP, especially in static contractions. Seven studies evaluated MP using static contractions. However, only 2 (Handel et al., 1997; Rees et al., 2007) showed positives results related to chronic stretching. The lack of effectiveness of stretching might be related to the stretching protocols used among the studies. Perhaps, the given stimulus was not sufficient to generate adaptations within the muscle cell, and the increase in muscle flexibility was a result of modification in stretch tolerance (Konrad et al., 2015). It is worth highlighting that the studies that found improvements in MP employed PNF stretching. Therefore, we cannot disregard the possibility that the improvements in isometric contractions observed may be partly related to some adaptation to the isometric contractions present in PNF stretching.

Another advantage of sarcomerogenesis is its capacity to potentiate dynamics activities by increasing muscular contraction velocity (Lieber & Bodine-Fowler, 1993). Twelve studies assessed MP by dynamic (concentric and eccentric) contractions. With respect to concentric contraction, 7 studies (Abdel-aziem & Mohammad, 2012; Chen et al., 2009, 2011; Handel, Horstmann, Dickhuth, & Gülch, 1997; Leite et al., 2015; Nelson et al., 2012; Worrell et al., 1994) showed positive results whereas 5 studies (Ferreira et al., 2007; LaRoche et al., 2008; Marshall et al., 2011; Morton et al., 2011; Wilson et al., 1992) showed no significant improvement in peak torque (PT). During eccentric contractions, though, all three studies (Abdel-aziem & Mohammad, 2012; Handel et al., 1997; Worrell et al., 1994) that performed this type of test found significant increase in PT. Rather interesting is that two studies (Ferreira et al., 2007; LaRoche et al., 2008) evaluated Work (W), and observed that chronic stretching is able to increase this variable. Angular work is described as the applied torque times the changes in angular distance. Accepting sarcomerogenesis as a real adaptation, we may infer that after stretching training, the muscle had the capability of moving the segment to a larger angular distance in the same time interval (Lieber & Bodine-Fowler, 1993).

To the best of the authors’ knowledge, this is the first review to systematically analyze the influence of chronic stretching on MP. The current review presents relevant methodological strengths such as the analysis of two of the most important components of physical fitness: muscle flexibility and muscle strength. Moreover, a strategy for a sensitive and comprehensive search to assure the location of all studies in this field was held. The low methodological quality of the included studies must be pointed as a relevant limitation. The majority of the studies failed to explain the generation of the random sequence. Only six studies blinded the outcome assessors. None of the included studies presented all the items in the risk of bias analysis. It is crucial that future investigations show greater concern about the internal validity in order to improve the data reliability.

5. Conclusion

Flexibility is an essential component of physical fitness, and as such, it should always be taken into account in any training routine. As this review has demonstrated, chronic stretching seems to play an important role on MP, especially during dynamic activities. However, there is a need for more high-quality studies on this topic to help clarify both the stretching parameters needed to enhance MP and the mechanisms behind such improvement.

Disclosures

No funding was received for the current study, and the authors declare no conflict of interest.

