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The effect of stretching on sports performance and the risk of sports injury: A review of the literature

Abstract

It is generally accepted that increasing the flexibility of a muscle-tendon unit allows a better performance and decreases the number of injuries. Stretching is regularly included in warm-up and in cooling-down exercises. However, contradictory findings have been reported in the literature. Since 1980, several authors have suggested that stretching has a beneficial effect on injury prevention. In contrast, since 1990, clinical evidence suggests that stretching not only does not prevent injuries, but can also decrease the level of performance. Some part of these contradictions can be explained by the various sports activities and the eclectic group of athletes studied. Sports activities requesting an increased flexibility, such as gymnastic, dancing, ice skating or diving, necessitate pre-exercise stretching to optimize the level of performance. In contrary, for sports with slow stretch-shortening cycle (SSC) such as jogging or cycling, there is no scientific data showing a positive effect of stretching on performance, injury prevention and recovery.
On the basis of the literature this article reviews the interest of the pre- and post-exercise stretching on the different modalities such as range of motion improvement, injury prevention and capacity of recovery.

Résumé

Il est indéniable que l'apparition des étirements dans les années '80 a constitué un progrès dans la préparation physique des athlètes, qui se sont ainsi intéressés à leurs différents groupes musculaires et mobilité articulaire. Subjectivement, il a été admis que le stretching pouvait améliorer la capacité de performance et aussi diminuer le risque de blessures liées à l'activité physique. Depuis lors, les exercices de stretching ont largement été inclus dans l'échauffement pré-compétitif et dans la récupération post-exercice. Cependant, dès le début des années '90, ont paru quelques études mettant en doute l'utilité du stretching dans la prévention du risque de blessures. Elles ont même pu démontrer que le stretching pouvait aussi diminuer la capacité physique dans certains types de sport. Une partie de ces études contradictoires peut être expliquée par les différents types de sport impliqués. En effet, les activités physiques qui requièrent une importante mobilité articulaire et musculaire comme la gymnastique artistique, le patinage, la danse ou le plongeon bénéficient avantageusement des effets des étirements musculaires alors que des sports tels le jogging ou le cyclisme peuvent au contraire en pâtir.
Le but de cet article est d'effectuer une revue de la littérature et d'examiner dans quelle mesure les exercices sont utiles dans les domaines de l'amélioration de l'amplitude articulaire, de la prévention du risque de blessures et de la récupération post-effort.

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Stretching before participation to physical activities is a standard practice for all levels of sports, competitive or recreational. Physicians, physiotherapists and trainers recommend stretching in order to enhance performance and prevent injuries. Consequently, stretching exercises are regularly included in warm-up and cool-down exercises. Numerous articles have been devoted to this topic, providing a variety of approaches for specific sports activities [1]. As more people participate in sports activities, injury prevention becomes more important. Today, however, the scientific evidence of injury prevention by a routine practice of a pre- or post-participation stretching seems unclear. Moreover, stretching exercises could negatively affect the performance [2, 3].

In fact, techniques of stretching, which initially had for objective the improvement of the articular flexibility, have been gradually allotted of quasi universal virtues of warm-up, recovery and muscle force improvement as well as the prevention of accidents.

Using MEDLINE from 1966 to September 2004 with searched terms: «stretching, injury prevention, sports injury», 373 articles were identified. These were reporting about flexibility, risk factors for injuries, alternative approaches to stretching, effects of stretching on sports performance and adverse effects of stretching and flexibility.

The purpose of this article is to review the pertinent literature on stretching and:

– flexibility improvement
– risk factors for injury
– performance
– recovery.

The contrasting results concerning the relationship between stretching and those different aspects can be explained by the difference in the types of sports studied in the current literature.

