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REVIEW

A SYSTEMATIC REVIEW INTO THE EFFICACY OF STATIC STRETCHING AS PART OF A WARM-UP FOR THE PREVENTION OF EXERCISE-RELATED INJURY

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A systematic review of the literature was undertaken to assess the efficacy of static stretching as part of the warm-up for the prevention of exercise-related injuries. Computer-aided literature search for articles post-1990 and pre-January 2008 related to static stretching and injury prevention using MEDLINE, SPORT Discus, PubMed, and ScienceDirect databases. All relevant randomised clinical trials (RCTs) and controlled clinical trials (CCTs) satisfying inclusion/exclusion criteria were evaluated by methodological assessment to score the studies using accredited criteria. Seven out of 364 studies met the inclusion/exclusion criteria. All four RCTs concluded that static stretching was ineffective in reducing the incidence of exercise-related injury, and only one of the three CCTs concluded that static stretching did reduce the incidence of exercise-related injury. Three out of the seven studies noted significant reductions in musculotendinous and ligament injuries following a static stretching protocol despite nonsignificant reductions in the all-injury risk. All RCTs

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scored over 50 points (maximum possible score = 100), whereas all CCTs scored under 45 points. There is moderate to strong evidence that routine application of static stretching does not reduce overall injury rates. There is preliminary evidence, however, that static stretching may reduce musculotendinous injuries.

Keywords: review, static stretching, injury prevention, sport

INTRODUCTION

Since the early 1980s, static stretching has been widely promoted before performing physical activity as a method to prevent injury and improve physical performance (Shrier 2005). It has become a popular routine included in the warm-up to exercise as it is believed that the slow, controlled movement allows the stretch to be performed easily and safely, with reduced risk of injury compared with other forms of stretching (Smith 1994). There currently appears to be little sound empirical evidence to substantiate these claims, however, with literature on the subject being scarce and often contradictory. Moreover, some research appears to indicate that static stretching prior to exercise even may increase the risk of injury (Shrier 1999, 2005).

Flexibility has been cited by epidemiological research as one of the primary aetiological factors associated with injury, and more specifically with musculotendinous strains (Cross and Worrell 1999), the most frequent sporting injury (Weldon and Hill 2003). There is some debate as to the optimal level of flexibility required to aid performance and prevent injury, with research reporting that individuals with both extremes of flexibility appear to have a greater risk of injury than the average group (Jones, Cowan, and Tomlinson 1993; Taimela, Kujla, and Osterman 1990). Moreover, Lysens et al. (1989) observed low flexibility as a risk factor for overuse injury, and high flexibility as a risk factor for acute injury in males.

Static stretching is widely regarded as an effective method of increasing range of motion (ROM) and flexibility (Godges et al. 1989; Moore and Hutton 1980; Osternig et al. 1990; Wallin et al. 1985; Wiktorsson-Moller et al. 1983). In addition, there is a general belief that increased ROM decreases injury risk during exercise (Shellock and Prentice 1985; Smith 1994).

Two common factors associated with exercise-related musculoskeletal injury are muscle stiffness and lack of ROM (Agre 1985; Cornelius and Hinson 1980; Ekstrand, Gillguist, and Liljedah 1983; Hess, Cappiello, and Pole 1987; Safran, Seaber, and Garret 1989; Shellock and Prentice 1985), both of which may be addressed by the static stretching technique (Amako et al. 2003; McCullough 1990; Smith 1994) to help reduce injury risk. The effect of static stretching on muscle stiffness has been well documented and shown to correlate highly to the incidence of muscle injury (Ekstrand and Gillquist 1983). Correlation, however, does not infer causation.

Not all scientific studies investigating the relationship between static stretching and injury prevention have revealed it to demonstrate a positive effect. Several authors have questioned whether an increased ROM would prevent injuries, as injuries usually occur within the normal range (Shrier 2000). Research also suggests that stretching, which increases flexibility and ROM beyond that needed for physical activity or sport-specific movements, may not be beneficial and actually may cause injury (Ingraham 2003), as even mild stretching can cause damage at the cytoskeletal level (Shrier 1999, 2000). Murphy (1991) also convincingly argued that static stretching preexercise does not facilitate injury prevention. It was claimed that preexercise warm-up is performed primarily to increase body temperature, which can increase muscle flexibility and therefore reduce risk of injury. Static stretching is a passive technique, however, which fails to warm a muscle and therefore will not aid injury prevention.

Although static stretching has been linked to injury prevention, various additional factors should be considered. Exercise-related injuries may be influenced also by eccentric contractions and nutrition (Worrell 1994; Zarins and Ciullo 1983) as well as performers' level of fitness, which has been linked as a factor for sustaining injury (Pope et al. 2000). Age, weight, and height, however, do not appear to be relevant factors related to injury risk (Finestone et al. 1991; Pope et al. 2000).

The relationship between stretching and injury prevention has been substantially researched, and several systematic reviews have been conducted, with the general census showing stretching to have no positive effect on preventing injury (Herbert and Gabriel 2002; Shrier 1999; Thacker et al. 2004; Weldon and Hill 2003). These studies, however, have focussed largely on general stretching, which has consequently included a variety of different techniques and interventions including static, dynamic, proprioceptive neuromuscular facilitation (PNF), and ballistic stretching. It is difficult, therefore, to identify specifically which type of stretching actually may aid injury prevention without isolating and reviewing the individual techniques separately.