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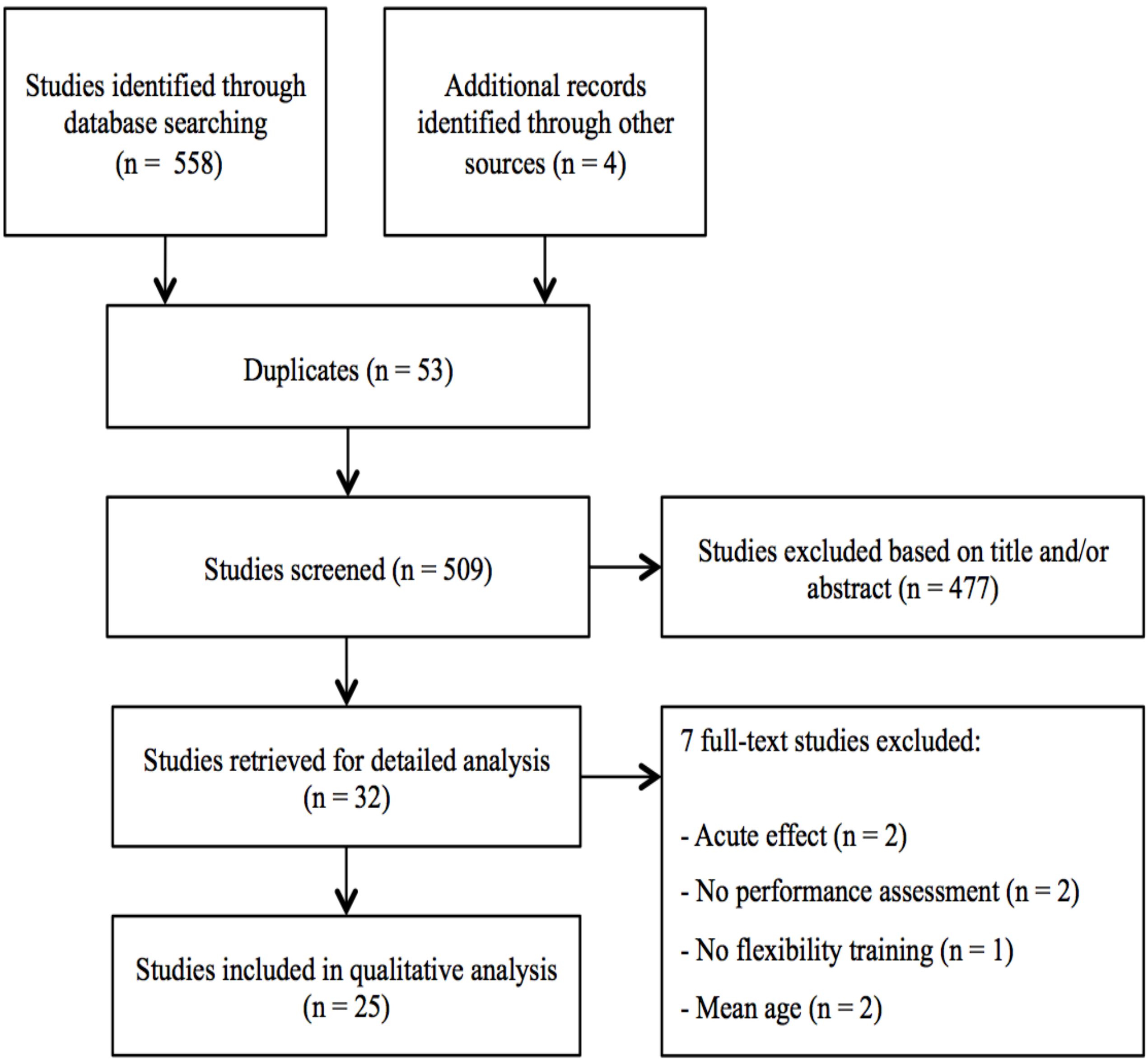

Figure 1. Flowchart of the included studies.

Tables

Table 1. Characteristics of the studies that utilized stretch-shortening cycle tests.

Study (year)	Sample (n)	Mean age ± SD	Stretching technique	Protocol	Muscle group/exercise evaluated	Muscle performance assessment	Conclusions
Caplan et al. (2009)	18 Rugby players	20.2 ± 1.8	Static stretching and PNF	3 x 10s 4 x week/5 weeks	Knee flexors	Running mechanics Stride rate (SR) Stride length (SL) Contact time (CT)	↓ SR ↑ SL CT unchanged
Hunter and Marshall (2001)	50 active male	24.0 ± 4.0	Static stretching	3 x 20-60s 4 x week/10 weeks	Lower limbs	CMJ, DP from 30-, 60-, and 90cm (DJ30, DJ60, DJ90).	↑ CMJ the other variables remained unchanged
Kokkonen et al. (2007)	38 sedentaries and recreationally active subjects	22.5 ± 3.5	Static stretching	3 x 15s 3 x week/10 weeks 15 stretching exercises	Knee flexors and extensors	*Standing long jump* Vertical jump 20-m sprint 1RM Endurance test	↑ of all variables analyzed
Wilson et al. (1992)	16 wheightlifters	24.4 ± 2.8	Static stretching	10-30s - 4 stretching exercises twice a week/8 weeks	Bench press	Rebound and conc performance	↑ on rebound performance; No significant change on conc performance

