Klee, A, Wydra, G (2023). Zur Wirkung des Dehnungstrainings als Verletzungsprophylaxe. Eine Analyse unter besonderer Berücksichtigung des Verletzungsrisikos bei verschiedenen sportlichen Aktivitäten. Bewegungstherapie und Gesundheitssport, 39, 3: 98–106.

Der folgende unveröffentlichte Beitrag in englischer Sprache ist dem deutschen Text sehr ähnlich, aber nicht identisch

The following unpublished article in English is very similar to the German text, but not identical

On the effect of stretching as injury prevention - an analysis with special regard to the risk of injury in various sporting activities

Abstract

Musculotendinous injuries account for a high proportion of all injuries, especially in high-speed strength sports. Both warm-up and regular stretching are expected to reduce musculotendinous injuries. An indication of the extent of reduction is given either as a percentage or as a recommendation of how many years of stretching is needed to avoid musculotendinous injuries. The figures show a wide range (5%-54%, 5-23 years). This article explains how these different figures come about and how they should be interpreted. The different risk of injury in various sports activities and the variation in the volume of training (hours per year) are of particular importance. Eleven primary studies were mainly considered in the corresponding meta-analyses of the last few years. The meta-analyses include different primary studies. Four primary studies in particular are suitable for calculating the relative risk. This calculation shows that about one third of the musculotendinous injuries can be avoided. This result is supported by five other primary studies. It is not clear whether this reduction is caused by short-term warm-up effects or long-term adaptations. As a result, great importance should be given to warm-up stretching in sports practice (dynamic stretching) and regular stretching (all methods: dynamic – static - and contract-relax stretching). In addition to stretching, there are other measures that can reduce the risk of injury, such as eccentric strength training. In future studies, the volume of training and the incidence of injury should be expressed in terms of injuries per 1000 hours. Since these data are missing in many primary studies, the results can hardly be compared. Furthermore, additional variables such as previous injuries should be recorded and included in a multivariate analysis.

Keywords: Stretching

incidence of injuries

injury prevention

musculotendinous injuries

Introduction

On professional football teams in England, 41% of injuries are muscle strains. In Australian football, hamstring strains account for 13% of all injuries (7, p. 388). Dadebo et al. (2004) suggest that the high proportion of hamstrings may be due to the fact that they contain a high proportion of type II fibers and few titin proteins. Muscle strains and muscle fiber tears are usually triggered by movements that place high demands on high-speed strength for a short period of time, e.g. a sprint, a jump, the kick of a ball, or movements that involve maximum range of motion such as hurdles (31).

In injury prevention, as with the other effects of stretching training, two temporal dimensions must be distinguished (3,32):

1) Short-term stretching, i.e., stretching programs lasting 10-20 min, as performed within a warm-up program, which produce short-term effects (warm-up effects) that subside after a few minutes and have completely subsided after an hour.

2) Long-term stretching, i.e., short-term stretching programs performed regularly over several weeks that lead to training adaptations that last for weeks and months (long-term effects).

The expectation that stretching exercises can reduce strains is based on the fact that stretching increases range of movement, tolerance to stretching tension, and maximum passive tension in both the short and long term.

The passive tension, i.e. the stretching tension in the submaximal range, decreases by 20% in the short term. In some training experiments, the passive tension increased over the long term and there were increases in strength and performance (3,19). Since the muscle tension when stretching is similar to that of strength training, this could be the result of growth processes. Schleip and Bayer (26) assume that both muscle soreness and muscle injuries are mainly caused in the connective tissue and cite studies that demonstrate growth processes in the connective tissue.

Some authors also expect sarcomeres to be added in series in the long term, as has only been demonstrated in animal experiments up to now, especially due to immobilization of muscles in a lengthened position (9), but also in the case of regular stretching (14,23).

Since muscles and tendons act as a unit and flow into one another, we usually speak of musculotendinous injuries. Witvrouw et al. (34) cited studies that showed that the viscoelasticity of tendons can be changed both in the short and long term by stretching and that the tendons become more pliable.

