Scand J Med Sci Sports 2013: 23: 131–148
doi: 10.1111/j.1600-0838.2012.01444.x

© 2012 John Wiley & Sons A/S

SCANDINAVIAN JOURNAL OF MEDICINE & SCIENCE IN SPORTS

Review

Does pre-exercise static stretching inhibit maximal muscular performance? A meta-analytical review

L. Simic[1], N. Sarabon[2], G. Markovic[1]

[1]Motor Control and Human Performance Laboratory, School of Kinesiology, University of Zagreb, Zagreb, Croatia, [2]Institute for Kinesiology Research, University of Primorska, Science and Research Center, Koper, Slovenia
Corresponding author: Goran Markovic, Motor Control and Human Performance Laboratory, School of Kinesiology, University of Zagreb, Horvacanski zavoj 15, 10000 Zagreb, Croatia. Tel: +385 1 3658 606, Fax: +385 1 3634 146, E-mail: gmarkov@kif.hr

Accepted for publication 3 January 2012

We applied a meta-analytical approach to derive a robust estimate of the acute effects of pre-exercise static stretching (SS) on strength, power, and explosive muscular performance. A computerized search of articles published between 1966 and December 2010 was performed using PubMed, SCOPUS, and Web of Science databases. A total of 104 studies yielding 61 data points for strength, 12 data points for power, and 57 data points for explosive performance met our inclusion criteria. The pooled estimate of the acute effects of SS on strength, power, and explosive performance, expressed in standardized units as well as in percentages, were –0.10 [95% confidence interval (CI): –0.15 to –0.04], –0.04 (95% CI: –0.16 to 0.08), and –0.03 (95% CI: –0.07 to 0.01), or –5.4% (95% CI: –6.6% to –4.2%), –1.9% (95% CI: –4.0% to 0.2%), and –2.0% (95% CI: –2.8% to –1.3%). These effects were not related to subject's age, gender, or fitness level; however, they were more pronounced in isometric vs dynamic tests, and were related to the total duration of stretch, with the smallest negative acute effects being observed with stretch duration of ≤45 s. We conclude that the usage of SS as the sole activity during warm-up routine should generally be avoided.

Static stretching (SS) is commonly performed prior to exercise (ACSM, 2000) and athletic events (Beaulieu, 1981; Holcomb, 2000). It is generally believed that pre-exercise SS will promote better performances and reduce the risk of injury during exercise (Shellock & Prentice, 1985; Smith, 1994). However, recent reviews have suggested that pre-exercise SS might reduce the incidence of some (e.g., muscle strains) (McHugh & Cosgrave, 2010), but not all injuries (Herbert & Gabriel, 2002; Thacker et al., 2004), and that it may actually reduce performance (Shrier, 2004; Rubini et al., 2007; McHugh & Cosgrave, 2010; Behm & Chaouachi, 2011). More importantly, stretch-induced reductions in performance are particularly evident in maximal and explosive muscular efforts that play an essential role in a number of individual and team sports (Markovic & Mikulic, 2010; Cormie et al., 2011). These results have already made an impact on sports and exercise professionals who now start to recommend avoidance of SS during warm-up for sport and exercise (Pearson, 2001; Young & Behm, 2002; Knudson, 2007).

Despite an increasing number of studies that demonstrated an acute reduction in muscular performance following SS (for recent reviews, see Magnusson & Renstrom, 2006; Rubini et al., 2007; McHugh & Cosgrave, 2010; Behm & Chaouachi, 2011), it has to be acknowledged that many studies reported no reduction in strength, power, or explosive muscular performance following SS (Bazett-Jones et al., 2005; Burkett et al., 2005; Cramer et al., 2005, 2007b; Unick et al., 2005; Little & Williams, 2006; McMillian et al., 2006; O'Connor et al., 2006; Maisetti et al., 2007; Kinser et al., 2008; Torres et al., 2008; Wallmann et al., 2008; Di Cagno et al., 2010; Haag et al., 2010; Handrakis et al., 2010; Molacek et al., 2010; Murphy et al., 2010), while some of them even reported improvement in performance (O'Connor et al., 2006; Gonzalez-Rave et al., 2009; Haag et al., 2010). Moreover, we still do not know a precise magnitude of stretch-induced acute changes in muscular performance. Finally, the total duration of muscle stretching in most studies in this area was much longer than the ranges normally used in practice and recommended in literature, i.e., 15–30 s per muscle group (Rubini et al., 2007; Young, 2007). Given the widespread use of SS in exercise and rehabilitation settings, it is of both scientific and practical relevance to determine a precise estimate of acute effects of SS on muscle function and exercise performance.

While two narrative reviews (McHugh & Cosgrave, 2010; Behm & Chaouachi, 2011) and one systematic review (Kay & Blazevich, 2011) have been recently published on this topic and reported average effects of acute

SS on various performance measures, none of those studies actually used an appropriate statistical tool for combining and analyzing individual study findings in a quantitative manner. Thus, the precise magnitude of stretch-induced acute changes in muscular performance is still unknown. In the present study, we applied a meta-analytical approach to derive a robust estimate of the acute effects of SS on muscle strength, power, and explosive muscular performance. We also seek to understand whether these effects (a) were specific with respect to the subject characteristics (age, gender, and training status) and type of performance test, and (b) depend on the total duration of SS per muscle group.

Methods

Literature search and study selection

Searches of PubMed, SCOPUS, and Web of Science were performed for studies published in English up to and including December 2010. We used the following search phase (static stretch OR static stretching OR acute stretch OR acute stretching OR passive stretch OR warm-up) AND (strength OR force OR torque OR jump OR sprint OR throw OR performance). Reference lists in review and original research articles identified were also examined. The present meta-analysis includes studies published in journals that have presented original research data on healthy human subjects. No age or gender restrictions were imposed at the search stage. Abstracts and unpublished theses/dissertations were excluded from this analysis due to lack of methodological details. Inclusion criteria applied in this study were as follows: (a) crossover, randomized, and non-randomized control trials; (b) studies that evaluated acute effects of SS on human muscular strength, power, and explosive muscular performance; (c) studies in which SS lasted not longer than 30 min; and (d) English language studies published in peer-reviewed journals. Our search strategy retrieved 1168 hits in PubMed, 285 hits in SCOPUS, and 216 hits in Web of Science. Studies that examined the acute effects of SS on other fitness qualities (e.g., muscular or cardiorespiratory endurance, flexibility, agility, balance, repeated-sprint ability, etc.; Zakas et al., 2003, 2006c, e; Knudson et al., 2004; Young et al., 2004; Nelson et al., 2005b; Beckett et al., 2009; Sim et al., 2009; Costa et al., 2009a; Amiri-Khorasani et al., 2010; Covert et al., 2010; Samogin Lopes et al., 2010; Wilson et al., 2010) were not included in this meta-analytical review. Also, due to significant contralateral effect of acute SS (Cramer et al., 2005), studies that used the contralateral (unstretched) limb as a control were not considered in this meta-analytical review. A total of 115 articles that studied the acute effects of SS (either active or passive) on maximal muscle strength [one repetition maximum (1 RM), isometric or isokinetic force or torque], muscle power, and explosive muscular performance [rate of force or torque development (RFD), jumping, sprinting, and throwing performance] was identified. Note that we excluded from this list several potentially relevant studies on the grounds of having no control (i.e., prestretch) condition (Faigenbaum et al., 2005, 2006a, b; Thompsen et al., 2007; Taylor et al., 2009). Furthermore, some studies were excluded as they combined SS with dynamic stretching (Fletcher & Anness, 2007; Sim et al., 2009; Taylor et al., 2009). Finally, some studies were excluded because SS lasted more than 30 min (Avela et al., 1999, 2004), or because they combined stretching and maximal voluntary contractions (Kay & Blazevich, 2009a, 2010). Note also that numerous studies met our inclusion criteria but failed to report all or some of the results in numerical format (Kokkonen et al., 1998; Fowles et al., 2000; Behm et al., 2001, 2004, 2006; Cornwell et al., 2001, 2002; Nelson et al. 2001a, b; Siatras et al., 2003, 2008; Power et al., 2004; Papadopoulos et al., 2005; Knudson & Noffal, 2005; Wallmann et al., 2005, 2008; Little & Williams, 2006; O'Connor et al., 2006; Behm & Kibele, 2007; Ogura et al., 2007; Bradley et al., 2007; Maisetti et al., 2007; Herda et al., 2008, 2009, 2010; Holt & Lambourne, 2008; Samuel et al., 2008; Bacurau et al., 2009; Hough et al., 2009; Kay & Blazevich, 2009a; Pearce et al., 2009). In these cases, a personal contact was made with the authors to retrieve appropriate information. However, several authors did not respond to our request; therefore, we manually calculated the results from the figures (in combination with data from articles). Only one study was partly excluded (i.e., for one primary outcome) for poor reporting of data (Winke et al., 2010). Thus, altogether, 104 studies met our inclusion criteria and were included in this meta-analytical review.

Assessment of study quality

Methodological quality was assessed with the PEDro scale (Maher et al., 2003). The quality of the included studies was assessed independently by two assessors, and disagreements were resolved by a third independent assessor.

Coding and classifying variables

Each study that met our inclusion criteria was recorded on a coding sheet. The major categories coded included (a) study characteristics; (b) subject characteristics; (c) intervention characteristics; and (d) primary outcome characteristics. The study characteristics that were coded included author(s) name, journal, year of publication, and the number of subjects. Subject characteristics that were coded included age, gender, and fitness level. Gender was coded as a variable representing the proportion of men in the sample (e.g., 1 for all men; 0.5 for five women and five men; and 0 for all women). Fitness level was coded as "non-athletes" (physically inactive persons and recreationally trained individuals) and "athletes" (competitive level). Intervention characteristics that were coded included stretched muscles and total duration of stretching per muscle group per limb. Note that in several cases, the total duration of SS per muscle group per limb was not explicitly defined; in these cases, we calculated it from the available data (i.e., total duration of SS, number of sets, and/or exercises). Furthermore, in several cases, researchers applied different number of stretching exercises per selected muscle groups. This resulted in large variation in mean duration of SS per muscle group. In these cases, we reported mean duration of SS of primary muscle group(s) (with respect to primary outcome), together with the respective range of duration of SS per muscle group per limb. Finally, primary outcome characteristics that were coded included type of exercise test applied for the assessment of maximal muscle strength (1RM, isometric peak force/torque, or isokinetic peak torque), muscle power (mean or peak power), and explosive muscular performance (RFD, jumping, sprinting, or throwing performance). Note that many of the included studies applied a one-group repeated-measure design (i.e., no stretch and SS condition). Although it is possible to perform a meta-analysis on studies that applied different study designs (i.e., independent groups vs matched groups; Borenstein et al., 2009), we decided to treat each study included in this meta-analysis as a one-group pre-/posttest intervention (Peterson et al., 2010). Therefore, coding of performance change was only carried out for groups receiving the SS treatment. Specifically, for all studies, means and standard deviation (SD) for pre- and poststretching condition were extracted. In cases where the author(s) measured >1 poststretching condition (i.e., time course of changes in performance after static stretching; e.g., Fowles et al., 2000; Brandenburg et al., 2007), only the first poststretching condition was considered.

Data extraction and data analyses

Given that each treatment group was considered a one-group pre-/posttest intervention, the study estimate for the acute effect of SS on muscle strength, muscle power, and explosive muscular performance is given by the difference between the post- and prestretching results in primary outcomes divided by a within-group SD (SD_{within}; Borenstein et al., 2009), i.e., the standardized mean difference *d*. The within-group SD (SD_{within}) was obtained using the following formula:

$$SD_{within} = \frac{S_{diff}}{\sqrt{2 \times (1 - r)}}$$

where S_{diff} is the standard deviation of the difference scores and *r* is the correlation between pairs of observation (i.e., the pretest–posttest correlation of performance measures). Note that many of the studies did not report S_{diff}. Rather, the majority of studies obtained for this analysis included the SDs for the pre- and poststretching performance outcomes, or sometimes the standard errors of the mean. For all other studies, S_{diff} was calculated using the pre- and poststretching SDs, as well as pretest–posttest correlation of performance measures *r* using the following equation (Follmann et al., 1992; Peterson et al., 2010):

$$SD_{diff} = \sqrt{\left[SD_{pre}{}^2 + SD_{post}{}^2 - 2 \times r \times SD_{pre} \times SD_{post}\right]}$$

For the purpose of this meta-analysis, pretest–posttest correlation of performance measures r was 0.9. Note that changing r to 0.8 or to 0.7 had a little effect on pooled estimates and would not change the main conclusion of this meta-analytical review. The standard error (SEd) of d is given by (Borenstein et al., 2009):

$$SE_d = \sqrt{\left(\frac{1}{n} + \frac{d^2}{2 \times n}\right) \times 2 \times (r - 1)}$$

where *n* is the number of pairs.

We also expressed the study estimates relative to the prestretching mean value, that is, in percentage values. Percentage effects were converted to factors (= 1 + effect/100), log transformed for the analysis, and then back transformed to percentages (Bonetti & Hopkins, 2009). In this case, the standard error (SE_d) of *d* was approximated by the following equation (Peterson et al., 2010):

$$SE_d = \frac{R \times \sqrt{\left[CV_{pre}{}^2 + CV_{post}{}^2 - 2 \times r \times CV_{pre} \times CV_{post}\right]}}{\sqrt{n}}$$

where *R* represents the ratio of post- and prestretch performance measures, *CV* denotes the coefficient of variation equaling the ratio of *SD* and mean at the respective time (i.e., pre- and poststretching), *r* is pretest–posttest correlation of performance measures, and *n* represents the number of participants.