Hence, it is the aim of this review to examine the literature specifically concerning static stretching and its effects on injury prevention when compared with either no stretching at all or an unaltered stretching/ warm-up routine.

METHOD

A computer-aided literature search was performed using MEDLINE, SPORT Discus, PubMed, and ScienceDirect databases, selected as they all contain large amounts of relevant literature in the areas of sport and physical activity. The electronic databases were searched using a number of key terms as selected by the authors: stretching, static, injury, prevention, and exercise. In relation to study type, a further set of key terms were selected in order to retrieve relevant study designs to later meet inclusion criteria: randomised, controlled, trial, clinical, double, single, and blind. Searches were performed by systematically combining the key terms to enable a maximum amount of exposure for potentially relevant studies (using Boolean operators 'OR' and 'AND').

Topic Search

#1 STRETCHING (medical subjects heading term, all subject headings and in text)
#2 STATIC (all subject headings and in text)
#3 STATIC AND STRETCHING (medical subjects heading term, all subject headings and in text)
#4 INJURY AND PREVENTION (in text)
#5 STRETCHING OR STATIC AND INJURY AND PREVENTION (in text)
#6 SPORT OR EXERCISE AND STRETCHING
#7 SPORT OR EXERCISE AND INJURY AND PREVENTION

Publication Type Search

#8 RANDOMISED AND CONTROLLED AND TRIAL (in publication type)
#9 CONTROLLED AND CLINICAL AND TRIAL (in publication type)
#10 RANDOMISED AND CONTROLLED AND TRIAL (in text)
#11 CONTROLLED AND CLINICAL AND TRIAL (in text)
#12 DOUBLE AND BLIND AND METHOD OR SINGLE AND BLIND AND METHOD (medical subjects heading term and all subject headings)

In addition to this search, further examination of references from the retrieved studies was performed and any key journals identified were hand searched for any relevant studies not previously recovered by other methods.

The methodological design of the review included a set of criteria that had to be adhered to in order to select only relevant studies: (1) The studies should preferably be RCTs, as they are seen as the gold standard by which the benefits of therapy are judged (Greenhalgh 1997). As RCTs are relatively scarce in this field, however, CCTs also were reviewed, with all studies retrieved investigating static stretching as an injury prevention measure (additional interventions were to be allowed as long as a control group also was present). Both RCTs and CCTs were defined using definitions determined by the *Cochrane Guide for Systematic Reviews* by Van Tulder et al. (2003), with RCTs defined as a trial in which individuals are assigned prospectively to one of two or more intervention programmes using some quasirandom method of allocation, and CCTs defined as a trial in which individuals are assigned prospectively to one of two or more intervention programmes using a random allocation method. (2) Participants ideally should be professional or amateur sportsmen; however, due to the lack of relevant studies using these participants, studies involving subjects engaging in physical activity or exercise also were reviewed. Participants also must be between 18 and 48 years old of either sex, as this population identified should provide an adequate yield of studies whilst also revealing results of benefit to the adult sporting community. Furthermore, younger athletes if included would create additional complications, as various physiological factors involved during their growth phase in life potentially may impair results. There also must be a minimum of 20 participants taking part in each study, as it generally is accepted that any fewer would result in higher confidence intervals and greater *P* values, therefore increasing the likelihood of misleading results. Furthermore, smaller sample sizes are more likely to increase the difficulty in detecting smaller, potentially clinically important, effects (Batterham and Atkinson 2005). (3) Only studies from 1990 to January 2008 were reviewed; earlier studies, although considered, were excluded from assessment in order to review findings from more recently conducted studies reflecting modern-day static stretching practices. (4) Any abstracts or unpublished studies were excluded. (5) The injury rate must be determined using a standardised “time loss” definition of injury, or a definition expressing to the same effect: a recordable injury is one that causes absence from training or competition participation, from which the study must be conducted over at least a 12-week period. This definition has been employed previously by research conducted by Hägglund et al. (2005) for the Union of European Football Associations (UEFA) and is common to exercise-based experimental research studies.

To assess the methodological quality of the included trials, an adapted version of the criteria list by van Tulder et al. (2003) then was used to score the relevant studies as commonly has been utilised with success for numerous previous systematic reviews. Studies were scored by the principal author, assisted by an additional author of the study with previous experience in conducting review articles, and also with the aid of the standardised criteria by Koes et al. (1991) as is based on generally accepted principles of intervention research as used by previous authors (Ter Riet et al. 1990; Weldon and Hill 2003). This criteria used for methodological assessment consisted of four main categories: group, treatment, outcome measures, and data presentation and analysis. Each of these categories was scored equally out of 25 points, the total number of points available for each study being 100. Furthermore, each category was broken down into separate subcategories (Table 1, A–K) for individual scoring, with the weighting of points given for each subcategory aimed to reflect their relative importance (Table 1). Along with the methodological assessment, a brief description of those studies that met the inclusion criteria was given, detailing the key points of each study.