Methods

In order to gain an overview of the effect of stretching training as injury prophylaxis, the most important reviews on this topic and the primary studies involved are reviewed. In a next step, these primary studies will be examined to determine whether they allow a statement to be made about the effect of stretching training as a prophylaxis against muscle tendon injuries (i.e. retrospective data analysis of publically available data). Based on the results of these studies, the relative risk and the weighted relative risk of developing muscle tendon injuries is calculated by means of the software Comprehensive Meta Analysis (CMA) release 2.2.064, Biostat, Englewood 2011.

Results

Meta-analysis and reviews

From 2002 to 2004, meta-analysis and reviews accumulated, which attributed little or no effect to stretching training as injury prevention (12,21,28,33). In particular, the meta-analysis by Herbert and Gabriel (12) received a lot of attention in literature and on the Internet. Two results were often quoted: "… stretching decreased the risk of injury by 5% … the average subject would need to stretch for 23 years to prevent one injury" (p. 5).

Then an overview was published pointing out that no or only a few acute musculotendinous injuries were recorded in the underlying primary studies (15). The majority was acute injuries and overload injuries to other structures (ligaments, bursas, joints, bones). However, since it can be assumed above all that acute musculotendinous injuries can be avoided by stretching, the validity of the primary studies and reviews were questioned in this publication. The author presented two primary studies that demonstrated the effect of stretching on preventing acute musculotendinous injuries (6,7). In 2013, his calculations showed a greater effect in preventing musculotendinous injuries (17, 25-50% reduction, 5-9 Years) than Herbert and Gabriel (12, 5%, 23 years, see above).

The first review in international publications which explicitly refers to a distinction between the effect of stretching as injury prophylaxis for all injuries and the effect on preventing musculotendinous injuries, was published by Small et al. (27). After reviewing 346 publications, the authors concluded that only seven of them could be included in an evaluation. However, even these seven studies do not meet all requirements and only receive between 26 and 79 points out of a possible 100 points when evaluated based on the Criteria for a Methodological Assessment of Clinical Trials. This shows that the quality of the studies is not very high. If the highest demands are set here, not many studies can be included in the evaluation. Overall, Small et al. (27) also conclude that stretching has no effect on the avoidance of all injuries. Only one of the seven studies shows a positive effect (11). Small et al. then focus on musculotendinous and ligament injuries and find a positive effect in three studies (1,5,6).

They also point out that both Ekstrand and Gillquist (8) and Pope et al. (25) provide similar information on avoiding musculotendinous injuries.

McHugh and Cosgrave (22) include seven studies in their evaluation. Like Small et al. (26), McHugh and Cosgrave (22) also found that stretching cannot reduce overuse injuries. In four studies, they also found an effect in reducing musculotendinous injuries (1,5,8,10). Since the study by Hadala and Barrios appeared in 2009, Small et al. were unable to take it into account in 2008. In addition, there are further differences between the two reviews. Table 1 shows which primary studies were considered by which meta-analysis. Small et al. (27) does not include Ekstrand and Gillquist (8), but McHugh and Cosgrave (22) do. Cross and Worrell (6), on the other hand, is included by Small et al. (27), but not by McHugh and Cosgrave (22) and not listed in the literature list. Cross and Worrell (6) is then included in the 2016 meta-analysis (4). McHugh and Cosgrave (22) point out the problem that some studies implemented several measures to reduce injuries. With these multi-component interventions, the effect cannot be assigned exactly to one particular intervention. Ekstrand and Gillquist's study (8) included e.g. seven interventions. McHugh and Cosgrave (22) emphasize the advantage of investigations on military recruits where training can be controlled. As a counterexample, they use the study by van Mechelen et al. (29) on volunteers, of whom only 47% actually observed the training.

Only a small part of the publication by Behm et al. (4) deals with injury prevention (p. 8). Behm (3) reveals that this part is from McHugh (p. 96). From six studies (table 1, last column), Behm et al. calculated a 54% reduction in the relative risk of sustaining an acute musculotendinous injury through stretching. However, own calculations based on these values from the six studies come to a different conclusion. The sum of injuries of the six control groups is only 214, not 264. The reduction in the relative risk of acute musculotendinous injuries is thus overstated with 54% and is instead 44%. In his book, Behm (3) presents the calculation result of 54% again (p. 97).