Yukitasir et al. (2009)	28 healthy men	21.8 ± 9.0	Static stretreching and PNF	4 x 30s 4 x week/6 weeks	Knee flexors and plantar flexors	DJ	No significant change on jump performance

PNF = Proprioceptive Neuromuscular Facilitation; CMJ = Counter Movement Jump; RM = Repetition Maximum; DP = Drop Jump.

Table 2. Characteristics of the studies that assessed isometric contraction.

Study (year)	Sample (n)	Mean age ± SD	Stretching technique	Protocol	Muscle group/exercise evaluated	Muscle performance assessment	Conclusions
Blazevitch et al. (2014)	22 healthy men	18.6 ± 0.9	Static stretching	4 x 30s - twice a day daily/3 weeks	Plantar flexors	ID, isom PT	No significant change on isom PT
Guissard and Duchateau (2004)	12 healthy subjects	Age range 21-35	Static stretching	5 x 30s - 4 stretching exercises 5 x week/6 weeks	Plantar flexors	ID, MVC	No significant change on MVC
Konrad and Tilp (2014)	49 police cadets	22.9 ± 2.7	Static stretching	4 x 30s 5 x week/6 weeks	Plantar flexors	ID, MVC	No significant change on isom PT
Konrad and Tilp (2014) b	48 police cadets	22.6 ± 2.5	Ballistic stretching	4 x 30s 5 x week/6 weeks	Plantar flexors	ID, MVC	No significant change on isom PT

Konrad et al. (2015)	49 police cadets	23.6 ± 2.5	PNF	4 x 30s 5 x week/6 weeks	Plantar flexors	ID, MVC	No significant change on isom PT
Kubo et al. (2001)	8 healthy men	24.6 ± 1.8	Static stretching	5 x 45s - twice a day daily/3 weeks	Plantar flexors	Isom PT, and hysteresis	No significant change on isom PTe and ê of hysteresis
Minshull et al. (2013)	18 healthy subjects	20.3 ± 2.2	Passive stretching and PNF	60s for both stretching techniques 3 x week/8 weeks	Knee flexors	MVC, RFD, Sensorimotor performance	No significant change in any of the variables analyzed
Rees et al. (2007)	20 healthy active women	19.7 ± 1.6	PNF	4-6 sets of 6-10 maximal contraction 3 x week/4 weeks	Plantar flexors	MIC, RTD	↑ MIC and RTD

PNF = Proprioceptive Neuromuscular Facilitation; ID = Isokinetic Dynamometry; PT = Peak Torque; MVC = Maximal Voluntary Contraction; RM = Repetition Maximum; RFD = Rate of Force Development; RTD = Rate of Torque Development; MIC = Maximal Isometric Force.

Table 3. Characteristics of the studies that assessed isotonic contraction.