A random-effects model was chosen for meta-analysis to account for heterogeneity in effect *d* among trials. The weight factor by which the study estimates were weighted was

$$\frac{1}{SE_d{}^2 + \tau^2}$$

where τ is the between-study variation (Borenstein et al., 2009). Separate meta-analyses were performed for maximum muscle strength (peak isometric force or torque, 1RM, concentric or eccentric isokinetic peak torque), muscle power (mean and peak power), and explosive muscular performance (RFD, jumping performance, sprinting performance, and throwing performance). Furthermore, within the maximal muscle strength and explosive muscular performance category, separate meta-analyses were performed for isometric vs dynamic maximal strength, and for rate of force/torque development vs jumping performance (vertical jump height and horizontal jump distance) vs sprinting performance (sprint velocity or sprint time over distances between 5 and 100 m) vs throwing performance (throwing velocity or throwing distance). Note that a number of studies reported >1 primary outcome owing to >1 performance test measured. In cases where multiple outcomes belonged to the same performance category being meta-analyzed, we computed the composite effect and the respective *SE* according to Borenstein et al. (2009). For all pooled estimates, we calculated the 95% confidence intervals (95% CI), and we made probabilistic magnitude-based inferences about the true values of the effects, as suggested by Hopkins and co-workers (Batterham & Hopkins, 2006; Bonetti & Hopkins, 2009; Hopkins et al., 2009). An effect was deemed unclear if its 95% CI overlapped the thresholds for smallest positive and negative effects; equivalently, the effect was unclear if chances of the true value being substantially positive and negative were both >5% (Batterham & Hopkins, 2006). The probabilities for each meta-analyzed effect were derived using a published spreadsheet (Hopkins, 2007). An estimate of the smallest substantial change in performance is required to make these inferences. Based on variability in competitive athletic performance reported by Hopkins and co-workers (Hopkins, 2004, 2005; Bonetti & Hopkins, 2010; Smith & Hopkins, 2011), we defined the threshold change in performance for benefit and harm for field-based explosive performance tests (i.e., jumping, sprinting, and throwing performance) and muscle power as 1%. For strength performance [i.e., maximal muscle strength and RFD], the corresponding threshold change were derived from the within-individual variability in strength performance, expressed as coefficient of variation. The within-individual variation in muscle strength and RFD varies considerably due to the well-known factors like type of test, type and velocity of contraction, muscle group being tested, subject's characteristics, etc. (Abernethy et al., 1995; Wilson & Murphy, 1996). However, it usually ranges between 3% and 15%. If we conservatively take 3% as a typical within-individual variation in strength performance, we may approximate the smallest substantial change by multiplying this value with the factor of 1.5 or 2 (Hopkins, 2000). We therefore defined this threshold change as 5%.

Heterogeneity of effects for each meta-analysis was assessed using the quantity I^2, as suggested by Higgins and co-workers (Higgins et al., 2003). In brief, I^2 was calculated as follows: $I^2 = 100\% \cdot (Q - \text{d.f.})/Q$, where *Q* is Cochran's χ^2 heterogeneity statistic and d.f. is the degrees of freedom. The Cochran's *Q* is calculated by summing the squared deviations of each trial's estimate from the overall meta-analytical estimate. I^2 describes the percentage of variability in point estimates which is due to heterogeneity rather than sampling error. I^2 values of 25%, 50%, and 75% represent low, moderate, and high statistical heterogeneity, respectively (Higgins et al., 2003).

Publication bias, as well as evidence of outliers, was examined by funnel plots of standard errors of the estimate of the acute effect vs calculated study estimates *d*. In addition, publication bias was also statistically evaluated by calculating rank correlations between effect estimates and their standard errors (i.e., Kendall's τ statistic; Begg & Mazumdar, 1994). A significant result was considered to be suggestive of publication bias.

Subgroup analyses for each primary outcome included subject's training status (athletes vs non-athletes), SS categories formed according to stretch duration per muscle (≤45 s vs 46 s to 90 s vs >90 s), and type of muscular performance test (isometric vs dynamic test for maximal muscle strength; RFD vs jumping performance vs sprinting performance vs throwing performance for explosive muscular performance), and were performed using a *Q*-test based on analysis of variance (Borenstein et al., 2009). In cases where the total duration of stretching was different among stretched muscle groups, the average stretch duration was used in

further analyses. Similarly, for studies that reported acute effects of SS of different durations on a particular primary outcome (e.g., Zakas et al. 2006a; Zakas et al. 2006b; Zakas et al. 2006d; Ogura et al., 2007; Kay & Blazevich, 2008; Ryan et al. 2008b; Winchester et al., 2009), along with calculation of the composite effect (see previous text), we averaged the total duration of stretching per muscle group. Meta-regression was used for analyzing the relationship between study estimates and the selected subject or training characteristics: subject's age, gender, and total duration of stretching per muscle (Borenstein et al., 2009). The level of significance was set to $P < 0.05$.

Results

Descriptive statistics

Altogether, 104 published investigations were included in the meta-analyses, giving 61 study estimates for maximal muscle strength, 12 study estimates for muscle power, and 57 study estimates for explosive muscular performance. Tables 1–3 summarize the characteristics of the included studies. Altogether, 962 subjects (593 males and 369 females) were included in the meta-analysis of maximal muscle strength, 195 subjects (125 males and 70 females) were included in the meta-analysis of muscle power, and 1072 subjects (719 males and 353 females) were included in the meta-analysis of explosive muscular performance. The average duration of pre-exercise SS per muscle group per limb for maximal muscle strength, muscle power, and explosive muscular performance tests was 314, 255, and 86 s, respectively.

Methodological quality of included studies

The range of quality scores was 2–5 (median 4) out of 10. Often a report did not clearly specify that a criterion was met, and, consequently, we scored the study as not satisfying the criterion. Note that all studies failed to satisfy the following five methodological criteria: treatment allocation concealment, blinding of all subjects, blinding of all therapists, blinding of all assessors, and intention to treat analyses (i.e., items 3, 5, 6, 7, and 9, respectively).

Primary outcomes

Tables 1–3 report individual changes in the primary outcomes and summarize the pooled estimates of the acute effects of SS on maximal muscle strength, muscle power, and explosive muscular performance.

Maximal muscle strength

For the maximal muscle strength (i.e., peak force, torque, or 1RM), pooled estimate of the acute effect of SS, expressed in standardized units, was $d = -0.10$ (95% CI: −0.15 to −0.04). When expressed in percentages, the respective pooled estimate was −5.4% (95% CI: −6.6% to −4.2%), indicating a likely negative acute effect. The statistical heterogeneity of the acute effect of SS on muscle strength was low ($I^2 = 5\%$). The inspection of the funnel plot as well as Kendall's τ statistic ($r = -0.11$; $P = 0.20$) suggests no presence of publication bias in maximal muscle strength tests. Notably, one study could be defined as outlying (Behm et al., 2001); however, its exclusion from the meta-analysis did not affect the pooled estimate. Subgroup analyses showed similar acute effect of SS on maximal muscle strength in both athletes and non-athletes ($P = 0.97$). With respect to the type of test applied, significantly larger ($P = 0.012$) pooled negative acute effect of SS was observed for isometric vs dynamic strength tests (Fig. 1(a)), although the average stretch duration per muscle group did not differ significantly between the two groups of tests (333 s vs 290 s; $P > 0.05$). Specifically, pooled estimates for the acute effect of SS on isometric and dynamic strength tests were −6.5% (95% CI: −8.3% to −4.6%; almost certainly negative effect) and −3.9% (95% CI: −4.8% to −2.9%; most likely trivial effect), respectively. With respect to the stretch duration, we observed a trend ($P = 0.18$) toward diminishing the negative acute effect of SS on maximal muscle strength with shorter stretch duration (Fig. 2(a)). In particular, pooled estimates for the acute effect of SS lasting ≤45 s, 46–90 s, and >90 s per muscle group on maximal muscle strength were −3.2% (95% CI: −5.6% to −0.8%; most likely trivial effect), −5.6% (95% CI: −7.3% to −3.8%; likely negative effect), and −6.1% (95% CI: −7.9% to −4.3%; almost certainly negative effect), respectively.

Muscle power

Pooled estimate of the acute effect of SS on muscle power was $d = -0.04$ (95% CI: −0.16 to 0.08). When expressed in percentages, the respective pooled estimate was −1.9% (95% CI: −4.0% to 0.2%), indicating an unclear acute effect of SS on muscle power. We also observed very low heterogeneity of acute effects of SS on muscle power ($I^2 = 3.6\%$). Note also that both funnel plot and Kendall's τ statistic ($r = -0.36$; $P = 0.09$) showed no evidence of publication bias in muscle power tests. Subgroup analyses showed similar acute effect of SS on muscle power in both athletes and non-athletes ($P = 0.7$). Although limited by the number of studies, subgroup analysis related to stretch duration showed a trend ($P = 0.10$) toward reduction of the negative acute effect of SS on muscle power with shorter stretch duration (Fig. 2(b)). Specifically, pooled estimates for the acute effect of SS lasting ≤45, 46–90, and >90 s per muscle group on muscle power were 0.4% (95% CI: −5.8% to 6.6%; an unclear effect), −1.7% (95% CI: −5.1% to 1.6%; possibly negative effect), and −3.3% (95% CI: −7.2% to 0.6%; a likely negative effect), respectively.

Table 1. Summary of the investigations included in the meta-analyses of acute effects of static stretching on maximal muscle strength