Following on from the methodological assessment, we were unable to conduct meta-analysis, which, although may prove to be a slight limitation

Table 1. Criteria List for a Methodological Assessment of Clinical Trials of Static Stretching for Injury Prevention

Criterion	Weighting
Group Category:	
A. Subject selection—clear definitions of inclusion/exclusion criteria, specific characteristic of participants.	10 Points
B. Subject numbers—points awarded dependent on amount of participants (i.e., the greater the number, the higher the amount of points awarded).	10 Points
C. Homogeneity—similar subject characteristics (i.e., age, gender, activity performed, previous injury background).	5 Points
Treatment Category:	
D. Description of method—clear details given, including information on duration, application, interventions, etc.	10 Points
E. Design—control group and other interventions included along with static stretching.	10 points
F. Consideration factors to make study generally applicable?	5 Points
Outcome Measures Category:	
G. Appropriate/relevant outcome measures—details given concerning relevant reliability and validity measures.	13 Points
H. Assessment carried out blind (i.e., whether injuries were recorded by a person blind to prevention methods/control group).	12 Points
Data Presentation and Analysis Category:	
I. Sampling methods described (i.e., randomised awarded higher points than convenience samples, where appropriate).	10 Points
J. Presentation of data—appropriate and clear use of graphics, plots, and tables.	5 Points
K. Data analysis—appropriate use and interpretation of statistical results and procedures.	10 Points
Total:	100 Points

to the review, was due to the heterogeneity of the included studies. Alternatively, for secondary analysis of results, a two-tier vote count of studies investigating static stretching and injury prevention was performed, in accordance with the recommendations in the method guidelines for systematic reviews (van Tulder et al. 1997). Studies were judged to be positive if the results concluded that a static stretching protocol preexercise resulted in a significant reduction in the total injury risk ($P < 0.05$). A trial was otherwise judged to be negative if the results concluded that a static stretching protocol preexercise failed to significantly reduce the total injury risk, or increased the injury risk ($P > 0.05$). Following the vote count, a conclusion then was made from the reviewed literature into the efficacy of static stretching as part of the warm-up for the prevention of exercise-related injuries.

RESULTS

A total of 364 studies were retrieved from the literature search: however, only seven matched the inclusion criteria, four of which were RCTs and three of which were CCTs (Table 2). A summary of the process involved in retrieving suitable studies can be viewed in the flowchart presented based on the process developed for the quality of reporting of meta-analyses (Moher et al. 1999; See Figure 1).

The trials then underwent methodological assessment as previously described, with results ranging in quality from 26 to 79 points out of a possible 100 (Table 3). All four RCTs and two of the three CCTs (those by Bixler and Jones 1992; Cross and Worrell 1999) were deemed to be negative for static stretching. Conclusions were based, however, on the effect of static stretching on total injuries risk and not necessarily the author's own conclusions to make the results more comparable. Findings from both Bixler and Jones (1992) and Cross and Worrell (1999) suggested that static stretching was in fact beneficial in reducing the risk of sprain and strain type injuries; however, their results revealed no significant difference between control and intervention groups for total number of injuries ($P > 0.05$). These studies, therefore, were deemed negative. All four RCTs scored over 50 points, showing a reasonably sound overall methodological quality, whereas all CCTs scored under 50 points, the lowest being 26, and therefore showing less satisfactory methodological quality.

Common areas in which the CCTs often performed poorly in terms of methodological quality included subject selection and clear definitions of the inclusion and exclusion criteria and details on specific characteristics of participants (criterion A); sampling methods described (i.e., randomised awarded higher points than convenience samples, where appropriate;

Table 2. Brief Summaries of the Clinical Trials into the Efficacy of Static Stretching for the Prevention of Injury (Separated Between RCTs and CCTs and in Hierarchical Order Based on Date Published)

Author	Method	Participants	Intervention	Outcome
Amako et al. (2003)	RCT – between 1996 and 1998.	901 healthy male army recruits between the ages of 18–25 yrs.	Intervention: 18 static stretches: 4 to the upper extremity, 7 to the lower extremity, and 7 to the trunk. Each stretch maintained for 30 s, total time of routine 20 mins. Control: No static stretches preexercise.	No significant difference between groups for all-injuries risk ($P > 0.05$). Significantly lower incidence of muscle/tendon injury and low back pain in intervention group ($P < 0.05$).
Pope et al. (2000)	RCT – over a 12 week period.	1,538 male army recruits aged between 17–35 yrs.	Intervention: One 20 s static stretch for 6 major lower extremity muscle groups interspersed with 4 min warm-up of jogging and side-stepping. Control: Warm up only.	No significant effect of pre-exercise stretching on all-injuries risk (Hazard Ratio = 0.95, 95% CI 0.77–1.18).
Pope et al. (1998)	RCT – over a 12 week period.	1,093 male army recruits aged between 17–35 yrs	Intervention: Two 20 s static stretches of soleus and gastrocnemius muscles with 3 min light warm up exercises.Control: Two 20 s static stretches of wrist flexors and triceps muscles with identical 3 min light warm up.	No significant evidence of an effect of static stretching on reducing injury risk ($P = 0.76$).
Van Mechelen et al. (1993)	RCT – over a 16 week period.	421 male recreational runners aged between 40–47 yrs.	Intervention: warm-up of 6 mins running exercises, 3 mins loosening exercises, and 10 min stretching routine: 3 bouts of 10 s static stretching for iliopsoas, quadriceps, hamstrings, soleus and gastrocnemius muscles. Control: no advised warm-up routine.	No significant difference between groups for all-injuries risk ($P > 0.05$).