Primary studies

Table 2 shows the 11 primary studies included in the meta-analyzes in chronological order. The study by Pope et al. (24) from Table 1 is not included in the following as no musculotendinous injuries were recorded. First, the six studies from the last-mentioned meta-analysis are presented (4). In three of these studies, the question is whether they can be included in the calculation. In Arnason et al. (2), the number of muscle injuries was not reduced on closer examination. In Ekstrand and Gillquist (8) a total of seven treatments were carried out, Hadala and Barrios (10) performed two treatments, so that the reduction in muscle injuries cannot be clearly attributed to stretching.

The aim of the study by Arnason et al. (2) was to test the effect of three treatments as injury prevention. For this purpose, the strains on the hamstring muscles in elite soccer teams from Iceland and Norway were recorded over four seasons from 1999 to 2002. The first two seasons without treatments served as comparative data. In the last two seasons three treatments were then carried out in different combinations (contract three times (5-10 s.) relax (20 s.) stretching when warming up, 3 x C (10 s.) - R (45 s.) stretching as regular training, eccentric strength training). There was no effect with CR stretching as regular training, while the combination of contract-relaxing stretching during warm-up and eccentric strength training could reduce the number of strains of the hamstrings by 65%. In Behm et al. (4) this investigation is included in the calculation of the reduction in musculotendinous injuries with -6%, although they previously found no effect in this investigation. Since seven of the Norwegian teams did not perform any treatments in the 2001 season and the Icelandic teams had already carried out the eccentric strength training, these values should not have been compared. Arnason et al. (2) indicate that it is not possible to randomize professional athletes and that it is difficult to control training.

Ekstrand and Gillquist (8) divided the 12 soccer teams (180 players) into two groups of 90 players for a period of 6 months. The injury prevention program consisted of seven interventions. One was a 10-minute CR stretching of adductors, quadriceps, hamstring muscles, iliopsoas and calf muscles. Information on the duration of each stretch is missing. These muscles were also stretched during the 5-minute cool-down. The number of strains was 74% lower in the intervention group at 6 than in the control group (24). The authors attribute this to stretching. However, since six other interventions were also carried out (improvement of equipment, rehabilitation, information, taping), the causal relationship is not clear.

The aim of Hadala and Barrios (10) was to analyze the effectiveness of different strategies of preventive interventions during competition periods in an America's Cup yachting crew of 30 professional sailors. In the first season 2004, athletes did not receive any preventive intervention. In the second season of 2005, the preventive intervention consisted of 30-minute stretching exercises (14 exercises, 1-2 times per muscle, 20-30 s.) before the yacht race and preventive taping. The rate of musculotendinous injuries was 81% lower this season (2004: 23, 2005: 4). In their Table 5, Behm et al. (4) noted that this effect cannot be clearly assigned to stretching. In addition, sailing is a very special sport in which, for example, there is hardly any sprinting.

In the other three studies from the evaluation by Behm et al. (4) there are no obvious methodological shortcomings.

Cross and Worrell (6) had followed the injuries of 195 football players over two seasons. In the second season, in contrast to the first season, the athletes stretched the back and front thigh muscles, the adductors and the calf muscles 3 times for 15 seconds before each sprint training. While the number of injuries did not differ in the two seasons (first season: 155, second season: 153), the number of muscle and tendon strains was significantly lower in the second season (21) than in the first season (43).