Study	Age (years)	Fitness level	Sample size M/F	Duration of stretch (s)	Stretched muscle groups	Performance measure	Effect size (SE)	95% CI	% change (SE)	95% CI
Allison et al. (2008)	25	A	10/0	240 (240–360)	PF, KE, KF, HF	F	–0.25 (0.28)	–0.80 to 0.30	–5.7 (3.1)	–11.8 to 0.4
Babault et al. (2010)	23	N-A	10/0	600	PF	T	–0.56 (0.57)	–1.69 to 0.57	–10.1 (2.5)	–15.0 to –5.2
Bacurau et al. (2009)	23.1	N-A	0/14	270	KE,KF	1RM	–0.78 (0.94)	–2.62 to 1.06	–13.4 (1.8)	–16.9 to –9.9
Bazett-Jones et al. (2005)	20.6	A	10/0	90	KE, KF, HE, HF	F	0.05 (0.14)	–0.23 to 0.33	0.9 (2.8)	–4.6 to 6.5
Beedle et al. (2008)*	20.4	N-A	19/0	45	KE, KF, UB	F	–0.05 (0.14)	–0.33 to 0.23	–1.2 (2.3)	–5.7 to 3.3
Beedle et al. (2008)*	20.4	N-A	0/32	45	KE, KF, UB	F	–0.05 (0.14)	–0.33 to 0.23	–0.8 (1.3)	–3.3 to 1.8
Behm et al. (2006)*	25	N-A	9/9	90	PF, KE, KF	F	–0.16 (0.24)	–0.64 to 0.32	–6.5 (3.9)	–14.1 to 1.1
Behm et al. (2006)	21.9	N-A	12/0	90	PF, KE, KF	F	–0.36 (0.42)	–1.19 to 0.47	–7.4 (3.7)	–14.7 to –0.2
Behm et al. (2004)	24.1	N-A	16/0	135 (135–270)	PF, KE, KF	F	–0.41 (0.53)	–1.45 to 0.63	–6.9 (1.9)	–10.7 to –3.1
Behm et al. (2001)	N/A	N-A	18/0	900	KE	F	–2.36 (3.17)	–8.58 to 3.86	–12.2 (0.5)	–13.2 to –11.2
Brandenburg (2006)	23.4	N-A	10/6	135 (90–180)	KF	F	–0.27 (0.35)	–0.95 to 0.41	–6.2 (2.5)	–11.1 to –1.3
Brandenburg (2006)	23.4	N-A	10/6	135 (90–180)	KF	T (120°/s)	–0.17 (0.17)	–0.51 to 0.17	–4.3 (2.2)	–8.6 to –0.1
Costa et al. (2009c)*	20.8	N-A	0/13	480	PF,KF	T (60/180/300°/s)	–0.19 (0.20)	–0.58 to 0.20	–6.9 (3.5)	–13.9 to 0.0
Costa et al. (2009b)*	22	N-A	15/0	480	PF, KF	T (60/180/300°/s)	–0.03 (0.10)	–0.23 to 0.17	–0.7 (2.1)	–4.7 to 3.4
Cramer et al. (2007a)*	22	N-A	15/0	480	KE	T (60/240°/s)	–0.14 (0.20)	–0.53 to 0.25	–2.4 (1.9)	–6.2 to 1.5
Cramer et al. (2005)*	20.8	N-A	7/14	480	KE	T (60/180°/s)	–0.11 (0.17)	–0.45 to 0.23	–3.8 (3.9)	–11.5 to 3.9
Cramer et al. (2004)*	21.4	N-A	0/14	480	KE	T (60/300°/s)	–0.12 (0.20)	–0.51 to 0.27	–3.6 (1.0)	–5.5 to –1.6
Cramer et al. (2006)*	23	N-A	0/13	480	KE	T (60/300°/s)	–0.95 (0.94)	–2.79 to 0.89	–2.5 (1.5)	–5.4 to 0.3
Cramer et al. (2007b)*	23.4	N-A	8/10	480	KE	T (–60/–180°/s)	–0.03 (0.17)	–0.37 to 0.31	–0.4 (2.5)	–5.2 to 4.4
Cramer et al. (2007b)*	21.5	N-A	7/14	480	KE	T (60/240°/s)	–0.12 (0.20)	–0.51 to 0.27	–3.5 (2.6)	–8.5 to 1.6
Egan et al. (2006)*	20	A	0/11	480	KE	T (60/300°/s)	0.06 (0.24)	–0.42 to 0.54	1.0 (2.7)	–4.4 to 6.3
Evetovich et al. (2010)	19.9	A	0/15	480	KE	T (60°/s)	–0.24 (0.32)	–0.86 to 0.38	–7.1 (2.9)	–12.8 to –1.4
Evetovich et al. (2010)	21	A	0/14	480	KE	T (60°/s)	–0.21 (0.26)	–0.73 to 0.31	–5.3 (3.6)	–12.4 to 1.9
Evetovich et al. (2003)*	22.7	N-A	10/8	360	EF	T (30/270°/s)	–0.14 (0.22)	–0.58 to 0.30	–6.2 (4.0)	–14.1 to 1.7
Fletcher and Monte-Colombo (2010a)	20.8	A	21/0	30 (30–60)	PF, KE, KF, HE,HF	T (30°/s)	–0.14 (0.17)	–0.48 to 0.20	–3.6 (1.8)	–7.2 to 0.0
Fowles et al. (2000)	21	N-A	8/4	1755	PF	T	–1.27 (1.40)	–4.01 to 1.47	–27.7 (3.0)	–33.5 to –21.9
Gurjao et al. (2009)	64.6	N-A	0/23	90	KE, KF, HE	T	–1.31 (1.99)	–5.21 to 2.59	–7.6 (0.6)	–8.7 to –6.6
Herda et al. (2010)	23	N-A	11/0	360	PF	T	–0.60 (0.64)	–1.85 to 0.65	–9.4 (2.1)	–13.5 to –5.2
Herda et al. (2009)	24	N-A	15/0	1200	PF	T	–0.52 (0.64)	–1.77 to 0.73	–10.2 (2.1)	–14.4 to –6.1
Herda et al. (2008)*	25	N-A	14/0	1215	KF	T	–0.25 (0.30)	–0.84 to 0.34	–6.5 (2.4)	–11.2 to –1.8
Kay and Blazevich (2008)*	25.5	N-A	4/3	30 (5–60)	PF	T (180°/s)	–0.31 (0.26)	–0.83 to 0.21	–7.0 (3.1)	–13.0 to –1.0
Kay and Blazevich (2009b)	20.2	N-A	8/7	180	PF	T (5°/s)	–	–	–5.0 (1.2)	–7.3 to –2.7
Knudson and Noffal (2005)*	N/A	N-A	33/24	10	WF	F	–0.31 (0.41)	–1.12 to 0.50	–8.5 (1.45)	–11.3 to –5.6
Kokkonen et al. (1998)*	22	N-A	15/15	90	PF, KE, KF, HF	1RM	–0.25 (0.44)	–1.1 to 0.60	–7.9 (2.4)	–12.5 to –3.3
Kubo et al. (2001)	25.3	N-A	7/0	600	PF	T	–0.17 (0.22)	–0.61 to 0.27	–1.9 (1.9)	–5.6 to 1.9

Table 1. (continued)

Study	Age (years)	Fitness level	Sample size M/F	Duration of stretch (s)	Stretched muscle groups	Performance measure	Effect size (SE)	95% CI	% change (SE)	95% CI
Maisetti et al. (2007)	25	N-A	0/11	75	PF	T	–0.54 (0.58)	–1.68 to 0.60	–8.5 (2.0)	–12.3 to –4.6
Marek et al. (2005)*	23	N-A	9/10	480	KE	T (60/300°/s)	–0.02 (0.10)	–0.22 to 0.18	–0.9 (4.3)	–9.3 to 7.4
McBride et al. (2007)*	21.4	N-A	8/0	270	KE	F	–0.50 (0.47)	–1.42 to 0.42	–11.9 (3.5)	–18.7 to –5.0
Molacek et al. (2010)*	19.9	A	15/0	95 (40–150)	UB	1RM	–0.05 (0.14)	–0.33 to 0.23	–0.6 (1.2)	–3.0 to 1.8
Nelson et al. (2005c)*	22	N-A	18/13	360	PF, KE, KF, HF	1RM	–0.14 (0.24)	–0.62 to 0.34	–4.4 (2.4)	–9.0 to 0.3
Nelson et al. (2001a)*	22	N-A	25/30	480	KE	T	–0.03 (0.10)	–0.23 to 0.17	–1.3 (1.9)	–5.0 to 2.4
Nelson et al. (2001b)*	24	N-A	10/5	90	KE	T	–0.39 (0.50)	–1.37 to 0.59	–9.2 (2.4)	–13.9 to –4.5
Ogura et al. (2007)*	20	A	10/0	30	KF	F	–0.43 (0.45)	–1.31 to 0.45	–5.4 (1.6)	–8.5 to –2.3
Papadopoulos et al. (2005)	20.7	N-A	32/0	180 (90–180)	KE, KF	T (30°/s)	–0.31 (0.42)	–1.14 to 0.52	–4.5 (0.9)	–6.2 to –2.8
Papadopoulos et al. (2006)	19.7	N-A	10/0	90	PF, KE, KF, HF	F	–0.03 (0.14)	–0.31 to 0.25	–0.8 (3.8)	–8.3 to 6.7
Power et al. (2004)	32	N-A	12/0	270	PF, KE, KF	F	–0.49 (0.55)	–1.56 to 0.58	–9.0 (2.5)	–13.9 to –4.0
Ryan et al. (2008b)*	22	N-A	7/6	120	PF	T	–0.30 (0.33)	–0.95 to 0.35	–4.7 (3.2)	–10.9 to 1.6
Sekir et al. (2010)*	20	A	0/10	80	KE, KF	T (60/180°/s)	–0.42 (0.32)	–1.04 to 0.20	–9.8 (2.2)	–14.2 to –5.4
Siatras et al. (2008)*	22.1	N-A	20/0	10	KE	T	0.06 (0.17)	–0.28 to 0.40	1.4 (1.9)	–2.4 to 5.2
Siatras et al. (2008)*	21	N-A	20/0	20	KE	T	–0.14 (0.17)	–0.48 to 0.20	–2.9 (2.2)	–7.1 to 1.4
Siatras et al. (2008)*	21.1	N-A	20/0	30	KE	T	–0.71 (0.59)	–1.87 to 0.45	–6.6 (1.2)	–8.9 to –4.3
Siatras et al. (2008)*	21.1	N-A	20/0	60	KE	T	–0.82 (0.67)	–2.13 to 0.49	–12.5 (1.8)	–16.0 to –8.9
Thigpen (1989)*	27.3	N-A	12/12	90	KF	T (60/150/240°/s)	–0.01 (0.10)	–0.21 to 0.19	–0.2 (1.42)	–3.0 to 2.6
Torres et al. (2008)	19.6	A	11/0	30	UB	F	0.21 (0.26)	–0.31 to 0.73	3.2 (2.2)	–1.0 to 7.5
Viale et al. (2007)	23.1	N-A	7/1	390	KE	T	–0.46 (0.45)	–1.34 to 0.42	–8.0 (2.6)	–13.2 to –2.9
Weir et al. (2005)	23.1	N-A	0/15	600	PF	T	–0.42 (0.53)	–1.46 to 0.62	–7.1 (1.9)	–10.8 to –3.3
Winchester et al. (2009)*	22.5	N-A	10/8	105 (30–180)	KF	1RM	–0.25 (0.26)	–0.77 to 0.27	–8.9 (2.6)	–13.9 to –3.8
Yamaguchi et al. (2006)*	23.8	N-A	12/0	720	KE, HF	T	–0.02 (0.20)	–0.41 to 0.37	–0.7 (1.4)	–3.4 to 2.1
Zakas et al. (2006b)*	18.5	A	14/0	172 (45–300)	KE	T (60/90/150/210/270°/s)	–0.31 (0.24)	–0.79 to 0.17	–4.3 (1.3)	–6.8 to –1.9
Zakas et al. (2006a)*	13	A	16/0	60	KE	T (30/60/120/180/300°/s)	–0.29 (0.30)	–0.88 to 0.30	–4.2 (1.1)	–6.5 to –2.0
Zakas et al. (2006d)*	25	A	15/0	270 (30–480)	KE	T (60/90/150/210/270°/s)	–0.25 (0.26)	–0.77 to 0.27	–3.5 (1.2)	–5.9 to –1.2
Overall mean (all)	**22.9**	**–**	**10/6**	**314**	**–**	**–**	**–0.10 (0.03)**	**–0.15 to –0.04**	**–5.4 (0.6)**	**–6.6 to –4.2**

*Study that reported more than one primary outcome.

A, athletes; N-A, non-athletes; PF, ankle plantar flexors; KE, knee extensors; KF, knee flexors; HE, hip extensors; HF, hip flexors; UB, upper body; WF, wrist flexors; 1 RM, one repetition maximum; F, peak force; T, peak torque; CI, confidence interval; SE, standard error.

Table 2. Summary of the investigations included in the meta-analyses of acute effects of static stretching on muscle power

Study	Age (years)	Fitness level	Sample size M/F	Duration of stretch (s)	Stretched muscle groups	Performance measure	Effect size (SE)	95% CI	% change (SE)	95% CI
Muscle power										
Chaouachi et al. (2010)*	20.6	A	22/0	60	PF, KE, KF, HE, HF	MP	0.17 (0.27)	–0.35 to 0.70	1.6 (0.9)	–0.1 to 3.3
Cornwell et al. (2001)*	20.6	N-A	10/0	90	KE, HE	PP	–0.18 (0.22)	–0.61 to 0.26	–2.9 (2.2)	–7.1 to 1.4
Cramer et al. (2007b)*	23.4	N-A	15/0	480	KE	MP	–0.03 (0.17)	–0.36 to 0.30	–0.4 (2.5)	–5.2 to 4.4
Cramer et al. (2005)*	21.5	N-A	7/14	480	KE	MP	–0.12 (0.30)	–0.71 to 0.46	–2.7 (3.0)	–8.7 to 3.2
Egan et al. (2006)*	20.0	A	0/11	480	KE	MP	–0.04 (0.22)	–0.46 to 0.38	0.2 (5.0)	–9.6 to 10.1
Manoel et al. (2008)*	24.0	N-A	0/12	90	KE	MP	–0.13 (0.19)	–0.49 to 0.24	–2.9 (2.8)	–8.5 to 2.7
Marek et al. (2005)*	22.0	N-A	9/10	480	KE	MP	–0.04 (0.11)	–0.26 to 0.19	–1.5 (4.0)	–9.3 to 6.23
O'Connor et al. (2006)	21.4	N-A	16/11	30 (20–40)	PF,KE,KF,HE,HF	MP	0.13 (0.23)	–0.32 to 0.57	6.1 (4.5)	–2.7 to 14.8
Samuel et al. (2008)	22.0	N-A	12/12	90	KE,KF	MP	–1.89 (2.93)	–7.63 to 3.85	–3.4 (0.2)	–3.7 to –3.1
Torres et al. (2008)	19.6	A	11/0	30	UB	PP	0.14 (0.20)	–0.25 to 0.53	2.2 (2.2)	–2.1 to 6.5
Yamaguchi and Ishii (2005)	22.8	N-A	11/0	30	PF, KE, KF, HE, HF	MP	–0.27 (0.31)	–0.89 to 0.35	–5.1 (2.4)	–9.8 to –0.5
Yamaguchi et al. (2006)*	23.8	N-A	12/0	720	KE, HF	PP	–0.44 (0.40)	–1.23 to 0.35	–8.2 (1.7)	–11.6 to –4.8
Overall mean	**21.8**	**–**	**10/6**	**255**	**–**	**–**	**–0.04 (0.06)**	**–0.16 to 0.08**	**–1.9 (1.1)**	**–4.0 to 0.2**

*Study that reported more than one primary outcome.

A, athletes; N-A, non-athletes; PF, ankle plantar flexors; KE, knee extensors; KF, knee flexors; HE, hip extensors; HF, hip flexors; UB, upper body;. MP, mean power; PP, peak power; CI, confidence interval; SE, standard error.

Fig. 1. Meta-analyzed acute effects of static stretching on maximal muscle strength tests (a) and explosive muscular performance tests (b). ISOM, isometric muscle strength; DYN, dynamic muscle strength; RFD, rate of force or torque development; JUMP, jumping performance; SPRINT, sprinting performance; THROW, throwing performance.