Hartig and Hendersen (1999)	CCT – over a 13 week period.	298 male basic army trainees with an average age of 20 yrs.	Intervention: 3 extra hamstring static stretching sessions added daily plus normal training and stretching routine preexercise, inc hamstrings stretches. Extra hamstring static stretches performed 5 times in each extremity and held for 30 sec. Control: normal training and stretches.	Significantly fewer lower extremity overuse injuries in the intervention group ($P < 0.02$).
Cross and Worrell (1999)	CCT – over one year.	195 college football players, mean age = 18.6 ± 1.5 yrs.	Intervention: static stretches for hamstrings, quadriceps, hip adductors, and gastrocnemius-soleus muscles held until a stretch sensation felt for 15 s. Control: No static stretching program.	No significant difference for total injury rate between control and intervention. Significantly fewer lower extremity musculotendinous strains following the intervention ($P < 0.05$).
Bixler and Jones (1992)	CCT – over 52 games (1 football season).	5 high-school football teams (exact no. or ages not given).	Intervention: At halftime- 1.5 min warm-up running and jumping, and static stretching routine: 25 s hamstring stretch, groin stretch, and quad stretch. Control: unaltered halftime activities.	No significant difference in total third-quarter injuries, although significantly fewer third-quarter sprains and strains per game for the intervention group ($P < 0.05$).

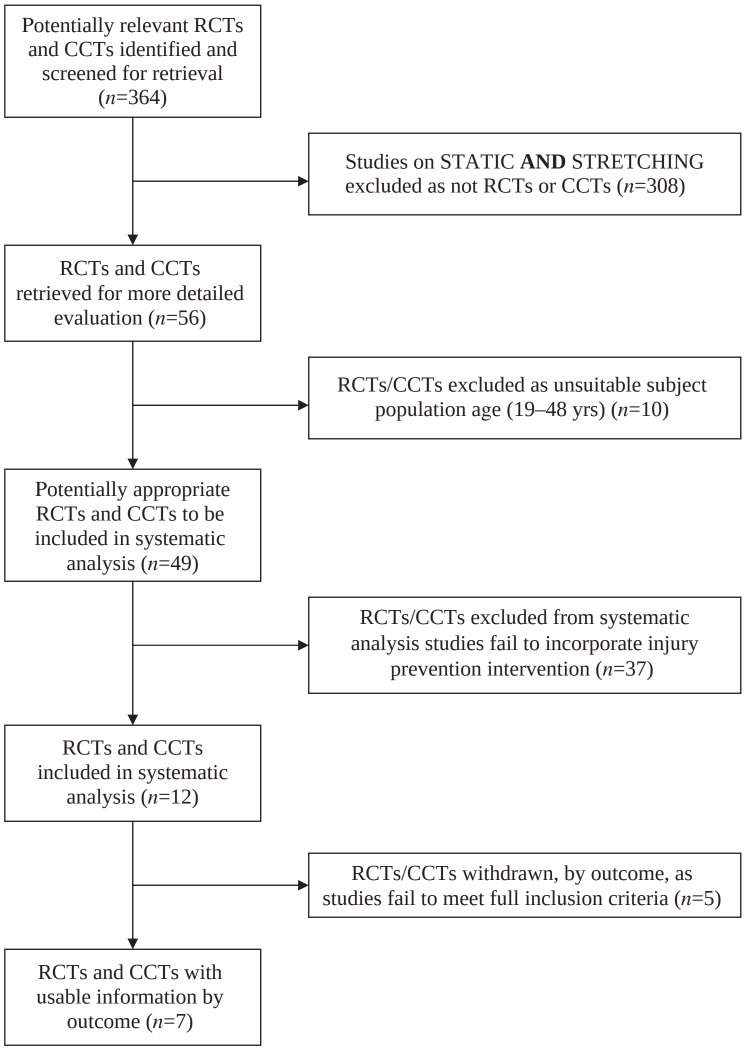

Figure 1. A flowchart presenting a summary of the process involved in retrieving suitable studies.

criterion I); presentation of data using appropriate and clear graphics, plots, and tables (criterion J); and also data analysis in terms of appropriate use and interpretation of statistical results and procedures (criterion K). These criteria generally received relatively low scores, especially when compared with those from the RCTs often scoring double. There was one notable exception in “criterion I however,” whereby due to the

Table 3. Clinical Trials of the Efficacy of Static Stretching for the Prevention of Injury in Hierarchical Order Based on Date Published with Reference to Point's Allocation from Table 1