The meta-analysis by Herbert and Gabriel (12), which has already been cited, included only two primary studies (24,25). Both were conducted with Australian recruits and have a high number of subjects (24: 1093; 24: 1538). In the first study, no musculotendinous injuries were recorded in the (24). In the study at Pope et al. (25) subjects in the stretching group performed a 20-s supervised static stretch for each of six major leg muscle groups (gastrocnemius, soleus, hamstring, quadriceps, hip adductor, and hip flexor muscle groups) once every second day for 11 weeks (40 sessions). The quality of this study is rated highest by Small et al. with 79 out of a possible 100 points (27, p. 223). There was no significant effect of pre-exercise stretching on the risk of all injuries (Pope et al., 25, p. 274, stretch-group: 158, control-group: 175). The table also shows that there were 14 muscle strains in the stretching group and 21 in the control group. However, this difference is not statistically evaluated. These values are included in the meta-analysis by Behm et al. (4). McHugh and Cosgrave comment on yet another result from Pope et al. (25): „The most striking difference was the occurrence of 10 thigh strains in the control group vs two thigh strains in the stretching group. These injuries amount to a 1.2% prevalence in the control group (10 strains in 803 subjects) vs a 0.3% prevalence in the stretching group (two strains in 735 subjects), which is statistically significant (P < 0.05).” (22, p. 176)

The study by Amako et al. (1) is similar to that of Pope et al. (25) and was conducted with 901 Japanese recruits (stretching-group: 518, control-group: 383). The static stretching consisted of 18 exercises which were completed for 30 seconds each with a total of 20 minutes before and after each physical training session. The difference between the overall incidence of injuries was not statistically significant. The number of muscle injuries in the control group was significantly higher than in the stretching group (6.9% versus 2.5%).

These were the six studies from the meta-analysis by Behm et al. (4). In addition, Table 2 lists five other studies cited in the other meta-analyzes.

The study by van Mechelen et al. (29) is included in three reviews, but then not taken into account in the evaluation because strains are not evaluated separately. There is no indication of an effect of stretching as injury prevention by the number of all injuries. On the contrary, the number is higher in the stretch group (5.5 running injuries per 1000 hours, control: 4.9).

In the study by Bixler and Jones (5), three high school football teams warmed up and stretched for 1.5 minutes after the half-time break while two control teams did not. There are two problems in this study. First, there is no distinction between the effects of warming up and stretching. Secondly, although there were fewer strains and sprains in the stretch group, no distinction was made between strains and sprains. In addition, the stretching time of 1.5 minutes was rather short. The timing after the half-time break was also unusual. However, the number of strains / sprains in the stretching group (1) was significantly lower in the control group (13).

Hartig and Henderson (11) had compared two groups of recruits over the course of their 13-week basic training. While the first group of 148 recruits only did their normal stretching exercises prior to physical training, the 150 recruits in the stretch group additionally performed five 30-second static stretches of the hamstring muscles three times a day. In the control group there were significantly more injuries (stress fractures, patellofemoral knee pain, muscle strains, tendinitis, plantar fasciitis, shin splints, anterior compartment syndrome) with 43 cases than in the stretch group with 25 cases. Since this investigation does not differentiate between the different types of injuries, it does not allow any conclusions to be drawn with regard to the reduction in muscle strains.

These last three studies (5,11,29) do not provide a clear conclusion about the effect of stretching in preventing musculotendinous injuries, but the remaining two studies do. The study by Jamtvedt et al. (13) has so far only been marginally considered in the reviews. The reviews by Klee (15) and Small et al (27) appeared before publication, the review by McHugh and Cosgrave (22) almost simultaneously. The study by Jamtvedt et al. (13) is only used in the text by Behm et al. (4) to support the calculated 54% (p. 8). It is an internet-based survey with 2,377 experimental subjects over a period of 12 weeks. The 1,220 participants in the intervention group stretched 7 muscle groups of the lower extremities and trunk for 30 seconds each before and after physical activity. This treatment reduced the risk of injuries to muscles, ligaments and tendons by 25%. Jamtvedt et al. (13) report the number of injuries in the stretch group as 133 per 1000 test subjects and 177 in the control group (summary of results in table on p. 12). Based on these figures, they calculate the risk of one injury per year in the stretch group to be 0.66, and 0.88 in the control group (p. 6). This result carries a lot of weight because one of the authors of the study mentioned above, which concluded that it takes 23 years to avoid injury (12), is a co-author of this publication (4). The source of error pointed out by the authors was that the results were self-reported and the participants were not blinded.

