Does Stretching Improve Performance?

A Systematic and Critical Review of the Literature

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Objective: The purpose of this article was to evaluate the clinical and basic science evidence surrounding the hypothesis that stretching improves performance.

Data Sources and Selection: MEDLINE and Sport Discus were searched using MeSH and textwords for English-language and French-language articles related to stretching and performance (or performance tests). Additional references were reviewed from the bibliographies and from citation searches on key articles. All articles related to stretching and performance (or performance tests) were reviewed.

Main Results: Of the 23 articles examining the effects of an acute bout of stretching, 22 articles suggested that there was no benefit for the outcomes isometric force, isokinetic torque, or jumping height. There was 1 article that suggested improved running economy. Of 4 articles examining running speed, 1 suggested that stretching was beneficial, 1 suggested that it was detrimental, and 2 had equivocal results. Of the 9 studies examining the effects of regular stretching, 7 suggested that it was beneficial, and the 2 showing no effect examined only the performance test of running economy. There were none that suggested that it was detrimental.

Conclusions: An acute bout of stretching does not improve force or jump height, and the results for running speed are contradictory. Regular stretching improves force, jump height, and speed, although there is no evidence that it improves running economy.

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Although many clinicians and authors currently advise that stretching prevents injury,[1–3] recent reviews[4,5] have suggested that stretching immediately prior to exercise does not prevent injury. However, there is some weak evidence that stretching at other times may indeed prevent injury.[6]

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*Tables 1 to 4 cited within the text are available via the Article Plus feature at www.cjsportmed.com. Please go to the September/October issue and click on the Article Plus link posted with the article in the Table of Contents.

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Although clinicians are now generally aware of the issues related to stretching and injury, many authors also recommend stretching to improve performance.[7–9] If stretching decreases muscle stiffness (via changes in passive visco-elastic properties), less energy is required to move the limb, and force/speed of contraction may be increased. Alternatively, decreased stiffness may decrease storage of recoil energy, which would lead to greater energy requirements. If performance is enhanced, the issue of increased risk of injury may be moot for some persons.

Because of the nature of research, we can never test actual competition performance with appropriate scientific rigor. Therefore, we rely on tests of performance that relate directly or indirectly to sport performance. The closer the test is to the performance required, the more relevant the test. For example, running speed over 50 m would be considered very relevant if the race distance interested in was 50 m, and less relevant if the race distance interested in was 1000 m. In addition, running speed in a race is dependent on force generated, speed of contraction, running economy, and psychology. Therefore, results from tests of only 1 of these (e.g., only force, only running economy) have to be interpreted with caution. That being said, some sports can often be categorized as a combination of single activities. In basketball, both speed and jump height are direct skills that affect the ability to perform, and in this case, results of performance tests become very relevant measures on their own.

Therefore, this article reviews the evidence on whether acute or regular long-term stretching affects tests of sport performance. For brevity, *performance* is used instead of *tests of performance* throughout the article.

METHODS

MEDLINE and Sport Discus were searched for all clinical articles related to stretching and performance using the strategy outlined in Table 1.* All pertinent articles from the bibliographies of these clinical articles were reviewed. A citation search was performed on the key articles found in each search. Articles were separated into those that investigated the effects from an acute bout of stretching (i.e., within 60 minutes of stretching) and those that investigated the effects of regular long-term stretching over days to weeks. Study designs included only randomized controlled trials, cross-over trials (each subject is used as his/her own control), and repeated-measures studies.

Results in the tables are presented as they were in the original articles. To compare results across studies in a figure, the relative effect (e.g., $MVC_{stretch}/MVC_{control}$; maximum voluntary contraction) is also reported. Where not given in the article, the relative effect was estimated as (mean $post_{stretch}$)/(mean $post_{control}$), which is not equivalent to the true relative effect (i.e., the relative effect should be calculated for each individual, and then the mean should be taken). In simple pre-post studies, the relative effect is simply (post-pre)/pre. Because it is not possible to calculate the confidence intervals without the raw data, the figures display only point estimates.

RESULTS

There were 23 studies (24 articles; 1 study published results in 2 articles) that investigated the effects of an acute bout of stretching and 9 studies that investigated the effects of repeated stretching after days to weeks.

Does Pre-Exercise Stretching Improve Performance?

A detailed summary of each study examining the acute effects of stretching on force, torque, and jump can be found in Table 2,* and those examining running can be found in Table 3.* Figures 1, 2, and 3 illustrate the effects of an acute bout of stretching for MVC, jump height, and isokinetic torque, respectively. The results of the effects on isometric force, isokinetic torque, and jump height are summarized below. The effects on running are discussed separately because the studies present conflicting results.