	A (10)	B (10)	C (5)	D (10)	E (10)	F (5)	G (13)	H (12)	I (10)	J (5)	K (10)	Total (100)	Conclusion
Randomised Clinical Trials													
Amako et al. (2003)	6	9	4	8	8	4	4	0	3	4	8	57	Negative
Pope et al. (2000)	6	10	3	8	8	3	8	12	8	5	8	79	Negative
Pope et al. (1998)	8	9	3	8	7	2	6	0	8	4	8	63	Negative
Van Mechelen et al. (1993)	8	7	4	9	3	3	4	0	3	3	7	51	Negative
Controlled Clinical Trials													
Hartig and Henderson (1999)	2	7	4	9	8	3	7	0	0	0	5	45	Positive
Cross and Worrell (1999)	3	6	2	7	8	3	6	0	0	2	5	42	Negative
Bixler and Jones (1992)	2	0	4	7	2	1	4	0	0	3	3	26	Negative

nature of CCTs, they do not perform randomisation in their allocation of subjects to the different interventions, and therefore could not receive any points for that criterion that was scored out of 10. Although both studies by Bixler and Jones (1992) and Hartig and Henderson (1999) did attempt a pseudorandom design for treatment allocation of their subjects, this method is not considered reliable in eliminating selection bias (Weldon and Hill 2003), and, consequently, both studies remained unable to receive any points for this criterion.

The RCTs conversely all performed to a good standard in most criteria, one possible exception being the information on appropriate and relevant outcome measures and details given concerning relevant reliability and validity measures (criterion G), as all four studies received between four and eight points out of a possible 13. There was, however, one additional criterion in which all RCTs and CCTs, except for the trial by Pope et al. (2000), failed to score any points; assessment was carried out blind (i.e., whether injuries were recorded by a person blind to prevention methods/ control group; criterion H). Only the medical officer in the study by Pope et al. (2000) was blind to information regarding subject allocation to intervention and control groups. This important point not only quite substantially affected overall scores (as all but one of the studies received 0 out of 10 points for this criterion), but also may have biased results during the study and therefore led to inaccurate outcomes.

The highest scoring studies from the review were both RCTs by Pope et al. (1998 and 2000), which concur with findings from a review by Weldon and Hill (2003), despite the authors' investigation of general stretching and its effects in injury prevention rather than specifically focus on static stretching. The more recent of the two studies by Pope et al. (2000), and highest point scorer from the review with 79 points, revealed no significant effect of static stretching on all-injuries risk ($P = 0.67$). This result substantiated earlier findings by Pope et al. (1998) in a similarly designed and conducted study that also found static stretching to be ineffective in the prevention of all-injuries risk ($P = 0.67$). Furthermore, both studies uncovered other factors that may predict injury risk. In the latter study by Pope et al. (2000) subjects' fitness level was found to be a significant predictor of injury risk following the results from multivariate analysis ($P < 0.001$), whereas the previous study by Pope et al. (1998) found flexibility to be a significant predictor of injury risk (positive likelihood ratio = 4.97; df = 1; $P = 0.03$), which supports previous literature (Jones et al. 1993; Shellock and Prentice 1985; Smith 1994; Taimela et al. 1990).

The most recent RCT review conducted by Amako et al. (2003) was furthermore deemed to be negative for static stretching. Findings showed no significant difference in the all-injuries rate between control and intervention groups ($P = 0.12$); however, it was found that the static stretching group had significantly lower incidences of muscle/tendon and lower back injuries ($P < 0.05$).

The final RCT review was conducted by Van Mechelen et al. (1993) and similarly found no significant difference in the all-injuries rate between control and intervention groups (chi-squared = 0.45, df = 1, $P < 0.05$). Results from this study may be more inaccurate than the later studies, however, due to the relatively high drop-out rate of 22.3%, only a 46.6% compliance rate with the prescribed program, and 39.6% of subjects in the intervention group failing to perform any kind of static stretches preexercise. Therefore, these results should be questioned and viewed in light of these facts.

From the CCTs reviewed, only one of the three studies, that by Hartig and Henderson (1999), was deemed positive for static stretching. The remaining two CCTs both were judged to be negative for static stretching despite the authors' own conclusions. Results from the study by Bixler and Jones (1992) stated no significant difference in total all-injuries rate between control and intervention groups. No results from statistical analysis were evident to validate these claims; therefore, these results should be taken with caution, especially as this study received the lowest score following methodological assessment, with only 26 points. The study did report, however, that static stretching preexercise reduced the risk of muscle/ligament injuries ($P < 0.05$), which may support corresponding claims by Amako et al. (2003). Similarly, the study by Cross and Worrell (1999), which received the second lowest score of 42 points, revealed a significant reduction in the number of lower extremity musculotendinous strains in the intervention group compared with the control group following X^2 analysis ($P < 0.05$), which led to the authors' conclusion of the effectiveness of static stretching at reducing injury risk. The number of total injuries recorded in the control season, however, was 155, and subsequently 153 the following season after the inclusion of a static stretching intervention program. Therefore, although no statistical analysis was presented to evaluate these specific findings, the raw data presented would suggest no significant difference between the two seasons for total injuries risk, and consequently as this is the factor assessed for during the final vote count, the study was deemed negative.