Explosive muscular performance

For all explosive muscular performance tests, pooled estimate of the acute effect of SS was $d = -0.03$ (95% CI: –0.07 to 0.01). When expressed in percentages, the respective pooled estimate was –2.0% (95% CI: –2.8% to –1.3%), indicating a very likely negative acute effect of SS on explosive muscular performance. We also observed very low heterogeneity of acute effects of SS on muscle power ($I^2 = 1.7\%$). Kendall's τ statistic ($r = -0.03$; $P = 0.71$) suggests no presence of publication bias in this performance category. However, a close inspection of the funnel plot recognized one study that had unrealistically large negative acute effect of SS on explosive performance ($d = -1.1$; percent change = –38.4%; McBride et al., 2007). Although its exclusion did not change the overall acute effect of SS on explosive muscular performance, it did affect two subgroup meta-analyses (i.e., groups based on the type of test and stretch duration, respectively). We therefore removed that study from those analyses. Subgroup analyses showed similar acute effect of SS on explosive muscular performance in both athletes and non-athletes ($P = 0.81$). With respect to the type of test applied, significant differences ($P < 0.05$)

Table 3. Summary of the investigations included in the meta-analyses of acute effects of static stretching on explosive muscular performance

Study	Age (years)	Fitness level	Sample size M/F	Duration of stretch (s)	Stretched muscle groups	Performance test	Effect size (SE)	95% CI	% change (SE)	95% CI
Jump										
Allison et al. (2008)	25.0	A	10/0	240 (240–360)	PF, KE, KF, HF	CMJ	–0.50 (0.52)	–1.52 to 0.52	–5.4 (1.5)	–8.3 to –2.5
Behm and Kibele (2007)	27.6	N-A	7/3	120	PF, KE, KF	SJ, DJ, CMJ	–0.29 (0.24)	–0.76 to 0.19	–4.7 (1.7)	–8.0 to –1.3
Behm et al. (2006)	25.0	N-A	9/9	90	PF, KE, KF	DJ	–0.08 (0.15)	–0.36 to 0.21	–2.0 (2.7)	–7.3 to 3.3
Behm et al. (2006)	21.9	N-A	12/0	90	PF, KE, KF	DJ, CMJ	–0.02 (0.31)	–0.63 to 0.60	1.1 (3.34)	–5.5 to 7.8
Bradley et al. (2007)	24.3	N-A	18/0	120 (120–240)	PF,KE,KF	CMJ, SJ	–0.12 (0.19)	–0.49 to 0.26	–4.0 (3.3)	–10.6 to 2.6
Brandenburg et al. (2007)	22.3	N-A	8/8	90	PF, KE, KF	CMJ	–0.15 (0.22)	–0.57 to 0.28	–3.0 (2.2)	–7.3 to 1.4
Burkett et al. (2005)	20.0	A	29/0	60	PF, KE, KF, HE, HF	CMJ	0.08 (0.15)	–0.22 to 0.38	0.7 (0.8)	–0.8 to 2.3
Chaouachi et al. (2010)*	20.6	A	22/0	60	PF, KE, KF, HE, HF	HJ, CMJ	0.01 (0.11)	–0.20 to 0.22	0.2 (0.7)	–1.3 to 1.6
Church et al. (2001)	20.3	A	0/40	n-a	KE, KF, HE, HF	CMJ	–1.31 (7.73)	–16.46 to 13.83	–1.2 (1.1)	–3.5 to 1.0
Cornwell et al. (2001)*	20.6	N-A	10/0	90	KE, HE	CMJ, SJ	–0.50 (0.51)	–1.49 to 0.49	–4.4 (1.2)	–6.8 to –2.0
Cornwell et al. (2002)*	22.5	N-A	10/0	180	PF	CMJ, SJ	–0.15 (0.24)	–0.61 to 0.31	–4.1 (4.0)	–11.9 to 3.8
Cronin et al. (2008)	22.7	A	10/0	90	KF	CMJ	0.00 (0.14)	–0.28 to 0.28	0.0 (3.9)	–7.7 to 7.7
Curry et al. (2009)	26.0	N-A	0/23	36	PF, KE, KF, HE, HF	CMJ	–0.18 (0.30)	–0.76 to 0.40	–2.9 (1.4)	–5.6 to –0.1
Dalrymple et al. (2010)	19.5	A	0/12	45	PF, KE, KF, HE	CMJ	–0.20 (0.25)	–0.70 to 0.30	–3.2 (2.1)	–7.3 to 0.8
Di Cagno et al. (2010)	14.1	A	0/38	90 (90–180)	PF,KE,KF	SJ	0.00 (0.05)	–0.10 to 0.10	0.0 (0.3)	–0.5 to 0.5
Fletcher and Monte-Colombo (2010a)	20.8	A	21/0	30 (30–60)	PF, KE, KF, HE, HF	CMJ	–0.37 (0.52)	–1.39 to 0.66	–4.3 (1.1)	–6.4 to –2.2
Fletcher and Monte-Colombo (2010b)	20.5	A	27/0	30 (30–60)	PF, KE, KF, HE, HF	CMJ	–0.38 (0.64)	–1.64 to 0.87	–4.1 (0.9)	–5.8 to –2.3
Gonzalez-Rave et al. (2009)*	21.8	N-A	8/0	45	PF, KE, KF	CMJ, SJ	0.58 (0.41)	–0.22 to 1.39	8.3 (1.7)	4.9 to 11.6
Handrakis et al. (2010)*	49.9	N-A	6/4	90	PF, KE, KF, HE	HJ	0.00 (0.14)	–0.27 to 0.26	–0.1 (1.9)	–3.8 to 3.6
Holt and Lambourne (2008)	20.7	A	64/0	15	KE,KF,HE,HF	CMJ	0.13 (0.20)	–0.26 to 0.53	1.6 (1.4)	–1.1 to 4.3
Hough et al. (2009)	21.0	A	11/0	30	PF, KE, KF, HE, HF	SJ	–0.25 (0.29)	–0.82 to 0.32	–4.3 (2.2)	–8.7 to 0.1
Kinser et al. (2008)*	11.3	A	0/8	40	HF, HE, KF	CMJ, SJ	–0.34 (0.34)	–1.00 to 0.32	–6.0 (2.4)	–10.6 to –1.3
Knudson et al. (2001)	23.7	A	10/10	135	PF, KE, KF	CMJ	–0.30 (0.44)	–1.16 to 0.56	–4.2 (1.4)	–7.0 to –1.4
Koch et al. (2003)	20.0	A	16/16	160	KE, KF	HJ	0.00 (0.08)	–0.15 to 0.15	0.0 (2.1)	–4.1 to 4.1
La Torre et al. (2010)*	23.0	A	17/0	120	PF, KE	SJ	–0.22 (0.27)	–0.75 to 0.31	–7.4 (2.3)	–12.0 to –2.9
Little and Williams (2006)	n/a	A	18/0	30	PF, KE, KF, HE, HF	CMJ	–0.21 (0.30)	–0.80 to 0.38	–2.5 (1.2)	–4.9 to –0.1
Mcmillian et al. (2006)	20.2	N-A	16/14	30	UB, PF, KE, KF, HE, HF	HJ	0.26 (0.45)	–0.63 to 1.14	3.2 (1.0)	1.2 to 5.1
McNeal and Sands (2003)	13.3	A	0/13	90 (60–90)	PF,KF	DJ	–0.56 (0.69)	–1.92 to 0.80	–9.6 (2.7)	4.2 to 15.0
Murphy et al. (2010)	26.0	N-A	11/0	36	PF,KE,HE	CMJ	0.37 (0.41)	–0.44 to 1.18	4.2 (1.5)	1.2 to 7.1
Pearce et al. (2009)	22.5	N-A	11/2	60	PF, KE, KF, HE, HF	CMJ	–0.37 (0.43)	–1.22 to 0.49	–7.8 (2.5)	–12.7 to –2.9
Robbins and Scheuermann (2008)*	20.3	A	10/10	60 (30–90)	PF, KE, KF	SJ	–0.12 (0.16)	–0.44 to 0.20	–2.1 (1.4)	–4.7 to 0.6
Samuel et al. (2008)	22.0	N-A	12/12	90	KE,KF	CMJ	–0.07 (0.17)	–0.40 to 0.26	–	–
Unick et al. (2005)*	19.2	A	0/16	90 (45–90)	PF, KE, KF	CMJ, DJ	0.13 (0.19)	–0.25 to 0.51	1.9 (1.6)	–1.2 to 4.9
Vetter (2007)	22.3	N-A	14/12	30	PF, KE, KF, HE	CMJ	–0.10 (0.19)	–0.47 to 0.27	–0.8 (0.7)	–2.2 to 0.5
Wallman et al. (2005)	26.0	N-A	8/6	90	PF	CMJ	–0.23 (0.29)	–0.80 to 0.35	–5.6 (2.9)	–11.4 to 0.1
Wallman et al. (2008)	26.0	N-A	7/6	90	PF	CMJ	0.09 (0.16)	–0.23 to 0.41	2.9 (3.8)	–4.6 to 10.4
Young and Behm (2003)*	26.0	N-A	13/4	120	PF, KE	SJ, DJ	–0.21 (0.29)	–0.77 to 0.35	–3.2 (1.8)	–6.7 to 0.3
Young and Elliott (2001)	22.0	A	14/0	45	PF, KE, HE	SJ	–0.19 (0.26)	–0.70 to 0.31	–1.9 (1.2)	–4.2 to 0.4
Young et al. (2006)*	22.8	N-A	12/8	60	PF	DJ	–0.17 (0.21)	–0.58 to 0.24	–3.5 (1.5)	–6.5 to –0.5
Overall jump	**22.5**	**–**	**12/7**	**79**	**–**	**–**	**–0.03 (0.03)**	**–0.08 to 0.02**	**–1.6 (1.5)**	**–2.5 to –0.7**

Table 3. (continued)

Study	Age (years)	Fitness level	Sample size M/F	Duration of stretch (s)	Stretched muscle groups	Performance test	Effect size (SE)	95% CI	% change (SE)	95% CI
RFD										
Alpkaya and Koceja (2007)	25.1	N-A	14/1	90	PF	RFD	0.12 (0.19)	–0.25 to 0.49	3.9 (3.9)	–3.8 to 11.6
Bazett-Jones et al. (2005)	20.6	A	10/0	90	KE, KF, HF	RFD	0.04 (0.15)	–0.25 to 0.32	0.9 (3.6)	–6.2 to 8.0
Gurjao et al. (2009)	64.6	N-A	0/23	90 (90–180)	KE,KF,HE	RFD	–1.28 (1.94)	–5.08 to 2.52	–14.1 (1.1)	–16.2 to –11.9
Maisetti et al. (2007)*	25.0	N-A	0/11	75	PF	RFD	0.09 (0.13)	–0.16 to 0.34	4.1 (5.0)	–5.8 to 14.0
McBride et al. (2007)	21.4	N-A	8/0	99	KE	RFD	–1.07 (0.97)	–2.97 to 0.83	–38.4 (5.5)	–49.2 to –27.5
Papadopoulos et al. (2006)	19.7	N-A	10/0	180 (90–180)	PF, KE, KF, HF	RFD	–0.13 (0.19)	–0.51 to 0.25	–3.6 (3.7)	–10.8 to 3.6
Yamaguchi et al. (2006)*	23.8	N-A	12/0	720	KE, HF	RFD	–0.41 (0.37)	–1.13 to 0.32	–16.4 (3.2)	–22.7 to –10.1
Young and Behm (2003)	26.0	N-A	13/4	120	PF, KE	RFD	–0.08 (0.15)	–0.37 to 0.21	–2.7 (3.8)	–10.2 to 4.8
Young and Elliott (2001)	22.0	A	14/0	45	PF, KE, HE	RFD	–0.23 (0.30)	–0.83 to 0.36	–6.1 (3.0)	–11.9 to –0.3
Young et al. (2006)*	22.8	N-A	12/8	60	PF	RFD	–0.09 (0.17)	–0.43 to 0.25	–2.3 (2.2)	–6.6 to 2.0
Overall RFD	**27.1**	**–**	**9/5**	**157**	**–**	**–**	**–0.02 (0.06)**	**–0.14 to 0.10**	**–4.5 (2.7)**	**–9.8 to 0.9**
Sprint§										
Chaouachi et al. (2010)	20.6	A	22/0	60	PF, KE, KF, HE, HF	Sprint 5, 10, 30 m	–0.42 (0.53)	–1.45 to 0.62	–2.4 (0.5)	–3.3 to –1.4
Chaouachi et al. (2008)	14.0	N-A	24/24	40	KE,KF	Sprint 10 m	–0.12 (0.26)	–0.63 to 0.39	–0.8 (0.4)	–1.7 to 0.1
Favero et al. (2009)*	22.0	A	10/0	90	PF, KE, KF, HE, HF	Sprint 10,40 m	–0.10 (0.19)	–0.47 to 0.27	–0.6 (0.8)	–2.1 to 0.9
Fletcher and Jones (2004)	23.0	A	28/0	20	PF, KE, KF, HE, HF	Sprint 20 m	–0.24 (0.40)	–1.00 to 0.52	–1.2 (0.45)	–2.1 to –0.3
Fletcher and Jones (2004)	23.0	A	24/0	20	PF, KE, KF, HE, HF	Sprint 20 m	–0.26 (0.41)	–1.06 to 0.54	–1.5 (0.55)	–2.6 to –0.4
Fletcher and Monte-Colombo (2010a)	20.8	A	21/0	30	PF,KE, KF,HE,HFADD,ABD	Sprint 20 m	0.00 (0.09)	–0.17 to 0.17	0.0 (0.8)	–1.5 to 1.5
Gelen (2010)	23.3	A	26/0	50	PF,KE,KF,HE,HF,ADD	Sprint 30 m	–1.18 (1.90)	–4.90 to 2.54	–8.5 (0.6)	–9.7 to 7.3
Kistler et al. (2010)	20.3	A	18/0	180	PF,KE,KF	Sprint 40 m	–0.61 (0.68)	–1.94 to 0.72	–1.4 (0.2)	–1.8 to –1.0
Little and Williams (2006)*	n/a	A	18/0	30	PF, KE, KF, HE, HF	Sprint 10, 20 m	0.00 (0.10)	–0.20 to 0.20	0.0 (0.5)	–0.9 to 0.9
Nelson et al. (2005a)*	20.0	A	11/5	120	PF, KF, HE	Sprint 20 m	0.00 (0.09)	–0.17 to 0.17	0.0 (0.1)	–0.2 to 0.2
Sayers et al. (2008)	19.4	A	0/20	90	PF,KE,KF	Sprint 30 m	–0.37 (0.53)	–1.42 to 0.67	–2.1 (0.6)	–3.2 to 1.0
Siatras et al. (2003)*	9.8	A	11/0	30	PF, DF, KE, KF	Sprint 5–15 m	0.18 (0.18)	–0.18 to 0.54	3.2 (1.9)	–0.5 to 6.9
Vetter (2007)	22.3	N-A	14/12	30	PF, KE, KF, HE	Sprint 30 m	–0.14 (0.25)	–0.63 to 0.34	–2.0 (1.3)	–4.5 to 0.5
Winchester et al. (2008)*	20.3	A	11/11	90	PF, KE, KF, HE	Sprint 20–40 m	–0.08 (0.16)	–0.40 to 0.24	–0.6 (1.3)	–3.2 to 2.0
Overall sprint§	**19.9**	**–**	**16/6**	**63**	**–**	**–**	**–0.04 (0.04)**	**–0.13 to 0.05**	**–1.6 (0.5)**	**–2.6 to –0.5**
Throwing										
Haag et al. (2010)	20.3	A	12/0	30	UB	Throwing	0.47 (0.53)	–0.57 to 1.52	1.7 (0.5)	0.8 to 2.6
Mcmillian et al. (2006)	20.2	N-A	16/14	30	UB, PF, KE, KF, HE, HF	Throwing	–0.07 (0.14)	–0.35 to 0.21	–2.1 (2.5)	–6.9 to 2.7
Torres et al. (2008)*	19.6	A	11/0	30	UB	Throwing	–0.13 (0.26)	–0.63 to 0.37	–1.2 (1.7)	–4.5 to 2.2
Overall throw	**20.0**	**–**	**13/5**	**30**	**–**	**–**	**–0.05 (0.12)**	**–0.29 to 0.19**	**0.2 (1.3)**	**–2.3 to 2.7**
Overall mean (all tests)	**22.8**	**–**	**12/6**	**86**	**–**	**–**	**–0.03 (0.02)**	**–0.08 to 0.01**	**–2.0 (0.4)**	**–2.8 to –1.3**