Dadebo et al. (7) had used questionnaires to determine how the players of 30 English teams in the first three football leagues stretch and which muscle injuries occur, in particular injuries to the hamstring muscles. In their multifactorial analysis, the authors can explain 79% of the 158 hamstring injuries that occurred by the following three factors: "holding time when stretching" (29%), "using a standard stretching protocol" (40%) and "applied stretching method" (10%). Players, who firstly used a standardized stretching program, secondly held the stretch for 15-30 s and thirdly did not use ballistic but static stretching or a PNF method, injured significantly less. The bivariate analysis showed only a correlation between the number of injuries of the hamstring muscles to the predictor "use of a standard stretching protocol".

This emphasizes the importance of multivariate evaluation methods and provides a possible explanation as to why some studies with bivariate analyzes could not prove any connections. Pope et al. (25) also found no correlation between the predictors and the number of injuries in the bivariate analysis and were then successful with the multivariate analysis. However, stretching was not one of these predictors, but rather poor fitness (poor 20m time), age and time of year.

In summary, these 11 studies are the most frequently cited in publications on stretching and prophylaxis of musculotendinous injuries. Some are of little or no informative value. In Arnason et al. (2) on closer inspection, the number of musculotendinous injuries was not reduced. But also studies in which muscle strains and other injuries were not recorded separately (5,11) or were not evaluated separately (29) do not allow any clear statements.

Studies in which other interventions were carried out in addition to stretching are also problematic, six other treatments in Ekstrand and Gillquist (8) and one intervention in Hadala and Barrios (10). The 73% reduction in Ekstrand and Gillquist (8) and 79% in

Hadala and Barrios (10) overestimate the effect, to what extent is unclear. In the study by Dadebo et al. (7) no figures are given on musculotendinous injuries and therefore cannot be included in a meta-analysis.

This leaves four studies that allow a statement on the prophylaxis of musculotendinous injuries (1,6,13,25).

Reducing the relative risk of acute musculotendinous injuries from stretching

In Table 3, the relative risk of sustaining a musculotendinous injury is calculated for these four studies. In the last line, a relative risk of 0.67 is calculated based on the sum of the test subjects and the injuries; i.e stretching reduces the number of injuries by 33.2%. A calculation with the weighted average results in a reduction of 31.4% (relative weight of each single study: 0.026 (1), 0.152 (6), 0.738 (13), 0.083, (25)). Both values are more than 20% below the 54% value given by Behm et al. (4).

Table 4 shows the figures on the incidence of injuries. Figures in bold are given in the relevant publication, the other figures were calculated. In three studies not all information needed to accurately calculate injury incidence is provided. This is defined as the number of injuries for a person for a fixed period, e.g. for the trial period or for a year. In order to do this, the number of test subjects and the number of musculotendinous injuries in the stretching and control groups would have to be specified. In Pope et al. (25) the number of test persons is given as 1538 and also the number of test persons for the stretching group and the control group, but not the exact dropout rate. Similarly, Jamtvedt et al. (13) only report the number of musculotendinous injuries per 1000 people, but not the exact number of test persons. In some of the four studies calculated values are given without citing the underlying figures. Jamtvedt et al.

(13) report the injury incidence of 0.66 musculotendinous injuries per person-year in the stretch group and 0.88 in the control group.

Since the frequency of injuries also depends on the length of time the load is applied, it is important to state the number of injuries per 1000 hours. Only this allows the comparison between different sports and different studies. Luig et al. (20) give a value of 50.2 injuries per 1000 hours of competition for the two highest leagues of men in soccer (p. 11, basketball: 97, ice hockey: 117.7, handball: 87.9). The distribution of injuries in training and in competition in soccer is 48%:52%, the number of injuries per player and season is 2.7. The proportion of injuries without contact with an opponent is rather low in all four sports, in soccer e.g. 24.5%. Luig et al. (20) do not provide any data on the use of stretching in various sports. Videbæk et al. (30) give values of 2.5 injuries per 1000 hours for long-distance athletes up to a maximum of 33.0 in a study of novice runners. This proves that both the sport and the state of training influence the incidence of injuries. The duration of the test period is always given (6: "one season", 1,13,24: "three months"), but only Pope et al. provide the exact total exercise time (40 sessions totaling 50 h). Only in Pope et al. (25) is it possible to calculate a value of 5 injuries per 1000 hours for the control group and 0.6 musculotendinous injuries per 1000 hours. In the other three studies, the volume of training is not given, so that the incidence of injuries per 1000 hours cannot be calculated or compared.