The only study reviewed to be judged positive for static stretching was the CCT by Hartig and Henderson (1999), which received the highest score for a CCT of 45 points, although this still was lower than any of the RCTs. Results from this study revealed a significantly lower number of total injuries for the intervention group compared with the control group ($P = 0.02$). It should be noted, however, that only lower extremity overuse injuries were recorded during this study, which may correspond with similar findings by Bixler and Jones (1992); Cross and Worrell (1999); and Amako et al. (2003), as overuse injuries generally are associated with musculotendinous injuries (Ball and Herrington 1998).

Despite the majority of results reporting static stretching to be insignificant at reducing the all injuries rate, what may be of more interest to researchers and sportsmen alike is how much of an effect static stretching actually has. In addition to calculating the level of significance, both studies by Pope et al. (1998, 2000) also added a measure of effect size using the Cox regression hazard ratio. In the earlier study by Pope et al. (1998), the authors reported a hazard ratio of 0.92 (95% CI 0.52 to 1.61), and with a figure of 0.95 (95% CI 0.77 to 1.18) reported in their subsequent study (Pope et al. 2000). Although both values reported are close to 1.00, which would indicate no difference in injury rates between groups, this may nevertheless still suggest some potentially more practically relevant effect of static stretching on injury prevention, which should be considered, as Pope et al. (1998) stated that whilst it may be possible to rule out large risk reductions with a high degree of certainty, small but clinically worthwhile effects may go undetected.

Despite the potential importance of results from measuring the effect size, of the seven studies reviewed, only those conducted by Pope et al.

(1998, 2000) included results on hazard ratio scores. A similar method, however, can be used to calculate an adjusted relative ratio (RR) relating to the relative risk of injury, and applied to the relevant values reported in the remaining five studies to provide more information on the potential clinical importance of static stretching for injury prevention. Results calculated by the authors of this review revealed contrasting results to those reported regarding the statistically insignificant effect of static stretching, with RR scores of 0.99 (95% CI 0.89–1.09) in the study by Cross and Worrell (1999), 0.77 (95% CI 0.54–1.08) by Amako et al. 2003, and 0.57 (95% CI 0.37–0.89) by Hartig and Henderson (1999), therefore implying greater clinical or practical effect and importance of static stretching for injury prevention. Of the seven studies, only those by Van Mechelen et al. (1993) and Bixler and Jones (1992) contrastingly would report values of above 1.00, 1.26 (95% CI 0.73–2.19), and 1.57 (95% CI 1.32–1.89), respectively, to indicate no clinical effect. Therefore, the overall calculated hazard ratio results would indicate that, although static stretching appears not to be statistically significant in reducing the all injury rate, it may have a potentially greater clinical effect in lowering the risk of exercise-related musculotendinous strain/sprain injuries.

DISCUSSION

In order to help conclude the findings from this systematic review, a vote count was performed on the included studies in accordance with recommendations in the method guidelines for systematic reviews (Van Tulder et al. 1997). From the RCTs reviewed, a vote count of all four negatives (100%) would suggest that static stretching preexercise does not reduce the risk of injury to performers, whereas for the CCTs, two of the three studies also were deemed negative (66.6%), further leading toward a conclusion of the ineffectiveness of static stretching for injury prevention when used preexercise. Only one of the seven studies reviewed was positive for static stretching, although this study was a CCT with an inferior trial design and therefore this result will be of less significance. The overall conclusion from the vote count therefore, would, not promote the efficacy of static stretching for the prevention of exercise-related injuries.

Despite the general consensus revealing static stretching as failing to significantly aid injury prevention, it should also be considered that results from hazard ratios contrastingly would support the clinical or practical importance of static stretching for injury prevention as was reported by both studies by Pope et al. (1998, 2000). Furthermore, there was one notable point documented in several of the studies reviewed. Although it was shown that static stretching failed to aid total injury prevention (Amako et al. 2003; Bixler and Jones 1992; Cross and Worrell

1999; Hartig and Henderson 1999; Pope et al. 1998, 2000; van Mechelen et al. 1993), the studies by Amako et al. (2003), Bixler and Jones (1992), and Cross and Worrell (1999) all contained results that revealed that static stretching significantly reduces the number of muscle/tendon and ligament injuries. Amako et al. (2003) reported that the static stretching group received significantly fewer muscle injuries compared with the control group ($X^2 = 6.170$; $P < 0.05$), Cross and Worrell (1999) also reported significantly fewer musculotendinous strains after the incorporation of a static stretching protocol, whilst the results from Bixler and Jones (1992) similarly showed a significant reduction in ligament sprain and muscle strain injuries following a static stretching programme ($P < 0.05$). These three results, as provided from a combination of both CCTs and a RCT, help provide credibility to their findings, respectively, especially as they can be supported by previous literature by Ekstrand et al. (1983), who investigated the prevention of soccer injuries. The studies by Pope et al. (1998 and 2000) furthermore found a general reduction in soft tissue injuries for the static stretching group, which also should be noted as these two studies received the highest point scores following methodological analysis.