*Study that reported more than one primary outcome.

§Sprint time, an inversely scaled variable, has been rescaled before meta-analysis.

A, athletes; N-A, non-athletes; ADD, hip adductors; ABD, hip abductors; PF, ankle plantar flexors; DF, ankle dorsiflexors; KE, knee extensors; KF, knee flexors; HE, hip extensors; HF, hip flexors; UB, upper body; CMJ, countermovement jump; DJ, depth jump; HJ, horizontal jump; SJ, squat jump; RFD, rate of force or torque development; CI, confidence interval; SE, standard error.

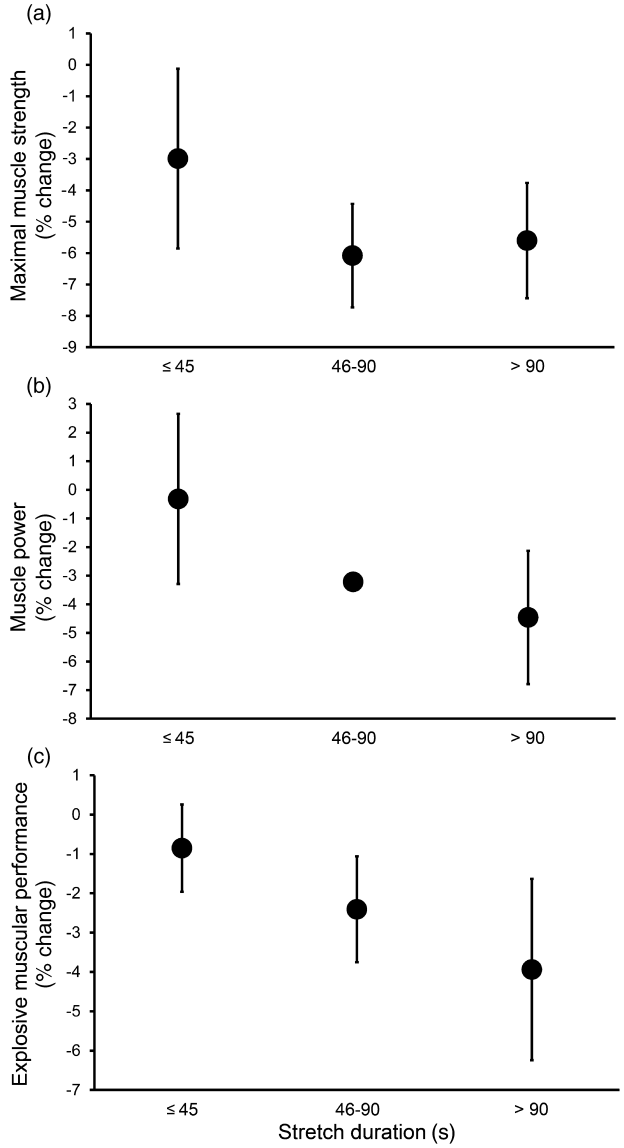


Fig. 2. Meta-analyzed acute effects of different duration of static stretching on maximal muscle strength (a), muscle power (b), and explosive muscular performance (c).

in pooled negative acute effects of SS were observed among four different explosive performance categories (Fig. 1(b)). Specifically, pooled estimates for the acute effect of SS on RFD, jump, sprint, and throw performance were –4.5% (95% CI: –9.8% to 0.8%; possibly negative effect), –1.6% (95% CI: –2.5% to –0.7%; a likely harmful effect), –1.6% (95% CI: –2.6% to –0.5%; a likely harmful effect), and 0.2% (95% CI: –2.3% to 2.7%; an unclear effect), respectively. Note that the observed magnitudes of stretch-induced changes, particularly explosive muscular performance tests, are in agreement with the corresponding average stretch duration per muscle group (i.e., 157, 79, 63, and 30 s for RFD, jump, sprint, and throw performance; see Table 3). With respect to the stretch duration, we observed a significant ($P = 0.0001$) reduction in the negative acute effect of SS on explosive muscular performance with shorter stretch duration (Fig. 2(c)). In particular, pooled estimates for the acute effect of SS lasting ≤45, 46–90, and >90 s per muscle group on explosive performance were –0.8% (95% CI: –2.0% to 0.5%; possibly negative effect), –2.5% (95% CI: –3.8% to –1.1%; almost certainly negative effect), and –4.5% (95% CI: –7.3% to –1.7%; almost certainly negative effect), respectively.

Meta-regressions

Significant negative relationships (all $P < 0.001$) were found between the total stretch duration per muscle group and individual study estimates in all three categories of muscular performance tests (Fig. 3). As mentioned already, subject's age and gender were not significantly related to study estimates in selected primary outcomes (all $P > 0.05$).

Discussion

This meta-analytical review provides clear evidence from 104 studies that (a) pre-exercise SS induces significant and practically relevant negative acute effects on maximal muscle strength and explosive muscular performance, regardless of subject's age, gender, or training status, while the corresponding acute effects of SS on muscle power are still unclear; (b) the acute effects of SS on maximal muscular performance are task-specific, with type of muscle contraction (isometric vs dynamic) being an important factor; and (c) negative acute effects of acute SS on maximal muscular performance tend to diminish with reduction of stretch duration. Prior to discussing these main findings, some methodological issues deserve to be discussed.

While a meta-analysis will yield a mathematically accurate synthesis of the studies included in the analysis, if these studies are a biased sample of all relevant studies, the mean effect computed by the meta-analysis will reflect this bias (Borenstein et al., 2009). In the present study, we found no evidence of publication bias in selected primary outcomes. Furthermore, there was a low heterogeneity of effect within each meta-analysis, suggesting that all trails generally examined the same effects. These issues generally support the robustness of our results; however, we have to acknowledge that we selected only studies published in peer-reviewed journals; thus, there is likelihood that some smaller studies without significant effects remained unpublished. Also, our meta-analytical review may have been biased by inclusion only of studies reported in English. In that regard, some caution is still warranted regarding the precise estimates of the acute effects of SS on selected muscular performance tests.

The major finding of this meta-analytical review is related to a precise quantitative estimate of the acute

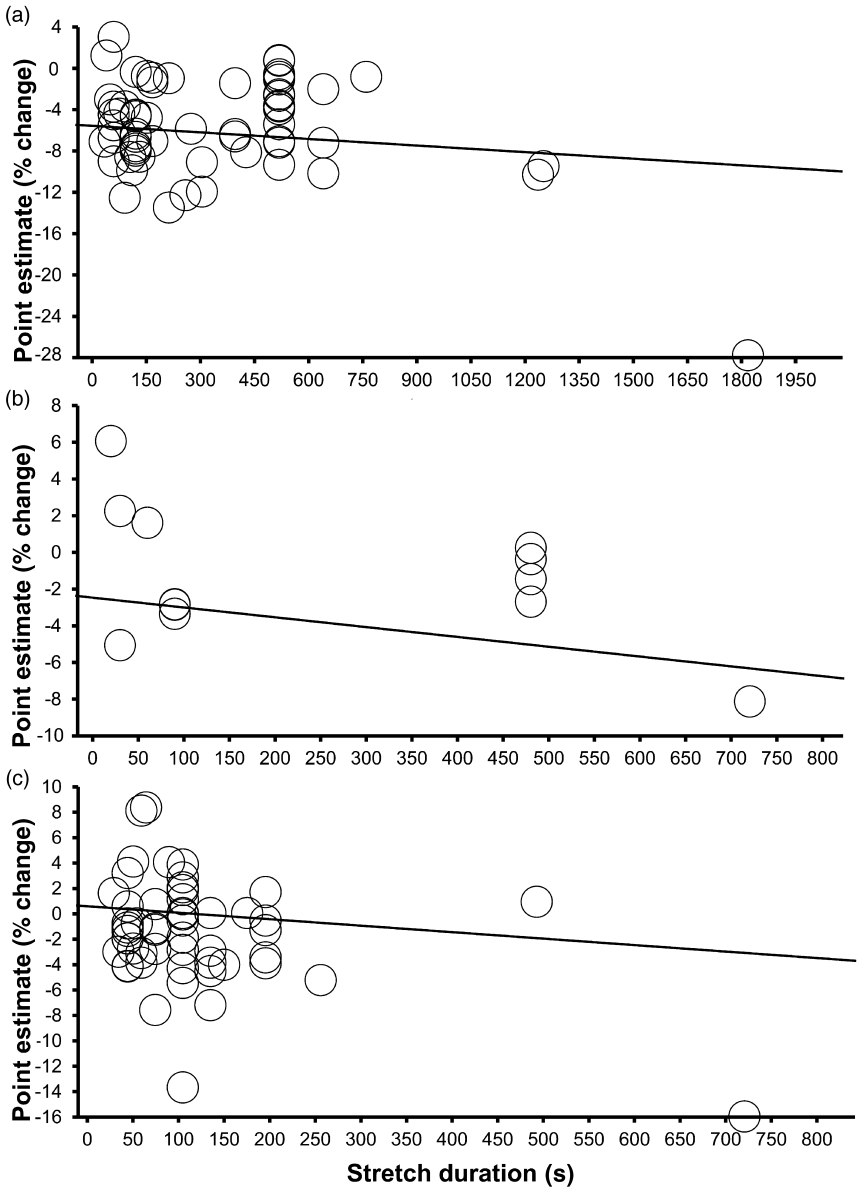


Fig. 3. Relationship between static stretch-induced change in performance (%) and the total duration of stretching in (a) maximal muscle strength tests, (b) muscle power tests, and (c) explosive muscular performance tests.

effects of SS on maximal muscular performance. Overall, our results indicate that an acute bout of SS decreases maximal muscle strength, muscle power, and explosive muscular performance by –5.4% (95% CI: –6.6% to –4.2%), –1.9% (95% CI: –4.0% to 0.2%), and –2.0% (95% CI: –2.8% to –1.3%), respectively. Based on the corresponding 95% CI, and selected thresholds for minimal practically relevant change in athlete's muscular performance (i.e., 5%, 1%, and 1%, respectively), we can conclude that these acute effects of SS were statistically significant and practically relevant for maximal muscle strength (a likely negative acute effect) and explosive muscular performance (a very likely negative acute effect), but not for muscle power (an unclear effect). More studies are needed to clarify the acute effects of SS on muscle power. More importantly, this study shows that the observed stretch-induced reductions in maximum muscular performance are generally independent of subject's age, gender, and training status, suggesting that they could be generalized to young and adult athletic, but also non-athletic population of both sexes. Obviously, factors other than age, sex, and training status (e.g., stretch duration and intensity, task specificity, etc.; see further paragraphs) are responsible for relatively high variability in research results on this topic (see the first paragraph). Without considering these factors, the above-discussed results of meta-analyses strongly suggest that the usage of SS as the sole activity during warm-up routine should generally be avoided. Given that even a small reduction in maximum muscular

performance could be detrimental for competitive performance of high-level athletes in certain sports, this conclusion particularly goes for the athletic population. Previous narrative and/or systematic reviews on this topic also came to the same conclusion (Shrier, 2004; Magnusson & Renstrom, 2006; Rubini et al., 2007; McHugh & Cosgrave, 2010; Behm & Chaouachi, 2011; Kay & Blazevich, 2011), but without robust quantitative evidence, obtained using an appropriate statistical approach.