Stretching to improve flexibility

Flexibility is an intrinsic property of the body tissues that determines the range of motion achievable without injury at a joint or group of joints. There are several methods of stretching aimed at improving flexibility like passive, static, isometric, ballistic and proprioceptive neuromuscular facilitation (PNF). Passive and PNF techniques require a second person with specific skills. PNF techniques might increase the risk of injuries because of the resulting increase in stretching tolerance. That method is the most

effective to improve the range of motion. Static stretching is the easiest and the most frequently used method [1]. The practice of ballistic stretching has caused some connective tissue damage and has fallen out of favour [4].

The literature on flexibility includes 27 studies looking at the effects of diverse methods of stretching on joints and muscles. Whatever was the technique used to test the flexibility, stretching was demonstrated to increase mobility about the knee, hip, trunk, ankle and shoulder including muscle and connective tissue. Although there is evidence that PNF is more effective in improving flexibility [5, 6, 7, 8, 9], the apparent result might be related to other factors like posture during stretching [10]. A 15-s or 30-s passive stretch is more effective than shorter duration stretches [11] and as effective as stretches of longer duration [12]. Passive stretching is more effective than dynamic. The efficiency of different protocols such as timing of rest periods, placement within a workout schedule and repeated passive stretching have also been tested. The duration of improved flexibility after stretching program is from 6 to 90 minutes [13], although an extensive program of several weeks duration had produced increased mobility that persists for several weeks [14].

In summary, according to the data currently available in the literature, one can say that stretching techniques are effective in improving the articular and muscular amplitude. This improvement is temporary except in the case of intensive exercises of stretching. However, stretching can have side effects in particular on sports performance as it will be discussed later.

Stretching and warm-up in preventing injury

What is the interest of stretching during the preparation to a competition? The defenders of the stretching affirm that the stretching allows a rise in the local temperature in the stretched muscles. In fact, the rise in the muscular temperature depends on vascularization. The latter is optimized by an alternation of contractions and muscular relaxation. However, the stretching causes an increase in the muscular tension which involves an interruption of blood circulation, therefore a reverse effect to what is researched [15]. Preparation for athletic activity often includes both stretching and warm-up, making it difficult to assess their independent effects on injury prevention. Stretching increases flexibility but has not been shown to prevent muscle soreness [16]. Stretching combined with warm-up, strength and balance training seems to prevent ankle and knee injuries, but the independent effects of warm-up and stretching were not determined [17, 18].

Stretching and athletic performance

Recent studies have shown a negative effect of pre-participation stretching on sport performance. These negative influences concern performance in speed (running economy), in strength (strength deficit up to 1 h), and especially in jump.

Stretching and sprint

Wieman and Klee [19] showed that the passive stretching negatively influences the level of performance in serial sprints. Athletes were enrolled in an experiment where they achieved a 15 minutes stretching session of the flexor and extensor muscles of the hip, followed by sprints of 40 meters. The stretching group saw its total time increased by 0.14 seconds (thus performed less quickly), whereas the control group which did only a slow race between the sprints did not present any significant increase in the time of race (+ 0,03 s).

Stretching and force

A study by Fowles et al. [20] on the plantar flexor muscle showed that the prolonged stretching of a muscular group decreased firing (EMG) and contractile force of the stretched group. This decrease of force is still present an hour after the end of the stretching. The reduction in muscle firing is quickly recovered (15 mn) but the contractile force remains 9% inferior to the control group up to 60 minutes post-stretching. Kokkonen [21] has tested the effect of introducing two protocols of stretching in the warm-up before a test of one Maximum Repetition (1 RM) applied to the extensor and flexor muscles of the knee. He noted a significant decrease in the force produced after passive as well as active stretching when compared to the reference group (without stretching). Nelson [22] confirmed this decrease in force after having tested the ballistic stretching. The decrease was 7 to 8% for the extensor and the flexor muscles respectively. He concluded that stretching before competitions which require an important level of force should be avoided.

Stretching and force endurance

Kokkonen et al. [21] showed that an excess of stretching can reduce the performance in force-endurance. Stretching before a test for maximal repetitions in hamstrings significantly reduced the number of well-coordinated movements. Based on their results, the authors suggested it is not advisable to perform stretching exercises before force-endurance competitions, such as rowing.