Study (year)	Sample (n)	Mean age ± SD	Stretching technique	Protocol	Muscle group/exercise evaluated	Muscle performance assessment	Conclusions
Aziem and Mohhammed (2011)	50 healthy subjects	Experimental group: 22.3 ± 2.3 Control group: 21.9 ± 4.1	Static stretching	5 x 30s - twice a day 5 x week/6 weeks	Plantar flexors	ID, ecc and conc PT at 30 and 120°/s	↑ ecc, and conc PT
Chen et al. (2009)	30 young men	22 ± 2.1	Static stretching and PNF	Static stretching: 10 x 30s PNF: 3 x 10s 3 x week/8 weeks	Knee flexors	ID, conc PT at 60°/s	↑ conc PT in both stretching techniques
Chen et al. (2011)	30 young men	20.8 ± 2.3	Static stretching and PNF	Static stretching: 10 x 30s PNF: 3 x 10s 3 x week/8 weeks	Knee flexors	ID, conc PT at 60°/s	↑ conc PT in both stretching techniques
Ferreira et al. (2007)	30 young subjects	22.7 ± 4.8	Static stretching	4 x 30s 5 x week/6 weeks	Knee flexors	ID, conc PT e at 60 and 300°/s and Work	No significant change on conc PT; ↑ Work

Handel et al. (1997)	18 male athletes	23.6 ± 3.9	PNF	10 minutes 3 x week/8 weeks	Knee flexors and extensors	ID, ecc PT at 60e 120°/s and conc PT at 60, 120, 180 e 240°/s	↑ ecc PT of knee flexors and extensors at 60 and 120 °/s; ↑ isom PT, and conc PT at 60, 180 e 240°/s of knee flexors
LaRoche et al. (2008)	29 male subjects	31.6 ± 15.2	Static and dynamic stretching	10 x 30s - 3 x week/4 weeks	Hip extensors	ID, conc PT 60°/s RTD Work	No significant change on conc PT, and RTD; ↑ Work
Leite et al. (2015)	28 trained women	Not informed	Dynamic stretching	3 x 30 reps each stretching 60min training	Bench press and Leg press	10RM test	Bench press' 10RM with no significant change and ↑ of Leg press' 10RM
Marshall et al. (2011)	22 recreationally active subjects	22.7 ± 3.8	Static stretching	3 x 30s - 4 stretching exercises 5 x week/4 weeks	Knee flexors	ID, conc PT 30 and 120°/s	No significant change on conc PT
Morton et al. (2011)	36 sedentary subjects	21.9 ± 3.6	Static stretching	1 x 30s each stretching- 35 minutes of lower and upper limp static stretching training 5 weeks	Knee flexors and extensors	ID, conc PT 180°/s	No significant change on conc PT

Nelson et al. (2012)	25 healthy subjects	23.2 ± 3.2	Static stretching	4 x 30s 3 x week/10 weeks	Plantar flexors	1RM test	↑ 1RM test
Simão et al. (2011)	80 untrained women	34.5 ± 2.0	Static stretching (not clear)	4 x 15-60s upper and lower body stretching training alternate days/16 weeks	Bench press and Leg press	10RM test	No significant change on 10RM test
Wilson et al. (1992)	16 weightlifters	24.4 ± 2.8	Static stretching	10-30s - 4 stretching exercises twice a week/8 weeks	Bench press	Rebound and conc performance	↑ on rebound performance; No significant change on conc performance
Worrel et al. (1994)	19 healthy subjects	26.2 ± 3.6	Static stretching and PNF	4 x 15-20s 5 x week/3 weeks	Knee flexors	ID, ecc, and conc PT at 60 e 120°/s	↑ ecc PT at 60 and 120°/s, and conc PT at 120°/s

PNF = Proprioceptive Neuromuscular Facilitation; ID = Isokinetic Dynamometry; Ecc = Eccentric; Conc = Concentric; Isom = isometric; PT = Peak Torque; RM = Repetition Maximum.

Appendices

Appendix A. Complete Search strategy used for MEDLINE.