Thus, Pope et al.’s (25) 5 injuries per 1000 hours and 0.6 musculotendinous injuries per 1000 hours of recruit training is the only calculable value. The values are probably higher for other loads, since the number of injuries in Pope et al. (25) was rather low. Herbert and Gabriel's (12) statement that you have to stretch 23 years to avoid one injury only applies to the type of load tested (basic training of recruits) and the volume of training (50 hours in 11 weeks). This 23-year period would probably be reduced with a higher volume of training.

Discussion

The activities differ greatly in the four studies on injury prevention. The recruits were more likely to participate in general fitness training in Pope et al. and Amako et al. (1,25), various activities in Jamtvedt et al. (13) (32% running, 31% training in a gym, 14% cycling) and Division III college football in both training and competition in Cross and Worrell (6).

The four studies represent the possibilities of investigating the issue of injury prevention. In order to get sufficient musculotendinous injuries for an evaluation, either a large number of test subjects is required, as is possible in studies with recruits (1,25) and in internet surveys (13). Alternatively, the subjects must be observed over a longer period of time, as is possible with club athletes (6).

The three approaches however also pose problems. In the case of internet surveys, these consist primarily in the control of the treatment and in the assessment of the injuries. In the studies with recruits, the subjects are untrained and the sports activities consist less of sprints and more of marches. In the case of club athletes, it must be ensured that the subjects in the stretching group carry out the treatment over a long period, while the control group does not do this over a longer period. Problems are presented here e.g. by Arnason et al. (2).

Each of the four studies started stretching directly before the exercise as part of the warm-up. Nevertheless, long-term effects are also possible over the training period of three months (1,13,25) and one year (6). Since increases in strength and performance as well as an increase in passive tension have been demonstrated through long-term stretching (3,19,32), growth processes could be the cause of the reduction in musculotendinous injuries in these studies. According to Behm (3), stretching programs longer than 5 minutes in particular reduce the number of injuries. Only Hartig and Henderson (11) also used stretching specifically as long-term stretching, because while the control group stretched for three months before physical training, the stretching group also performed five 30-second static stretches three times a day. Although there were significantly more injuries in the control group than in the stretching group, no distinction was made between the various types of injuries. It cannot be clarified whether the reduction in musculotendinous injuries was caused by short-term effects (increase in range of motion, reduction in passive tension, changes in viscoelasticity, 34) or a combination with long-term effects. Other test designs would be necessary here (16).

There are other interventions besides stretching that can reduce the risk of injury. Eccentric strength training using the exercise "Nordic hamstring lowers" was shown by Arnason et al. (2) to reduce the number of hamstring strains by 65%. Dadebo et al. (7) and Pope et al. (25) show that the incidence of injury depends on many factors and emphasize the importance of multivariate evaluation. A whole range of factors can be considered.

“These include the volume of training (that is, the amount of time spent training or running), past injuries, previous physical condition, physical anomalies, body weight, sex, training surface, equipment, training techniques, whether the subject smokes cigarettes, and hamstring flexibility.” (11, p. 175).

Practical Applications

Reviewing the studies on the prophylaxis of musculotendinous injuries caused by stretching shows that only four studies allow statements (1,6,13,25). However, even these four studies do not meet all quality criteria, but suggest that approximately one third of musculotendinous injuries can be avoided by stretching. As a result, great importance should be attached to stretching training in sports practice. Since it is unclear whether this reduction is due to short-term warm-up effects or long-term adaptations, and both seem likely, athletes should consider both training measures. Dynamic stretching is usually recommended during warm-up stretching, as intense static stretching can impair explosive power transmission. Regular stretching should also include other methods such as static stretching or CR stretching. Besides stretching, there are other interventions that can reduce the risk of injury. Eccentric strength training through the exercise "Nordic hamstring lowers" combined with warm-up stretching could reduce the number of hamstring strains by 65%.