Stretching and quality of jump

Henning and Podzielny [23] have shown a 4% decrease in height jump performance and explosive force, after a warm-up containing stretching exercises, when compared to a control group (without stretching). Other studies have confirmed that stretching before jumping tests is detrimental. Knudson et al. [24] showed a slight decrease in results when vertical jumps were performed following a warm-up including stretching exercises. Church et al. [25] investigated different protocols of warm-up: general warm-up alone, warm-up and static stretching, warm-up and PNF. The group that performed stretching with PNF technique demonstrated significantly lower performances in vertical jumps. The authors thus concluded that using this technique during the warm-up has to be avoided. Finally Cornwell et al. [26] investigated the effects of passive stretching on the performance in squat and in countermovement jump (CMJ). They noted a significant decrease in the CMJ performance, but without a fall in muscle stiffness and activation (EMG).

Stretching and risk of injuries

Before discussing the available literature looking at the relationship between stretching and injury prevention, we need to understand how stretching can reduce the risk for athletic performance.

The compliance of the «muscle-tendon» unit is essential. According to Safran [27], the ability of a muscle to absorb energy depends upon both components: the muscle and the tendon. When the contractile elements are active to a high level, more energy can be absorbed by a compliant tendon tissue, thereby reducing the exposition of muscle fibres to trauma. In case of low compliance of the tendon, the forces are transferred to the contractile apparatus. After stretching of the muscle-tendon unit, we observe a lengthening of the tendinous fibres which loose their effectiveness for shock absorbance. This phenomenon (creeping effect) is reversible and persists more than one hour after stretching [28]. The energy is thus transmitted directly to the muscle fibres with an increased risk to generate a muscle injury and a reduction in flexibility. In contrary, a more compliant tendon with greater energy-absorbing capacities may reduce the risk of muscle damage. Based upon these considerations, stretching exercise seems not to be recommended in case of warm-up before training.

For years, it has been considered that stretching during warm-up had a positive effect on injury prevention [1]. However, several studies showed the opposite. In 1993, van Mechelen et al. [29] studied the effect of a health-education intervention on jogging

Author	Year	Study design	Population	Study group	Outcomes
Pope [30]	1998	Randomized trial	1093 army recruits in 26 platoons in 12-wk basis training	1) 2, 20-s stretches of calf before rigorous exercise (549 recruits in 13 platoons) 2) 2, 20-s stretches of wrist and triceps before rigorous exercise (543 recruits in 13 platoons)	1) 23 lower-extremity injuries 2) 25 lower-extremity injuries
Pope [31]	2000	Randomized trial	1538 army recruits in 39 platoons in 12-wk basis training	1) 735 recruits in 19 platoons, 29 sec supervised stretches of 6 major leg muscle groups before each physical training session 2) 803 recruits in 20 platoons, no stretching program	1) 158 lower-limb injuries (21%) 2) 175 lower-limb injuries (22%)
Cross and Worrell [32]	1999	Retrospective cross-sectional series	195 college football players 1994 and 1995 season	1) 1995 season: static stretching program prior to conditioning training 2) 1994 season: no stretching program	1) 153 injuries (21 lower-extremity injuries) 2) 155 injuries (43 lower-extremity injuries)
Hartig and Henderson [45]	1999	Randomized trial	298 army recruits in two companies	1) 148 recruits: static hamstring stretch, 3 times daily 2) 148 recruit controls: no stretching program	1) 25 lower-extremity overuses injuries (17%) 2) 43 lower-extremity overuses injuries (29%)

Table 1: Results of interventions studies to determine the effectiveness of stretching in the prevention of injuries, adapted from Stephen B. Thacker [44]

injuries. The intervention consisted of information, education, and a standardised protocol including warm-up, cooling-down and stretching exercises. 421 male joggers were randomly included into an intervention and control group. After analysis of a 16-week diary where both groups reported their running distance and injuries, the authors did not identify any evidence of a reduction of soft tissue damage in the intervention group, and concluded that the intervention was not effective in reducing the number of jogging injuries. In two studies, Pope et al. evaluated the effects of stretching in military trainees during a 12 weeks period [30, 31]. In the first one, the participants were split in two groups, a control group and a stretching group. At the end of the observation time, 214 musculo-skeletal injuries were identified, but no significant difference was found between the two groups. In the second one, six different muscle groups of the lower limb were tested with the same protocol. The results did not demonstrate any difference.