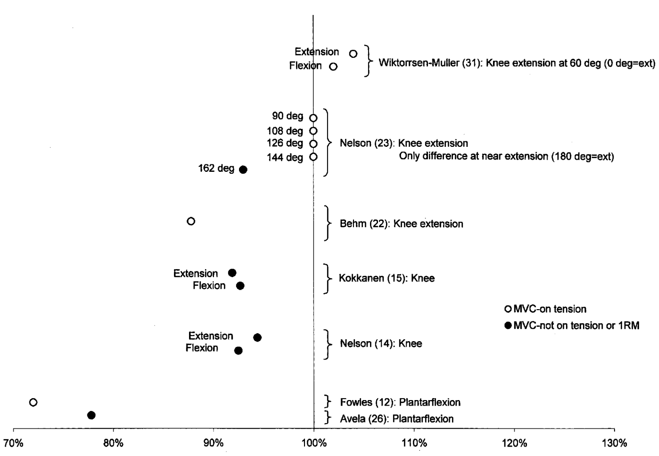

FIGURE 1. Isometric MVC or 1 repetition maximum (1RM) of the stretched leg as a percentage of the unstretched leg is plotted for all studies investigating an acute bout of stretching for which it could be calculated. Studies are divided according to whether the muscle was on stretch at the time it was being tested. In studies in which the results were not presented as a percentage of the unstretched leg, the means were used to estimate the true value (i.e., the mean of the individual subject percentages is not mathematically equivalent to the percentage calculated based on the mean changes across individuals).

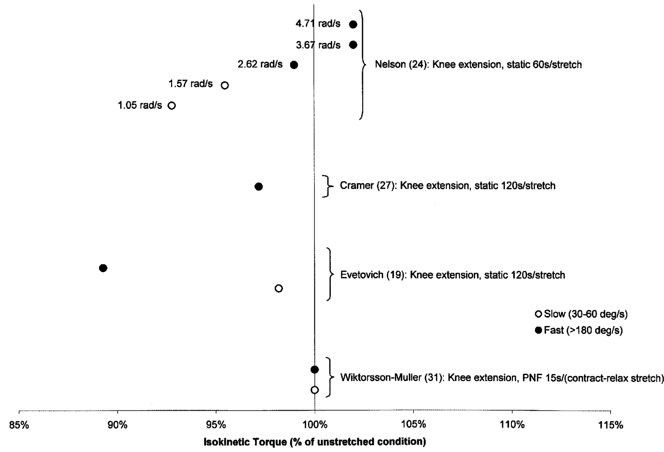

FIGURE 2. Isokinetic torque of the stretched leg as a percentage of the unstretched leg is plotted for all studies investigating an acute bout of stretching for which it could be calculated. Studies are divided according to whether the isokinetic testing speed was slow or fast. In studies in which the results were not presented as a percentage of the unstretched leg, the means were used to estimate the true value (i.e., the mean of the individual subject percentages is not mathematically equivalent to the percentage calculated based on the mean changes across individuals).

Force, Torque, and Jump: Positive Studies

There were no studies that suggested that stretching is beneficial for these aspects of performance.

Force, Torque, and Jump: Negative Studies

There were 20 studies (21 articles; 1 study reported results in 2 separate articles[10,11]) that found that an acute stretching session diminished performance.[10–29] The measures included MVC, power, jump height, jump force, and jump velocity. One of these studies found static stretching detrimental for jumping, whereas dynamic stretching had no effect.[29]

If stretching increases compliance, it is possible that the muscles' length-tension curve is shifted. This might lead to changes in MVC when the muscle is in a short position but not when tested in a position of tension (i.e., still on the plateau of the length-tension curve). Stretching decreased MVC only when the muscle was not on tension in 1 study on knee extension.[23] In the only other study looking at joint positions, this did not occur.[12] In this latter study, the plantar flexors were tested with the knee at 90° flexion and the ankle at 0°, 10°, and 20° dorsiflexion. The object of the study was to test the soleus muscle (on/off tension at different positions used). However,

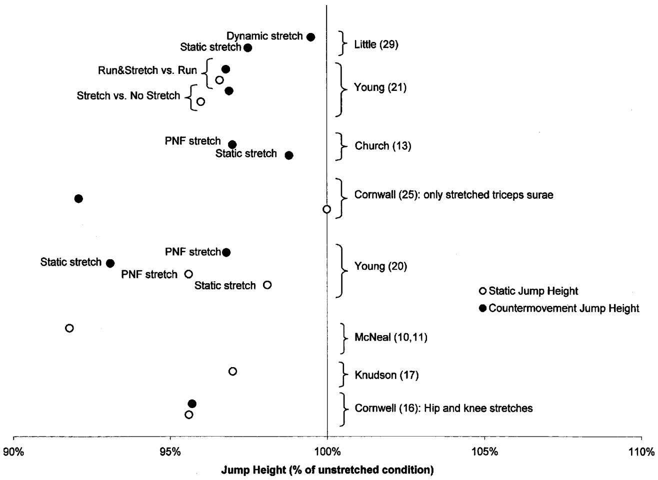

FIGURE 3. Jump height of the stretched leg as a percentage of the unstretched leg is plotted for all studies investigating an acute bout of stretching for which it could be calculated. Studies are divided according to whether the authors tested static jump height (i.e., jump from a stationary position) or countermovement jump height (i.e., subjects lower themselves toward the floor and then jump in 1 smooth motion). Tests that measured drop jump height (i.e., jump height after jumping down from a small height) were considered countermovement jumps for presentation on this graph. In studies in which the results were not presented as a percentage of the unstretched leg, the means were used to estimate the true value (i.e., the mean of the individual subject percentages is not mathematically equivalent to the percentage calculated based on the mean changes across individuals).

the gastrocnemius muscle was not on tension at any position, and therefore, its force production would have been decreased at all ankle angles.