Table 1: Meta-analyzes and reviews on the subject of injury prevention through stretching (1st line) and primary studies (1st column) in chronological order. X: Study was taken into account in the review article, Sna: Study was not yet available when the review article was published, S: Survey, I: only other injuries, no musculotendinous injuries, C: Confusion, Mne musculotendinous injuries are not evaluated.

	Herbert & Gabriel (2002)	Klee (2006)	Small et al. (2008)	McHugh & Cosgrave (2010)	Behm et al. (2016)
Ekstrand et al. (1983) C				X	X
Bixler & Jones (1992), C		X	X	X	
Van Mechelen et al. (1993) S		X	X	X	
Pope et al. (1998) I	X	X	X	X	
Cross & Worrell (1999)		X	X		X
Hartig & Henderson (1999) Mne		X	X		
Pope et al. (2000)	X	X	X	X	X
Amako et al. (2003)	Sna		X	X	X

Dadebo et al. (2004) S	Sna	X			
Arnason et al. (2008)	Sna	Sna			X
Hadala & Barrios (2009) C	Sna	Sna		X	X
Jamtvedt et al. (2010) S	Sna	Sna	Sna		
	2	7	7	7	6

Table 2: 11 studies that were included in the five reviews in alphabetical order.

Study	Subjects, control group (CG)	Study design, intervention	Results (violations, statistical significance), remarks
Amako et al. (2003)	901 healthy male Japanese recruits between the ages of 18-25 years, stretching group (N = 518), control group (N = 383)	- Stretching group: static stretching before and after training -18 exercises: 4 for the arms, 7 for the legs and 7 for the trunk - Each 30 s., A total of 20 min. - 3 months of training	- 114 injuries (58 in intervention, 56 in control group) - The frequency of muscle injuries (3), tendon injuries (10) and back muscle injuries (4) is significantly lower in the stretching group ($p < 0.05$) than in the control group muscle injuries (8), tendon injuries (14) and back muscle injuries (8) - Overall injury rate is almost the same in the two groups - Static stretching cannot prevent bone and joint injuries
Arnason et al. (2008)	Professional soccer	1999-2002, 1999-2000: baseline; Hamstrings strains, 3 treatments: 1) Pre 3 x 30 s CR-stretching, 2) post 3 x 55 s CR, 3) Eccentric strength training	**No difference** in the incidence of hamstring strains between the 7 teams that used the flexibility training program and those 7 who did not, **nor** was there a difference compared with the baseline data; Eccentric strength training with Nordic hamstring lowers combined with warm-up stretching appears to reduce the risk of hamstring strains (-65%)
Bixler and Jones (1992)	3 high school football teams: 28 games with intervention CG: 2 high school football teams: 24 games without intervention	Warm up (1.5 min) and stretching (1.5 min) at half time, one season	108 injuries, 38 (35%) of them strains and torn ligaments In the intervention group with a strain / torn ligament significantly less after treatment than in the CG (13); **Note**: 1) It is impossible to distinguish between the effects of warming up and stretching, 2) **Sprains and torn ligaments are not recorded separately**