Finally, Cross [32] studied the physical preparation of American football players. In 1994, there was no stretching in their physical preparation, whereas the following year stretching was introduced in the preparation. In 1994, 153 injuries were found, 43 in lower limb; in 1995, 155 injuries were found, 25 in lower limb.

On the basis of these studies, there is no sufficient evidence to suggest that stretching is effective in preventing lower limb injuries in sports with low stretch-shortening cycle, such as jogging, swimming and cycling.

The inefficiency of stretching to prevent injury can be explained by different reasons:

– the antalgic effect of the stretching
– the microtrauma generated by the stretching
– the loss of coordination antagonist-agonist.

Shrier [2] explained the antalgic effect of the stretching by an improvement of the stretch tolerance. The subject stretches further because he becomes accustomed to pain. Pain receptors are like «anaesthetized» and this explains the feeling of well-being after stretching.

According to Wiemann and Klee [19], passive stretching can induce an identical increase in muscular tension as maximal muscle contractions. The contractile elements can be over-loaded, and therefore damaged (microtrauma), leading to an alteration of the functional performance by the stretching. The authors have studied the effects on an eccentric training in female gymnasts. After the training, one lower limb was treated with passive stretching, whereas the other not. Two days later, the stretched limb was significantly more painful than the one non-stretched.

Moreover, according to different authors stretching can affect the agonist-antagonist compliance increasing the risk of injuries: over-stretched hamstrings are not ready to stabilise the thigh during a sprint.

Stretching and recovery

It is usually admitted that stretching is necessary and essential to facilitate a good recovery after a competition or training. Current studies do not confirm this statement. However, there are three aspects in the recovery process, where stretching has been shown to be effective:

– an increase in blood circulation in the stretched muscles which would facilitate the elimination of possible waste
– prevention or reduction of the Delayed Onset Muscle Soreness (DOMS)
– an action on the viscoelastic properties of muscles (reduction in the stiffness or possible tensions, as well as an improvement in the relaxation).

a) Stretching and vascularization

For Freiwald et al. [34], the static stretching compresses the capillaries and thus decreases blood circulation, what is the exact opposite of the needs of recovering muscle. Schober et al. [35] tested the effectiveness of the three methods of stretching on the recovery of the quadriceps. They noted that the long static stretching and stretching with the PNF technique do not help recovery (the static stretching had even a negative effect). Only the intermittent «dynamic» stretching made it possible to improve recovery. Stretching does not certainly constitute the best means to facilitate blood drainage.

b) Stretching and prevention of the DOMS

It is well-known that eccentric work causes DOMS. It is for this reason that experiments relating to muscle pain are designed with

this type of work. Some authors have tested the effect of stretching previous to an effort; others after the effort, and finally other authors during exercise.

– Pre-exercise stretching

Johansson et al. [36] studied the effect on the occurrence of DOMS of 4 stretching exercises of 20 seconds on hamstrings of one leg only before an eccentric training. No difference was noted between the stretched leg during warm-up and the control leg. In another experiment, Wessel and Wan [37] also noted the inefficiency of stretching before exercise.

– Post-exercise stretching

After a 30 minutes training session containing eccentric exercises on quadriceps and triceps muscles, Buroker et al. [38] studied a group of athletes that performed static stretching. No pain attenuation was noted in the 3 days following the session when compared to the control group. They also observed an increase in CK (Creatin Kinase) and a decrease of force in painful thighs. They concluded that stretching had no effect on DOMS. In a second experiment, Wessel and Wan [37] also tested the effect of stretching after exercises. No significant effect was found.