An important factor to consider when studying the acute effects of SS on maximal muscular performance is the type of performance test applied. In that regard, our results provide some new interesting findings related to the type of contraction. First, we have demonstrated that isometric maximal strength is significantly more negatively affected by an acute bout of SS compared with dynamic (concentric and eccentric) maximal strength. More interestingly, although not presented in the Results section, no evidence of contraction specificity in the acute effects of SS was found between the concentric vs eccentric maximal strength tests. As there were no significant differences in average stretch duration per muscle group between isometric and dynamic maximal strength tests, other factors are likely responsible for the observed contraction-specific acute effects of SS on maximal strength. We believe that the main candidate could be stretch-induced transient reduction in stiffness of the muscle-tendon complex (Weir et al., 2005; Ryan et al. 2008a). Specifically, a more compliant muscle-tendon complex would allow a less efficient transmission of force to the skeleton (Markovic & Mikulic, 2010), and this effect is likely to be more evident during isometric compared with dynamic maximal contractions. Consistent with this notion is the fact that significantly higher negative acute effects of SS were observed in RFD (isometric contraction) than in jump, sprint, or throw performance (dynamic, high-velocity contractions). Indeed, reduced RFD and prolonged electromechanical delay have been frequently associated with a reduction of musculotendinous stiffness (Costa et al., 2010; Herda et al., 2010). However, the above-mentioned difference could also be a result of noticeably higher mean stretch duration per muscle group in RFD tests compared with the remaining explosive muscular performance tests. Thus, more studies are needed to clarify this issue. In their recent review article, Behm and Chaouachi (2011) argued that the negative acute effects of SS could be lower in slow vs fast stretch-shortening cycle tasks. We found no evidence to support this viewpoint (see Table 3), although detailed quantitative analysis in this respect has not been performed. Finally, pooled estimate of the acute effects of SS on throwing performance, although seriously limited by the total number of meta-analyzed studies, suggest that these effects could be less harmful when compared with the corresponding acute effects on jumping and sprinting performance. Although more studies are definitely needed in this area, we may speculate that the high-velocity movements that require large operating ranges of motion (such as throwing) are much less adversely affected by an acute bout of SS. Theoretically speaking, for such movements, possible negative acute effects of SS on force-generating capacity of agonist muscle(s) could be counteracted by stretch-induced increase in active range of motion, thereby allowing muscles to perform similar amount of work during propulsion in both cases (i.e., pre- and post-stretching). Alternatively, one could simply argue that throwing represents a complex ballistic movement that requires sequential action of numerous lower-body, trunk and upper-body muscles, and that the acute SS of a particular upper-body muscle group has much less impact on performance. In that regard, it is interesting to note that the most prominent negative acute effects of SS on throwing performance among selected studies is seen in a study that applied SS of both upper- and lower-body muscles (see Table 3). These conjectures require further experimental verification.

Another important factor to consider when studying the acute effects of SS on maximal muscular performance is the total stretch duration per muscle group. In two most recent review papers, the authors argued that shorter-duration (<45 s per muscle group) pre-exercise SS might not be detrimental to performance (Behm & Chaouachi, 2011; Kay & Blazevich, 2011). However, without the use of an appropriate statistical tool for pooling the data from available SS studies, such conclusions lack firm scientific support. Results of our meta-analytical review indicate the existence of a dose–response relationship between stretch-induced performance decrements and average stretch duration per muscle group (see Figs 2 and 3), in line with the conclusions of several research studies (Ogura et al., 2007; Kay & Blazevich, 2008; Ryan et al. 2008b) and reviews (Behm & Chaouachi, 2011; Kay & Blazevich, 2011). In particular, stretch-induced negative acute effects on performance diminished with the reduction of stretch duration in all three groups of muscular performance tests; however, they still remained negative for two muscular performance categories. Thus, even short-duration pre-exercise SS (i.e., <45 s per muscle group) could possibly be harmful to muscular performance. So, we now come to an important question for clinicians and practitioners: *Should we completely exclude SS from warm-up routines that precede exercise or athletic events*? An answer to this question requires more than just acknowledging the results of the performed meta-analyses. Namely, we have to acknowledge that SS also has certain positive acute effects during warm-up – increased range of motion (McHugh & Cosgrave, 2010; Behm & Chaouachi, 2011) and reduced incidence of muscle strains (McHugh & Cosgrave, 2010). Indeed, based on a comprehensive literature review, McHugh and Cosgrave (McHugh & Cosgrave 2010) have recently concluded

that pre-exercise SS is beneficial for reducing muscle strains. Thus, while the usage of SS (regardless of its duration) as the sole activity during warm-up should generally be avoided, its incorporation into a comprehensive warm-up could be a possible practical solution that would minimize the negative acute effects of SS on performance, while still keeping its potentially positive effects. Related to that, Chaouachi et al. (2008) have recently showed that the addition of short-duration (i.e., 20 s) SS of quadriceps and hamstring muscles into a warm-up routine for sprint training increased the range of motion and diminished the detrimental acute effects of SS on sprint performance compared with a sprint-only training program. Clearly, there is a need for additional well-designed studies that examine the acute effects of short-duration SS, incorporated into a comprehensive pre-exercise warm-up routine, on maximal muscular performance.

This study has certain limitations. First, the PEDro scores of the studies included in the meta-analyses suggest that most studies are prone to subject and/or researcher bias. Given that the ultimate quality of a meta-analysis depends of the quality of the primary studies on which it is based, our results need to be appreciated with an awareness of the limitations of the primary studies. However, we should take into account that blinding of participants and therapists is impossible in exercise interventions. If these two items were deleted from the PEDro scale, the quality ratings of all the included studies would have changed substantially. Nonetheless, we recommend that future stretching studies improve their quality by randomizing subjects into groups, blinding the assessors, as well as by ensuring that treatment allocation concealment and intention to treat analyses are performed. Second, our study did not address the effects of several relevant factors related to acute SS, including the SS intensity, the time from cessation of the warm-up to the performance test, the particular stretching exercises, and the time course of any stretch-induced effects (Young, 2007). These factors need to be addressed in future well-designed SS studies.

Conclusions and recommendations

Our results clearly show that SS before exercise has significant and practically relevant negative acute effects on maximal muscle strength and explosive muscular performance, while the corresponding acute effects on muscle power remain unclear. These findings are universal, regardless of the subject's age, gender, or training status. However, the magnitude of the static stretch-induced negative acute changes in performance was more pronounced in maximal isometric tests compared with maximal dynamic tests. Finally, the observed stretch-induced negative acute changes in selected muscular performance tests were related to the total duration of stretch, with the smallest negative acute effects being observed with stretch duration of $\leq$45 s, respectively. Based on the evidence from this study, we recommend that the usage of SS as the sole activity during warm-up routine should generally be avoided. Given the potential positive effect of pre-exercise SS on the reduction of incidence of muscle strains, further studies should examine the acute effects of SS of shorter duration (e.g., 15–30 s per muscle group), incorporated into a comprehensive pre-exercise warm-up routine, on maximal muscular performance.

Key words: warm-up, stretch, performance, acute effects.

Acknowledgements

Goran Markovic was supported by the Croatian's Ministry of Science, Education and Sport Grant (no. 034-0342607-2623).

References

Abernethy P, Wilson G, Logan P. Strength and power assessment. Issues, controversies and challenges. Sports Med 1995: 19: 401–417.

ACSM. Guidelines for exercise testing and prescription. Philadelphia, PA: Lippincott Williams & Wilkins, 2000.

Allison SJ, Bailey DM, Folland JP. Prolonged static stretching does not influence running economy despite changes in neuromuscular function. J Sports Sci 2008: 26: 1489–1495.

Alpkaya U, Koceja D. The effects of acute static stretching on reaction time and force. J Sports Med Phys Fitness 2007: 47: 147–150.

Amiri-Khorasani M, Sahebozamani M, Tabrizi KG, Yusof AB. Acute effect of different stretching methods on Illinois agility test in soccer players. J Strength Cond Res 2010: 24: 2698–2704.

Avela J, Finni T, Liikavainio T, Niemela E, Komi PV. Neural and mechanical responses of the triceps surae muscle group after 1 h of repeated fast passive stretches. J Appl Physiol 2004: 96: 2325–2332.

Avela J, Kyrolainen H, Komi PV. Altered reflex sensitivity after repeated and prolonged passive muscle stretching. J Appl Physiol 1999: 86: 1283–1291.

Babault N, Kouassi BY, Desbrosses K. Acute effects of 15 min static or contract-relax stretching modalities on plantar flexors neuromuscular properties. J Sci Med Sport 2010: 13: 247–252.

Bacurau RF, Monteiro GA, Ugrinowitsch C, Tricoli V, Cabral LF, Aoki MS. Acute effect of a ballistic and a static stretching exercise bout on flexibility and maximal strength. J Strength Cond Res 2009: 23: 304–308.

Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes. Int J Sports Physiol Perform 2006: 1: 50–57.

Bazett-Jones DM, Winchester JB, McBride JM. Effect of potentiation and stretching on maximal force, rate of force development, and range of motion. J Strength Cond Res 2005: 19: 421–426.

Beaulieu JE. Developing a stretching program. Phys Sportsmed 1981: 9: 59–66.

Beckett JR, Schneiker KT, Wallman KE, Dawson BT, Guelfi KJ. Effects of static stretching on repeated sprint and change of direction performance. Med Sci Sports Exerc 2009: 41: 444–450.

Beedle B, Rytter SJ, Healy RC, Ward TR. Pretesting static and dynamic stretching does not affect maximal strength. J Strength Cond Res 2008: 22: 1838–1843.

Begg CB, Mazumdar M. Operating characteristics of a rank correlation test for publication bias. Biometrics 1994: 50: 1088–1101.

Behm DG, Bambury A, Cahill F, Power K. Effect of acute static stretching on force, balance, reaction time, and movement time. Med Sci Sports Exerc 2004: 36: 1397–1402.

Behm DG, Bradbury EE, Haynes AT, Hodder JN, Leonard AM, Paddock NR. Flexibility is not related to stretch-induced deficits in force or power. J Sports Sci Med 2006: 5: 33–42.

Behm DG, Button DC, Butt JC. Factors affecting force loss with prolonged stretching. Can J Appl Physiol 2001: 26: 261–272.

Behm DG, Chaouachi A. A review of the acute effects of static and dynamic stretching on performance. Eur J Appl Physiol 2011: 111: 2633–2651.

Behm DG, Kibele A. Effects of differing intensities of static stretching on jump performance. Eur J Appl Physiol 2007: 101: 587–594.

Bonetti DL, Hopkins WG. Sea-level exercise performance following adaptation to hypoxia: a meta-analysis. Sports Med 2009: 39: 107–127.

Bonetti DL, Hopkins WG. Variation in performance times of elite flat-water canoeists from race to race. Int J Sports Physiol Perform 2010: 5: 210–217.

Borenstein M, Hedges LV, Higgins JPT, Rothstein HR. Introduction to meta-analysis. Hoboken, NJ: Wiley, 2009.

Bradley PS, Olsen PD, Portas MD. The effect of static, ballistic, and proprioceptive neuromuscular facilitation stretching on vertical jump performance. J Strength Cond Res 2007: 21: 223–226.

Brandenburg J, Pitney WA, Luebbers PE, Veera A, Czajka A. Time course of changes in vertical-jumping ability after static stretching. Int J Sports Physiol Perform 2007: 2: 170–181.

Brandenburg JP. Duration of stretch does not influence the degree of force loss following static stretching. J Sports Med Phys Fitness 2006: 46: 526–534.

Burkett LN, Phillips WT, Ziuraitis J. The best warm-up for the vertical jump in college-age athletic men. J Strength Cond Res 2005: 19: 673–676.

Chaouachi A, Castagna C, Chtara M, Brughelli M, Turki O, Galy O, Chamari K, Behm DG. Effect of warm-ups involving static or dynamic stretching on agility, sprinting, and jumping performance in trained individuals. J Strength Cond Res 2010: 24: 2001–2011.

Chaouachi A, Chamari K, Wong P, Castagna C, Chaouachi M, Moussa-Chamari I, Behm DG. Stretch and sprint training reduces stretch-induced sprint performance deficits in 13- to 15-year-old youth. Eur J Appl Physiol 2008: 104: 515–522.