Cross and Worrell (1999)	195 College Football-players, 2 seasons	1st season without stretching, 2nd season of static stretching (3 x 15 s. Posterior and anterior thigh muscles, adductors, calf)	1st season: 155 injuries, 43 (27.7%) muscle tendon strains 2nd season: 153 injuries, 21 (13.7%) muscle tendon strains The difference (- 48.8%) in muscle tendon strains was significant
Dadebo et al. (2004)	30 football teams	Survey, One season	1435 injuries, 479 (33%) strains, of which 158 (11%) in the hamstrings; Predictors for multiple regression (R^2 = 0.79): 1. Use of a standard stretching program (40%), 2. Hold time (29%), 3. Stretching method (10%, static stretching or PNF)
Ekstrand et al. (1983)	6 intervention soccer teams (90 players), 6 control teams (90 Players)	Multi component (7 parts) with warm-up + CR stretching (10 min. pre, adductors, quadriceps, hamstrings, iliopsoas, calf and < 5 min. post), 6 months	74% fewer muscle strains (control: 23 injuries, Intervention: six P < 0.001), 75% fewer injuries (control: 93 injuries, intervention: 23 P < 0.001); the effect on muscle injuries was likely attributable to the warm-up and stretching as opposed to other components of the intervention (equipment, taping, rehabilitation, information => multicomponent intervention), **causal connection from stretching to strains likely, but not certain**
Hadala and Barrios (2009)	Intervention-group: 28 sailors (Professional Yachting), control: 30	Active stretch. + PNF-stretch., 30 min, trunk, upper & lower body stretches (20-30 s), 2 seasons	81% fewer muscle injuries (intervention: 4, control: 22), intervention consisted stretching exercises before the yacht race **and preventative taping** => multicomponent intervention
Hartig and Henderson(1999)	150 recruits CG: 148 recruits	Stretching group and CG stretched five 30-second static stretches of the hamstrings 3 times a day for 13 weeks	In the stretch group with 25 overuse injuries significantly less than in the CG (43) Extension group improved BRW by 7 °, CG: 3 °; **Note: muscle strains and other injuries not recorded separately**

Jamtvedt et al. (2010)	1220 intervention, 1157 control, 2/3 female, age ø 40 years, physical activity: running (32%), training in a gym (31%), cycling (14%).	Internet-based survey, pre- & post-SS, 7 lower body muscle groups, ~14 min, 12 weeks, median of 4 times per week	25% fewer muscle, tendon, ligament injuries, Number of injuries in the stretching group with 133 per 1000 test persons, in the control group with 177, risk of getting one injury per year in the stretching group 0.66, in the control group 0.88.
Pope et al. (2000)	735 recruits CG: 803 recruits	11 weeks, 1 time 20 s, (rear and front thigh muscles, adductors, calves, hip flexors), survey of all subjects: height, weight, age, 20 m sprint time	333 injuries, 158 in stretching group, 175 in CG, 214 soft tissue injuries, 94 in the stretching group, 120 in the CG, differences not significant, 35 (10.5%) strains; 14 in stretching group, 21 in CG; **Note: strains are not evaluated separately**, predictors for injuries: 20m time, age, season; bad fitness (bad 20m time) strongest predictor
Van Mechelen et al. (1993)	159 runners CG: 167 runners	Survey; the 159 runners were informed about proper warm-up and stretching (10 min, 4 muscle sizes), after which a diary was kept for 16 weeks.	49 injuries, 26 in the intervention group, 23 in CG, no difference between the groups, 16 (33%) of the 49 injuries are strains, **Note**: 1) The control group also stretched to the same extent, **2) Sprains are not evaluated separately**

Table 3: Prevalence of acute musculotendinous injuries in intervention (stretching) versus control Conditions and the associated relative risk.

	Stretching Conditions		Control Conditions		**Relative Risk**	
Reference	n	# injuries	n	# injuries	**95% CI**	
Amako et al. (2003)	518	3	383	8	0.28	0.07-1.04
Cross & Worrell (1999[a])	195	21	195	43	0.49	0.30-0.79
Jamtvedt et al. (2010)	1000	133	1000	177	0.75	0.61-0.92
Pope et al. (2000)	735	14	803	21	0.73	0.37-1.42
TOTAL	**2448**	**171**	**2381**	**249**	**0.67**	**0.55-0.80**

[a]Longitudinal trial

Table 4: Incidences of musculotendinous injuries in the four studies, numbers in bold are given in the relevant publication, the other numbers are calculated.

	Amako et al. (2003)	Cross & Worrell (1999)	Jamtvedt et al. (2010)	Pope et al. (2000)
Injuries per person-year without stretching	0,09	0,22	**0,88**	0,13
Injuries per person-year with stretching	0,025	0,11	**0,66**	0,09
Difference in injuries per person-year	0,065	0,11	0,22	0,04
Reduction of injuries in %	72,3	**48,5**	25	27,2
Years to avoid injury	15,3	8,86	4,55	25,97
Injuries per 1000 hours	No information	No information	No information	0,6

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