– Stretching during exercise

In a study by Wieman et al. [19], athletes were performing, during training sessions of force, passive stretching on one leg only. This has resulted in a more painful stretched limb than the unstretched one. Passive stretching adds microtraumatisms to the eccentric effort and worsens the myolysis.

c) Stretching and action on the visco-elastic properties of muscle

If stretching has no effect in improving recovery, there are, however, arguments to explain the positive effect of stretching in getting a better muscle relaxation post-exercise.

Physical activity increases passive stiffness of the muscle. This stiffness is more increased after concentric and isometric contraction than after eccentric contraction. After a competition such as football, muscle stiffness increases dramatically. Magnusson showed that stretching can decrease the muscle stiffness without altering the visco-elasticity [39].

Discussion

This review of the available information demonstrates that stretching is important to athletic performance by increasing muscle-joint mobility. Studies also suggest that great lack of mobility increases the risk of injury. However, within limits of normal flexibility, there is no evidence in the literature for a preventive effect of stretching on the occurrence of athletic injuries. Dynamic range of motion is greater than static range of motion due to the enhanced tissue elasticity and to the relaxation of opposing muscles during activity [40].

Qualitative flexibility is important in sports activities such as gymnastic, diving, ice skating or dance. At the same time, it is not clear whether there is a flexibility threshold for optimal performance or if additional mobility is necessary [41]. In any case, several studies seem to indicate that performance might be decreased at the limits of flexibility.

The president of the Council for Physical Fitness and Sports [42] recently wrote that not only stretching might not prevent the risk of injuries, but it might also compromise performance. Several animal studies suggest that stretching does not protect against acute strains [8]. Several theories explain how performance could be compromised, the rate of injury be unaffected and even increased as a result of stretching exercises [2]. These theories include decrease of joint proprioception and decrease of ability of tendon and muscle tissue to absorb energy, therefore leading to injury. Finally, because most injuries occur during eccentric contractions within a normal range of motion, it is not clear how the increase in range of motion brought by stretching will decrease the risk of injury [2].

According to this author [2], the basic science literature suggests five reasons to explain the lack of efficient prevention of pre-exercise stretching on injuries. 1. In animals, immobilization and heating-induced increase in muscle compliance causes tissues to rupture more easily; 2. Stretching before exercise has no effect in activities in which excessive muscle length is not requested; 3. Stretching does not affect muscle compliance during eccentric activity, when most strains occur; 4. Stretching can produce damage in the cytoskeleton; 5. Stretching appears to mask muscle pain in humans.

Looking at all these studies, there is no evidence strong enough to completely disqualify the recommendation of pre-exercise stretching. Furthermore, there is no study that has examined subpopulations of stiff athletes who might be at higher risk of injury, and thus might benefit of stretching. Finally, none of these studies compared the severity of injuries in experimental versus control groups.

There is evidence of effectiveness to prevent injury in various approaches of conditioning; warm-up and stretching combined with strength, plyometrics and proprioceptive training has shown to enhance performance and to prevent injuries [43]. In addition, stretching of specific muscles and joints for specific activities might increase their effectiveness, an approach consistent with multifactorial model for prevention. At the same time, stretching without adequate warm-up might impair the level of performance.

Further research on various stretching techniques on muscles and joints is urgently required. This will provide reliable information to physicians, physiotherapists and coaches in order to give the appropriate recommendations to their athletes.

In conclusion, there is no sufficient evidence to endorse or discontinue routine pre- or post-training stretching to prevent injury among competitive and recreational athletes. Further researches are needed to evaluate the real effect of stretching in sports. At this point, the data in the literature is conflicting. The aetiology of injuries is multifactorial. Taking out only stretching and examining its role on the incidence of injuries is a rather narrow outlook on this problem.

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