#1	“Muscle Strength”[Mesh] OR “Strength, muscle” OR "Muscle Strength Dynamometer"[Mesh] OR “Dynamometer, Muscle Strength” OR “Dynamometers, Muscle Strength” OR “Muscle Strength Dynamometers” OR “Athletic Performance”[Mesh] OR “Athletic Performances” OR “Performance, Athletic” OR “Performances, Athletic” OR “Sports Performance” OR “Performance, Sports” OR “Performances, Sports” OR “Sports Performances”
#2	“Muscle Stretching Exercises”[Mesh] OR “Exercise, Muscle Stretching” OR “Exercises, Muscle Stretching” OR “Muscle Stretching Exercise” OR “Dynamic Stretching” OR “Stretching, Dynamic” OR “Isometric Stretching” OR “Stretching, Isometric” OR “Active Stretching” “Stretching, Active” OR “Static-Active Stretching” OR “Static Active Stretching” OR “Stretching, Static-Active” OR “Static Stretching” OR “Stretching, Static” OR “Passive Stretching” OR “Stretching, Passive” OR “Relaxed Stretching” OR “Stretching, Relaxed” OR “Static-Passive Stretching” OR “Static Passive Stretching” OR “Stretching, Static-Passive” OR “Ballistic Stretching” OR “Stretching, Ballistic” OR “Proprioceptive Neuromuscular Facilitation (PNF) Stretching”
#3	(randomized controlled trial[pt] OR controlled clinical trial[pt] OR randomized controlled trials[mh] OR random allocation[mh] OR double-blind method[mh] OR single-blind method[mh] OR clinical trial[pt] OR clinical trials[mh] OR ("clinical trial"[tw]) OR ((singl*[tw] OR doubl*[tw] OR trebl*[tw] OR tripl*[tw]) AND (mask*[tw] OR blind*[tw])) OR ("latin square"[tw]) OR placebos[mh] OR placebo*[tw] OR random*[tw] OR research design[mh:noexp] OR follow-up studies[mh] OR prospective studies[mh] OR cross-over
#4	#1 AND #2 AND #3

Appendix B. Risk of bias of the included studies.

Study (year)	Adequate sequence generation	Allocation concealment	Bliding of outcome assessors	Description of losses and exclusions	Intention-to-treat analysis
Aziem and Mohhammed (2011)	NI	NI	NI	NI	NI
Blazevitch et al. (2014)	Yes	Yes	Yes	Yes	No
Caplan et al. (2009)	NI	NI	NI	NI	Yes
Chen et al. (2009)	No	No	NI	NI	Yes
Chen et al. (2011)	No	No	NI	NI	NI
Ferreira et al. (2007)	NI	NI	Yes	NI	Yes
Guissard and Duchateau (2004)	NI	NI	NI	NI	NI
Handel et al. (1997)	NI	NI	NI	NI	NI
Hunter and Marshall (2001)	NI	NI	NI	Yes	NI
Kokkonen et al. (2007)	NI	NI	No	No	No
Konrad and Tilp (2014)	NI	NI	NI	Yes	No
Konrad and Tilp (2014) b	Yes	Yes	Yes	Yes	No
Konrad et al. (2015)	Yes	NI	No	Yes	No
Kubo et al. (2002)	NI	NI	NI	NI	NI
LaRoche et al. (2008)	NI	NI	NI	NI	Yes
Leite et al. (2015)	NI	Yes	Yes	NI	NI
Marshall et al. (2011)	NI	NI	No	NI	Yes
Minshull et al. (2013)	NI	NI	NI	NI	NI
Morton et al. (2011)	NI	NI	NI	Yes	No
Nelson et al. (2012)	NI	NI	NI	NI	NI
Rees et al. (2007)	NI	NI	NI	NI	Yes
Simão et al. (2011)	NI	Yes	Yes	NI	Yes
Wilson et al. (1992)	NI	NI	NI	Yes	No
Worrel et al. (1994)	NI	NI	NI	NI	Yes
Yukitasir et al. (2009)	NI	NI	Yes	NI	Yes

NI, Not informed.

ANEXOS

ANEXO I

GUIDE FOR AUTHORS

Introduction

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