Therefore, there may be some preliminary evidence to suggest a relationship between static stretching and the prevention of musculotendinous and ligament sprain type injuries, even if not of all injuries. This may be due to static stretching improving the flexibility of ligaments and musculotendinous units by facilitating connective tissue plastic elongation, thereby promoting muscle relaxation and therefore further stretch and ROM around a joint (Amako et al. 2003; Smith 1994), which is believed to help reduce injury risk (Shellock and Prentice 1985; Smith 1994). Studies that revealed no reduction in overall injury rates may be explained by the fact that some injuries are simply unavoidable (Amako et al. 2003), and therefore statistics between control and intervention groups would have been virtually identical. These injuries would include bone and vascular-related injuries such as shin splints and chronic compartment syndrome, which could not be prevented by a static stretching program (cf. Amako et al. 2003).

RELEVENCE

It should be considered that within this review, and of the studies retrieved that met the inclusion criteria to be evaluated, several of the studies had been the subject of previous reviews. In particular, six out of the seven studies reviewed by the current authors had been assessed formerly in a similarly designed systematic review by Weldon and Hill (2003) into the efficacy of stretching for the prevention of exercise-related injury. It is the belief that the current review is unique, however, in that the literature has been reviewed from the perspective specifically focussed on static stretching and its effect on injury prevention, as opposed to alternative stretching methods employed. Therefore, findings from the review may be useful for sports performers, coaches, or trainers when considering incorporating a static stretching programme as part of their preexercise warm-up for injury prevention.

It may be considered that, despite the apparent failure of static stretching reducing the risk of allinjuries, as several of the studies revealed a reduction in the rate of musculotendinous injuries, static stretching as an injury prevention tool may be of particular interest to sports performers sustaining a high degree of these injuries, especially as is common in sports such as soccer, rugby, Australian football, and other sports involving sprinting (Orchard 2001).

CONCLUSION

Results seem to indicate that there is moderate-to-strong evidence that routine application of static stretching will not reduce overall injury rates on the basis of the work that has been undertaken. Secondary findings indicate, however, that there is preliminary evidence that static stretching may have a positive effect on preventing musculotendinous injuries.

Additional high-quality RCTs and carefully controlled clinical trials, ideally within the athletic setting and examining the effect on musculotendinous injuries risk, are required to investigate the matter further. Until then, the debate as to whether to employ static stretching as part of a preexercise warm-up remains unresolved and may be determined by performer or trainer preferences, with other factors to be considered relating to the potentially detrimental effects of static stretching on performance.

REFERENCES

Agre JC (1985) Hamstring injuries. Proposed aetiological factors, prevention and treatment. *Journal of Sports Medicine* 2: 21–33.

Amako M, Oda T, Masuoka K, Yokoi H, Campisi P (2003) Effect of static stretching on prevention of injuries for military recruits. *Journal of Military Medicine* 168(6): 442–446.

Ball D, Herrington L (1998) Training and overload: Adaptation and failure in the musculoskeletal system. *Journal of Bodywork and Movement Therapies* 2(3): 161–167.

Batterham AM, Atkinson G (2005) How big does my sample size need to be? A primer on the murky world of sample size estimation. *Journal of Physical Therapy in Sport* 6: 153–163.

Bixler BA, Jones RL (1992) High-school football injuries: Effects of post-half time warm-up and stretching routine. *Family Practice Research Journal* 12(2): 131–139.

Cornelius WL, Hinson MM (1980) The relationship between isometric contractions of hip extensors and subsequent flexibility in males. *Journal of Sports Medicine and Physical Fitness* 20: 75–80.

Cross KM, Worrell TW (1999) Effects of a static stretching program on the incidence of lower extremity musculotendinous strains. *Journal of Athletic Training* 34(1): 11–14.

Ekstrand J, Gillquist J (1983) The avoidability of soccer injuries. *International Journal of Sports Medicine* 4: 124–128.

Ekstrand J, Gillquist J, Liljedahl S-O (1983) Prevention of soccer injuries: Supervision by doctor and physiotherapist. *American Journal of Sports Medicine* 11: 116–120.

Finestone A, Shlamkovitch N, Eldad A, Wosk J (1991) Risk factors for stress fractures among Israeli infantry recruits. *Journal of Military Medicine* 156: 528–530.

Godges JJ, MacRae H, Longdon C, Tinberg C, MacRae P (1989) The effects of two stretching procedures on hip range of motion and gait economy. *Journal of Orthopedic Sports Physical Therapy* 1: 350–357.

Greenhalgh T (1997) Papers that summarise other papers (systematic reviews and meta-analysis). *British Medical Journal* (Clinical research ed.) 13;315(7109): 672–675.

Hägglund M, Waldén M, Balu R, Ekstrand J (2005) Methods for epidemiological study of injuries to professional players: Developing the UEFA model. *British Journal of Sports Medicine* 39: 340–346.

Hartig DE, Henderson JM (1999) Increasing hamstring flexibility decreases lower extremity overuse injuries in military basic trainees. *American Journal of Sport Medicine* 27(2): 173–176.

Herbert RD, Gabriel M (2002) Effects of stretching before and after exercising on muscle soreness and risk of injury: Systematic review. *British Medical Journal* 325: 468.

Hess GP, Cappiello WL, Pole RM (1987) Prevention and treatment of overuse tendon injuries. *Journal of Sports Medicine* 8: 371–384.

Ingraham SJ (2003) The role of flexibility in injury prevention and athletic performance: Have we stretched the truth? *Journal of Minnesota Medicine* 86(5): 58–61.