Church JB, Wiggins MS, Moode FM, Crist R. Effect of warm-up and flexibility treatments on vertical jump performance. J Strength Cond Res 2001: 15: 332–336.

Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: Part 1 – biological basis of maximal power production. Sports Med 2011: 41: 17–38.

Cornwell A, Nelson AG, Heise GD, Sidaway B. Acute effects of passive muscle stretching on vertical jump performance. J Hum Mov Stud 2001: 40: 307–324.

Cornwell A, Nelson AG, Sidaway B. Acute effects of stretching on the neuromechanical properties of the triceps surae muscle complex. Eur J Appl Physiol 2002: 86: 428–434.

Costa PB, Graves BS, Whitehurst M, Jacobs PL. The acute effects of different durations of static stretching on dynamic balance performance. J Strength Cond Res 2009a: 23: 141–147.

Costa PB, Ryan ED, Herda TJ, Defreitas JM, Beck TW, Cramer JT. Effects of static stretching on the hamstrings-to-quadriceps ratio and electromyographic amplitude in men. J Sports Med Phys Fitness 2009b: 49: 401–409.

Costa PB, Ryan ED, Herda TJ, DeFreitas JM, Beck TW, Cramer JT. Effects of stretching on peak torque and the H : Q ratio. Int J Sports Med 2009c: 30: 60–65.

Costa PB, Ryan ED, Herda TJ, Walter AA, Hoge KM, Cramer JT. Acute effects of passive stretching on the electromechanical delay and evoked twitch properties. Eur J Appl Physiol 2010: 108: 301–310.

Covert CA, Alexander MP, Petronis JJ, Davis DS. Comparison of ballistic and static stretching on hamstring muscle length using an equal stretching dose. J Strength Cond Res 2010: 24: 3008–3014.

Cramer JT, Beck TW, Housh TJ, Massey LL, Marek SM, Danglemeier S, Purkayastha S, Culbertson JY, Fitz KA, Egan AD. Acute effects of static stretching on characteristics of the isokinetic angle – torque relationship, surface electromyography, and mechanomyography. J Sports Sci 2007a: 25: 687–698.

Cramer JT, Housh TJ, Coburn JW, Beck TW, Johnson GO. Acute effects of static stretching on maximal eccentric torque production in women. J Strength Cond Res 2006: 20: 354–358.

Cramer JT, Housh TJ, Johnson GO, Miller JM, Coburn JW, Beck TW. Acute effects of static stretching on peak torque in women. J Strength Cond Res 2004: 18: 236–241.

Cramer JT, Housh TJ, Johnson GO, Weir JP, Beck TW, Coburn JW. An acute bout of static stretching does not affect maximal eccentric isokinetic peak torque, the joint angle at peak torque, mean power, electromyography, or mechanomyography. J Orthop Sports Phys Ther 2007b: 37: 130–139.

Cramer JT, Housh TJ, Weir JP, Johnson GO, Coburn JW, Beck TW. The acute effects of static stretching on peak torque, mean power output, electromyography, and mechanomyography. Eur J Appl Physiol 2005: 93: 530–539.

Cronin J, Nash M, Whatman C. The acute effects of hamstring stretching and vibration on dynamic knee joint range of motion and jump performance. Phys Ther Sport 2008: 9: 89–96.

Curry BS, Chengkalath D, Crouch GJ, Romance M, Manns PJ. Acute effects of dynamic stretching, static stretching, and light aerobic activity on muscular performance in women. J Strength Cond Res 2009: 23: 1811–1819.

Dalrymple KJ, Davis SE, Dwyer GB, Moir GL. Effect of static and dynamic stretching on vertical jump performance in collegiate women volleyball players. J Strength Cond Res 2010: 24: 149–155.

Di Cagno A, Baldari C, Battaglia C, Gallotta MC, Videira M, Piazza M, Guidetti L. Preexercise static stretching effect on leaping performance in elite rhythmic gymnasts. J Strength Cond Res 2010: 24: 1995–2000.

Egan AD, Cramer JT, Massey LL, Marek SM. Acute effects of static stretching on peak torque and mean power output in National Collegiate Athletic Association Division I women's basketball players. J Strength Cond Res 2006: 20: 778–782.

Evetovich TK, Cain RM, Hinnerichs KR, Engebretsen BJ, Conley DS.

Interpreting normalized and nonnormalized data after acute static stretching in athletes and nonathletes. J Strength Cond Res 2010: 24: 1988–1994.

Evetovich TK, Nauman NJ, Conley DS, Todd JB. Effect of static stretching of the biceps brachii on torque, electromyography, and mechanomyography during concentric isokinetic muscle actions. J Strength Cond Res 2003: 17: 484–488.

Faigenbaum AD, Bellucci M, Bernieri A, Bakker B, Hoorens K. Acute effects of different warm-up protocols on fitness performance in children. J Strength Cond Res 2005: 19: 376–381.

Faigenbaum AD, Kang J, McFarland JE, Bloom JM, Magnatta J, Ratamess NA, Hoffman JR. Acute effects of different warm-up protocols on anaerobic performance in teenage athletes. Pediatr Exerc Sci 2006a: 17: 64–75.

Faigenbaum AD, McFarland JE, Schwerdtman JA, Ratamess NA, Kang J, Hoffman JR. Dynamic warm-up protocols, with and without a weighted vest, and fitness performance in high school female athletes. J Athl Train 2006b: 41: 357–363.

Favero JP, Midgley AW, Bentley DJ. Effects of an acute bout of static stretching on 40 m sprint performance: influence of baseline flexibility. Res Sports Med 2009: 17: 50–60.

Fletcher IM, Anness R. The acute effects of combined static and dynamic stretch protocols on fifty-meter sprint performance in track-and-field athletes. J Strength Cond Res 2007: 21: 784–787.

Fletcher IM, Jones B. The effect of different warm-up stretch protocols on 20 meter sprint performance in trained rugby union players. J Strength Cond Res 2004: 18: 885–888.

Fletcher IM, Monte-Colombo MM. An investigation into the effects of different warm-up modalities on specific motor skills related to soccer performance. J Strength Cond Res 2010a: 24: 2096–2101.

Fletcher IM, Monte-Colombo MM. An investigation into the possible physiological mechanisms associated with changes in performance related to acute responses to different preactivity stretch modalities. Appl Physiol Nutr Metab 2010b: 35: 27–34.

Follmann D, Elliott P, Suh I, Cutler J. Variance imputation for overviews of clinical trials with continuous response. J Clin Epidemiol 1992: 45: 769–773.

Fowles JR, Sale DG, MacDougall JD. Reduced strength after passive stretch of the human plantarflexors. J Appl Physiol 2000: 89: 1179–1188.

Gelen E. Acute effects of different warm-up methods on sprint, slalom dribbling, and penalty kick performance in soccer players. J Strength Cond Res 2010: 24: 950–956.

Gonzalez-Rave JM, Machado L, Navarro-Valdivielso F, Vilas-Boas JP. Acute effects of heavy-load exercises, stretching exercises, and heavy-load plus stretching exercises on squat jump and countermovement jump performance. J Strength Cond Res 2009: 23: 472–479.

Gurjao AL, Goncalves R, de Moura RF, Gobbi S. Acute effect of static stretching on rate of force development and maximal voluntary contraction in older women. J Strength Cond Res 2009: 23: 2149–2154.

Haag SJ, Wright GA, Gillette CM, Greany JF. Effects of acute static stretching of the throwing shoulder on pitching performance of National Collegiate Athletic Association Division III baseball players. J Strength Cond Res 2010: 24: 452–457.

Handrakis JP, Southard VN, Abreu JM, Aloisa M, Doyen MR, Echevarria LM, Hwang H, Samuels C, Venegas SA, Douris PC. Static stretching does not impair performance in active middle-aged adults. J Strength Cond Res 2010: 24: 825–830.

Herbert RD, Gabriel M. Effects of stretching before and after exercising on muscle soreness and risk of injury: systematic review. BMJ 2002: 325: 468.

Herda TJ, Cramer JT, Ryan ED, McHugh MP, Stout JR. Acute effects of static versus dynamic stretching on isometric peak torque, electromyography, and mechanomyography of the biceps femoris muscle. J Strength Cond Res 2008: 22: 809–817.

Herda TJ, Ryan ED, Costa PB, Walter AA, Hoge KM, Uribe BP, McLagan JR, Stout JR, Cramer JT. Acute effects of passive stretching and vibration on the electromechanical delay and musculotendinous stiffness of the plantar flexors. Electromyogr Clin Neurophysiol 2010: 50: 277–288.

Herda TJ, Ryan ED, Smith AE, Walter AA, Bemben MG, Stout JR, Cramer JT. Acute effects of passive stretching vs vibration on the neuromuscular function of the plantar flexors. Scand J Med Sci Sports 2009: 19: 703–713.

Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ 2003: 327: 557–560.

Holcomb WR. Stretching and warm-up. In: Beachle TR, Earle RW, eds. Essentials of strength training and conditioning. Champaign, IL: Human Kinetics, 2000: 321–342.

Holt BW, Lambourne K. The impact of different warm-up protocols on vertical jump performance in male collegiate athletes. J Strength Cond Res 2008: 22: 226–229.

Hopkins WG. Measures of reliability in sports medicine and science. Sports Med 2000: 30: 1–15.

Hopkins WG. How to interpret changes in an athletic performance test. Sportscience 2004: 8: 1–7.

Hopkins WG. Competitive performance of elite track-and-field athletes: variability and smallest worthwhile enhancements. Sportscience 2005: 9: 17–20.

Hopkins WG. A Spreadsheet for deriving a confidence Interval, mechanistic Inference and clinical inference from a p value. Sportscience 2007: 11: 1–4.

Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 2009: 41: 3–13.

Hough PA, Ross EZ, Howatson G. Effects of dynamic and static stretching on vertical jump performance and electromyographic activity. J Strength Cond Res 2009: 23: 507–512.

Kay AD, Blazevich AJ. Reduction in active plantarflexor moment are significantly correlated with static stretching duration. Eur J Sport Sci 2008: 8: 41–46.

Kay AD, Blazevich AJ. Isometric contractions reduce plantar flexor moment, Achilles tendon stiffness, and neuromuscular activity but remove the subsequent effects of stretch. J Appl Physiol 2009a: 107: 1181–1189.

Kay AD, Blazevich AJ. Moderate-duration static stretch reduces active and passive plantar flexor moment but not Achilles tendon stiffness or active muscle length. J Appl Physiol 2009b: 106: 1249–1256.

Kay AD, Blazevich AJ. Concentric muscle contractions before static stretching minimize, but do not remove, stretch-induced force deficits. J Appl Physiol 2010: 108: 637–645.

Kay AD, Blazevich AJ. Effect of acute static stretch on maximal muscle performance: a systematic review. Med Sci Sports Exerc 2011: 44: 154–164.

Kinser AM, Ramsey MW, O'Bryant HS, Ayres CA, Sands WA, Stone MH. Vibration and stretching effects on flexibility and explosive strength in young gymnasts. Med Sci Sports Exerc 2008: 40: 133–140.

Kistler BM, Walsh MS, Horn TS, Cox RH. The acute effects of static stretching on the sprint performance of collegiate men in the 60- and 100-m dash after a dynamic warm-up. J Strength Cond Res 2010: 24: 2280–2284.

Knudson D. Warm-up and flexibility. In: Chandler TJ, Brown LE, eds. Conditioning for strength and human performance. Baltimore: Lippincott Williams & Wilkins, 2007: 166–181.

Knudson D, Bennett K, Corn R, Leick D, Smith C. Acute effects of stretching are not evident in the kinematics of the vertical jump. J Strength Cond Res 2001: 15: 98–101.

Knudson D, Noffal G. Time course of stretch-induced isometric strength deficits. Eur J Appl Physiol 2005: 94: 348–351.

Knudson DV, Noffal GJ, Bahamonde RE, Bauer JA, Blackwell JR. Stretching has no effect on tennis serve performance. J Strength Cond Res 2004: 18: 654–656.

Koch AJ, O'Bryant HS, Stone ME, Sanborn K, Proulx C, Hruby J, Shannonhouse E, Boros R, Stone MH. Effect of warm-up on the standing broad jump in trained and untrained men and women. J Strength Cond Res 2003: 17: 710–714.

Kokkonen J, Nelson AG, Cornwell A. Acute muscle stretching inhibits maximal strength performance. Res Q Exerc Sport 1998: 69: 411–415.

Kubo K, Kanehisa H, Kawakami Y, Fukunaga T. Influence of static stretching on viscoelastic properties of human tendon structures *in vivo*. J Appl Physiol 2001: 90: 520–527.

La Torre A, Castagna C, Gervasoni E, Ce E, Rampichini S, Ferrarin M, Merati G. Acute effects of static stretching on squat jump performance at different knee starting angles. J Strength Cond Res 2010: 24: 687–694.

Little T, Williams AG. Effects of differential stretching protocols during warm-ups on high-speed motor capacities in professional soccer players. J Strength Cond Res 2006: 20: 203–207.

Magnusson P, Renstrom P. The European College of Sports Sciences Position statement: the role of stretching exercises in sport. Eur J Sport Sci 2006: 6: 87–91.

Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. Phys Ther 2003: 83: 713–721.

Maisetti O, Sastre J, Lecompte J, Portero P. Differential effects of an acute bout of passive stretching on maximal voluntary torque and the rate of torque development of the calf muscle-tendon unit. Isokinetics Exerc Sci 2007: 15: 11–17.

Manoel ME, Harris-Love MO, Danoff JV, Miller TA. Acute effects of static, dynamic, and proprioceptive neuromuscular facilitation stretching on muscle power in women. J Strength Cond Res 2008: 22: 1528–1534.

Marek SM, Cramer JT, Fincher AL, Massey LL, Dangelmaier SM, Purkayastha S, Fitz KA, Culbertson JY. Acute effects of static and proprioceptive neuromuscular facilitation stretching on muscle strength and power output. J Athl Train 2005: 40: 94–103.

Markovic G, Mikulic P. Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. Sports Med 2010: 40: 859–895.

McBride JM, Deane R, Nimphius S. Effect of stretching on agonist-antagonist muscle activity and muscle force output during single and multiple joint isometric contractions. Scand J Med Sci Sports 2007: 17: 54–60.

McHugh MP, Cosgrave CH. To stretch or not to stretch: the role of stretching in injury prevention and performance. Scand J Med Sci Sports 2010: 20: 169–181.

McMillian DJ, Moore JH, Hatler BS, Taylor DC. Dynamic vs. static-stretching warm up: the effect on power and agility performance. J Strength Cond Res 2006: 20: 492–499.

McNeal JR, Sands WA. Acute static stretching reduces lower extremity power in trained children. Pediatr Exerc Sci 2003: 15: 139–145.

Molacek ZD, Conley DS, Evetovich TK, Hinnerichs KR. Effects of low- and high-volume stretching on bench press performance in collegiate football players. J Strength Cond Res 2010: 24: 711–716.

Murphy JR, Di Santo MC, Alkanani T, Behm DG. Aerobic activity before and following short-duration static stretching improves range of motion and performance vs. a traditional warm-up. Appl Physiol Nutr Metab 2010: 35: 679–690.

Nelson AG, Allen JD, Cornwell A, Kokkonen J. Inhibition of maximal voluntary isometric torque production by acute stretching is joint-angle specific. Res Q Exerc Sport 2001a: 72: 68–70.

Nelson AG, Driscoll NM, Landin DK, Young MA, Schexnayder IC. Acute effects of passive muscle stretching on sprint performance. J Sports Sci 2005a: 23: 449–454.

Nelson AG, Guillory IK, Cornwell C, Kokkonen J. Inhibition of maximal voluntary isokinetic torque production following stretching is velocity-specific. J Strength Cond Res 2001b: 15: 241–246.

Nelson AG, Kokkonen J, Arnall DA. Acute muscle stretching inhibits muscle strength endurance performance. J Strength Cond Res 2005b: 19: 338–343.

Nelson AG, Kokkonen J, Eldredge C. Strength inhibition following an acute stretch is not limited to novice stretchers. Res Q Exerc Sport 2005c: 76: 500–506.

O'Connor DM, Crowe MJ, Spinks WL. Effects of static stretching on leg power during cycling. J Sports Med Phys Fitness 2006: 46: 52–56.

Ogura Y, Miyahara Y, Naito H, Katamoto S, Aoki J. Duration of static stretching influences muscle force production in hamstring muscles. J Strength Cond Res 2007: 21: 788–792.

Papadopoulos C, Kalapotharakos VI, Noussios G, Meliggas K, Gantiraga E. The effect of static stretching on maximal voluntary contraction and force-time curve characteristics. J Sport Rehabil 2006: 15: 185–194.

Papadopoulos G, Siatras T, Kellis S. The effect of static and dynamic stretching exercises on the maximal isokinetic strength of the knee extensors and flexors. Isokinet Exerc Sci 2005: 13: 285–291.

Pearce AJ, Kidgell DJ, Zois J, Carlson JS. Effects of secondary warm up following stretching. Eur J Appl Physiol 2009: 105: 175–183.

Pearson A. Soccer: speed, agility and quickness for soccer (SAQ). London: A & C Black, 2001.

Peterson MD, Rhea MR, Sen A, Gordon PM. Resistance exercise for muscular strength in older adults: a meta-analysis. Ageing Res Rev 2010: 9: 226–237.

Power K, Behm D, Cahill F, Carroll M, Young W. An acute bout of static stretching: effects on force and jumping performance. Med Sci Sports Exerc 2004: 36: 1389–1396.

Robbins JW, Scheuermann BW. Varying amounts of acute static stretching and its effect on vertical jump performance. J Strength Cond Res 2008: 22: 781–786.

Rubini EC, Costa AL, Gomes PS. The effects of stretching on strength performance. Sports Med 2007: 37: 213–224.

Ryan ED, Beck TW, Herda TJ, Hull HR, Hartman MJ, Costa PB, Defreitas JM, Stout JR, Cramer JT. The time course of musculotendinous stiffness responses following different durations of passive stretching. J Orthop Sports Phys Ther 2008a: 38: 632–639.

Ryan ED, Beck TW, Herda TJ, Hull HR, Hartman MJ, Stout JR, Cramer JT. Do practical durations of stretching alter muscle strength? A dose-response study. Med Sci Sports Exerc 2008b: 40: 1529–1537.

Samogin Lopes FA, Menegon EM, Franchini E, Tricoli V, de MBRC. Is acute static stretching able to reduce the time to exhaustion at power output corresponding to maximal oxygen uptake? J Strength Cond Res 2010: 24: 1650–1656.

Samuel MN, Holcomb WR, Guadagnoli MA, Rubley MD, Wallmann H. Acute effects of static and ballistic stretching on measures of strength and power. J Strength Cond Res 2008: 22: 1422–1428.

Sayers AL, Farley RS, Fuller DK, Jubenville CB, Caputo JL. The effect of static stretching on phases of sprint performance in elite soccer players. J Strength Cond Res 2008: 22: 1416–1421.

Sekir U, Arabaci R, Akova B, Kadagan SM. Acute effects of static and dynamic stretching on leg flexor and extensor isokinetic strength in elite women athletes. Scand J Med Sci Sports 2010: 20: 268–281.

Shellock FG, Prentice WE. Warming-up and stretching for improved physical performance and prevention of sports-related injuries. Sports Med 1985: 2: 267–278.

Shrier I. Does stretching improve performance? A systematic and critical review of the literature. Clin J Sport Med 2004: 14: 267–273.

Siatras T, Papadopoulos G, Mameletzi D, Gerodimos V, Kellis S. Static and dynamic acute stretching effect on gymnasts' speed in vaulting. Pediatr Exerc Sci 2003: 15: 383–391.

Siatras TA, Mittas VP, Mameletzi DN, Vamvakoudis EA. The duration of the inhibitory effects with static stretching on quadriceps peak torque production. J Strength Cond Res 2008: 22: 40–46.

Sim AY, Dawson BT, Guelfi KJ, Wallman KE, Young WB. Effects of static stretching in warm-up on repeated sprint performance. J Strength Cond Res 2009: 23: 2155–2162.

Smith CA. The warm-up procedure: to stretch or not to stretch. A brief review. J Orthop Sports Phys Ther 1994: 19: 12–17.

Smith TB, Hopkins WG. Variability and predictability of finals times of elite rowers. Med Sci Sports Exerc 2011: 43: 2155–2160.

Taylor KL, Sheppard JM, Lee H, Plummer N. Negative effect of static stretching restored when combined with a sport specific warm-up component. J Sci Med Sport 2009: 12: 657–661.

Thacker SB, Gilchrist J, Stroup DF, Kimsey CD, Jr. The impact of stretching on sports injury risk: a systematic review of the literature. Med Sci Sports Exerc 2004: 36: 371–378.

Thigpen LK. Effects of statically performed toe touch stretches on torque production of the hamstrings and quadriceps muscle groups. J Hum Mov Stud 1989: 17: 71–88.

Thompsen AG, Kackley T, Palumbo MA, Faigenbaum AD. Acute effects of different warm-up protocols with and without a weighted vest on jumping performance in athletic women. J Strength Cond Res 2007: 21: 52–56.

Torres EM, Kraemer WJ, Vingren JL, Volek JS, Hatfield DL, Spiering BA, Ho JY, Fragala MS, Thomas GA, Anderson JM, Hakkinen K, Maresh CM. Effects of stretching on upper-body muscular performance. J Strength Cond Res 2008: 22: 1279–1285.

Unick J, Kieffer HS, Cheesman W, Feeney A. The acute effects of static and ballistic stretching on vertical jump performance in trained women. J Strength Cond Res 2005: 19: 206–212.

Vetter RE. Effects of six warm-up protocols on sprint and jump performance. J Strength Cond Res 2007: 21: 819–823.

Viale F, Nana-Ibrahim S, Martin RJ. Effect of active recovery on acute strength deficits induced by passive stretching. J Strength Cond Res 2007: 21: 1233–1237.

Wallmann HW, Mercer JA, Landers MR. Surface electromyographic assessment of the effect of dynamic activity and dynamic activity with static stretching of the gastrocnemius on vertical jump performance. J Strength Cond Res 2008: 22: 787–793.

Wallmann HW, Mercer JA, McWhorter JW. Surface electromyographic assessment of the effect of static stretching of the gastrocnemius on vertical jump performance. J Strength Cond Res 2005: 19: 684–688.

Weir DE, Tingley J, Elder GC. Acute passive stretching alters the mechanical properties of human plantar flexors and the optimal angle for maximal voluntary contraction. Eur J Appl Physiol 2005: 93: 614–623.

Wilson GJ, Murphy AJ. The use of isometric tests of muscular function in athletic assessment. Sports Med 1996: 22: 19–37.

Wilson JM, Hornbuckle LM, Kim JS, Ugrinowitsch C, Lee SR, Zourdos MC, Sommer B, Panton LB. Effects of static stretching on energy cost and running endurance performance. J Strength Cond Res 2010: 24: 2274–2279.

Winchester JB, Nelson AG, Kokkonen J. A single 30-s stretch is sufficient to inhibit maximal voluntary strength. Res Q Exerc Sport 2009: 80: 257–261.

Winchester JB, Nelson AG, Landin D, Young MA, Schexnayder IC. Static stretching impairs sprint performance in collegiate track and field athletes. J Strength Cond Res 2008: 22: 13–19.

Winke MR, Jones NB, Berger CG, Yates JW. Moderate static stretching and torque production of the knee flexors. J Strength Cond Res 2010: 24: 706–710.

Yamaguchi T, Ishii K. Effects of static stretching for 30 seconds and dynamic stretching on leg extension power. J Strength Cond Res 2005: 19: 677–683.

Yamaguchi T, Ishii K, Yamanaka M, Yasuda K. Acute effect of static stretching on power output during concentric dynamic constant external resistance leg extension. J Strength Cond Res 2006: 20: 804–810.

Young W, Behm D. Should static stretching be used during a warm-up for strength and power activities? Strength Cond J 2002: 24: 33–37.

Young W, Clothier P, Otago L, Bruce L, Liddell D. Acute effects of static stretching on hip flexor and quadriceps flexibility, range of motion and foot speed in kicking a football. J Sci Med Sport 2004: 7: 23–31.

Young W, Elias G, Power J. Effects of static stretching volume and intensity on plantar flexor explosive force production and range of motion. J Sports Med Phys Fitness 2006: 46: 403–411.

Young W, Elliott S. Acute effects of static stretching, proprioceptive neuromuscular facilitation stretching, and maximum voluntary contractions on explosive force production and jumping performance. Res Q Exerc Sport 2001: 72: 273–279.

Young WB. The use of static stretching in warm-up for training and competition. Int J Sports Physiol Perform 2007: 2: 212–216.

Young WB, Behm DG. Effects of running, static stretching and practice jumps on explosive force production and jumping performance. J Sports Med Phys Fitness 2003: 43: 21–27.

Zakas A, Doganis G, Galazoulas C, Vamvakoudis E. Effect of acute static stretching duration on isokinetic peak torque in pubescent soccer players. Pediatr Exerc Sci 2006a: 18: 252–261.

Zakas A, Doganis G, Papakonstandinou V, Sentelidis T, Vamvakoudis E. Acute effects of static stretching duration on isokinetic peak torque production of soccer players. J Bodyw Mov Ther 2006b: 10: 89–95.

Zakas A, Doganis G, Zakas N, Vergou A. Acute effects of active warm-up and stretching on the flexibility of elderly women. J Sports Med Phys Fitness 2006c: 46: 617–622.

Zakas A, Galazoulas C, Doganis G, Zakas N. Effect of two acute static stretching durations of the rectus femoris muscle

on quadriceps isokinetic peak torque in professional soccer players. Isokinetics Exerc Sci 2006d: 14: 357–362.

Zakas A, Grammatikopoulou MG, Zakas N, Zahariadis P, Vamvakoudis E. The effect of active warm-up and stretching on the flexibility of adolescent soccer players. J Sports Med Phys Fitness 2006e: 46: 57–61.

Zakas A, Vergou A, Grammatikopoulou MG, Zakas N, Sentelidis T, Vamvakoudis S. The effect of stretching during warming-up on the flexibility of junior handball players. J Sports Med Phys Fitness 2003: 43: 145–149.