Jones DC, Cowan DL, Tomlinson JP (1993) Epidemiology of injuries associated with physical training among young men in the army. *Journal of Medicine and Science in Sports and Exercise* 25: 197–203.

Koes BW, Assendelft WJJ, van der Heijden GJMG, Bouter LM, Knipschild PG (1991) Spinal manipulation and mobilization for back and neck pain: a blinded review. *British Medical Journal* 303: 1289–1303.

Lysens RJ, Ostyn MS, Auweele YV, Lefevre J, Vuylsteke M, Renson L (1989) The accident-prone and overuse-prone profiles of the young athlete. *American Journal of Sports Medicine* 17: 612–619.

McCullough C (1990) Stretching for injury prevention. *Journal of Patient Management* 14(6): 79–85.

Moher D, Cook DJ, Eastwood S, Olkin I, Rennie D, Stroup D (1999) Improving the quality of reports of meta-analyses of randomised controlled trials: The QUOROM statement. *The Lancet* 354: 1896–1900.

Mora J (1990) Dynamic stretching. *Triathlete* 84: 28–31.

Murphy DR (1991) A critical look at static stretching: are we doing our patient harm? *Journal of Chiropratic Sports Medicine* 5: 67–70

Orchard JW (2001) Intrinsic and extrinsic risk factors for muscle strains in Australian football. *American Journal of Sports Medicine* 29: 300–303.

Osternig LR, Robertson RN, Troxel RK, Hansen P (1990) Differential response to proprioceptive neuromuscular facilitation (PNF) stretch techniques. *Journal of Medicine and Science in Sports and Exercise* 22(1): 106–111.

Pope RP, Herbert RD, Kirwan JD (1998) Effects of ankle dorsiflexion and pre-exercise calf-muscle stretching on injury risk in army military recruits. *Australian Journal of Physiotherapy* 44(3): 165–172.

Pope RP, Herbert RD, Kirwan JD, Graham BJ (2000) A randomised trial of pre-exercise stretching for prevention of lower-limb injury. *Journal of Medicine and Science in Sports and Exercise* 32(2): 271–277.

Safran MC, Seaber AV, Garret WE (1989) Warm-up and muscular injury prevention: An update. *Journal of Sports Medicine* 2: 21–33.

Shellock FG, Prentice WE (1985) Warming-up and stretching for improved physical performance and prevention of sports-related injuries. *Journal of Sports Medicine* 2(4): 267–278.

Shrier I (1999) Stretching before exercise does not reduce the risk of local muscle injury: A critical review of the clinical and basic science literature. *Clinical Journal of Sport Medicine* 9(4): 221–227.

Shrier I (2000) Stretching before exercise: an evidence based approach. *British Journal of Sports Medicine* 34: 324–325.

Shrier I (2005) When and whom to stretch? Gauging the benefits and drawbacks for individual patients. *The Physician and Sports Medicine* 33(3): 22–26.

Smith CA (1994) The warm-up procedure: To stretch or not to stretch. A brief review. *Journal of Orthopaedic and Sports Physical Therapy* 19: 12–17.

Taimela S, Kujala UM, Osterman K (1990) Intrinsic risk factors and athletic injuries. *Journal of Sports Medicine* 9: 205–215.

Ter Riet G, Kleijnen J, Knipschild P (1990) Acupuncture and chronic pain: A criteria-based meta-analysis. *Journal of Clinical Epidemiology* 43: 1191–1199.

Thacker SB, Gilchrist J, Stroup DF, Kimsey CD, Jr. (2004) The impact of stretching on sports injury risk: A systematic review of the literature. *Journal of Medicine and Science in Sports and Exercise* 36(3): 271–378.

Van Mechelen W, Hlobil H, Kemper HCG, Voorn WJ, De Jongh HR (1993) Prevention of running injuries by warm-up, cool-down and stretching exercises. *American Journal of Sports Medicine* 21(5): 711–719.

Van Tulder MW, Assendelft WJJ, Koes BW, Bouter LM, The Editorial Board of the Cochrane Collaboration Back Review Group (1997) Method guidelines for systematic reviews in the Cochrane Collaboration Back Review Group for spinal disorders. *Spine* 22(20): 2323–2330.

Wallin D, Ekbolm B, Grahn R, Nordenborg T (1985) Improvement of muscle flexibility: A comparison of two techniques. *American Journal of Sports Medicine* 13(4): 263–268.

Weldon SM, Hill RH (2003) The efficacy of stretching for prevention of exercise-related injury: A systematic review of the literature. *Journal of Manual Therapy* 8(3): 141–150.

Wiktorsson-Moller M, Oberg B, Ekstrand J, Gillquist J (1983) Effects of warming up, massage, and stretching on range of motion and muscle strength in the lower extremity. *American Journal of Sports Medicine* 11(4): 249–252.

Worrell TW (1994) Factors associated with hamstring injuries: An approach to treatment and preventative measures. *Journal of Sports Medicine* 17: 338–345.

Zarins B, Ciullo JV (1983) Acute muscle and tendon injuries in athletes. *Clinical Journal of Sport Medicine* 2: 167–182.