One study reported that the diminished performance was limited to slow contraction speeds during isokinetic testing,[24] but another study found the effect at multiple joint velocities.[27] Both studies used similar ranges of velocities (results at very high velocities demonstrate more variability[30]), and there was no apparent methodological difference that would explain this discrepancy.

There was a decrease in the EMG in 4 studies[12,21,22,26] but not in a fifth.[19] The time spent stretching in the study without a decreased EMG was similar to some of the studies that showed a decrease in EMG, suggesting that this was not the reason for the difference. The duration of the effect on the EMG was variable. Where only 1 limb was stretched, the EMG decreased in the unstretched leg with knee isokinetic testing[27] but not in the study measuring MVC of the plantar flexors.[26]

Force, Torque, and Jump: Equivocal Studies

There was 1 study[31] suggesting equivocal results. The measured outcomes included isometric force and isokinetic torque.

Running

Of the 5 studies on running (Table 3;* 2 of these also reported on force, torque, or jump), 1 examined running economy, and 4 examined running speed. Although stretching improved running economy, the study population was limited to subjects with tight hip flexor or extensor muscles.[32] Because running speed is dependent on economy and force, this is only indirectly related to athletic performance.

Of the 4 studies that directly examined running speed, 2 studies had equivocal results. In 1 study, the numbers were very small (only 4 subjects in the study by de Vries[33]), and the results from the Pyke[34] study were reported only as not significant, without giving the actual numbers.

The 2 remaining studies contradicted each other. In the study showing a detrimental effect, stretching was 30 seconds, repeated twice,[28] compared with 30 seconds once for the study showing a beneficial effect.[29] Electronic timing was used in both studies. One study measured professional soccer players, and the other measured varsity athletes. Finally, the study showing that stretching was detrimental used static stretching, and the study showing that stretching was beneficial showed greater benefits with dynamic stretching compared with static stretching. Of note, although not statistically significant, the study that showed that stretching was beneficial for running had also showed that static stretching decreased jump height by 2.5% ($P = 0.07$), which is the same magnitude found in other studies. Dynamic stretching had resulted in only a 0.5% decrease in jump height.

Summary of Clinical Evidence

All but 1 study found that an acute bout of stretching diminished performance tests of force, torque, or jumping, or that there was no clinically relevant difference. The effects were observed for (1) static, ballistic, and proprioceptive neuromuscular facilitation (PNF) stretches; (2) males and females; (3) competitive and recreational athletes; (4) children and adults; (5) trained or untrained subjects; and (6) with or without warm-up. Similar results were found across study designs. There was limited research on the effect of the muscle's preexercise tension and of contraction velocity.

With regard to running speed, the results are conflicting. Variables that differed between studies included stretch time and dynamic versus static stretching.

Does Regular Stretching Improve Performance?

A detailed summary of each study examining the effects of repeated stretching over days to weeks can be found in Table 4.* Figures 4 and 5 illustrate the effects of regular stretching for MVC and isokinetic torque, respectively.

Positive Studies

There were 7 studies suggesting that regular stretching improves performance.[30,35–40] The measures of performance

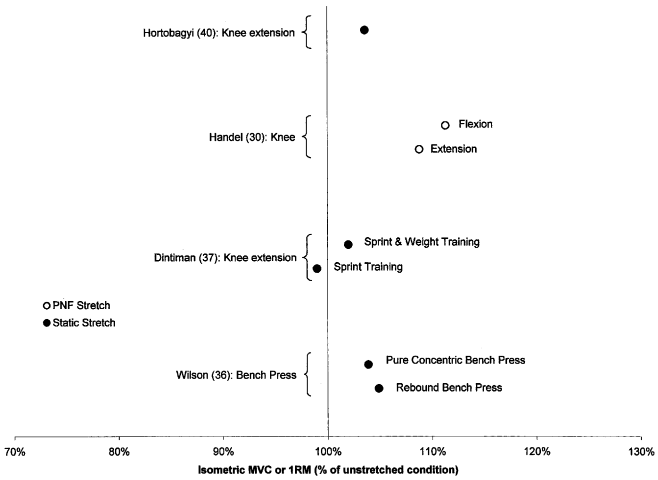

FIGURE 4. Isometric MVC or 1 repetition maximum (1RM) of the stretched leg as a percentage of the unstretched leg is plotted for all studies investigating a regular stretching over a period of days to weeks in all studies for which it could be calculated. Studies are divided according to whether the person performed PNF or static stretching. In studies in which the results were not presented as a percentage of the unstretched leg, the means were used to estimate the true value (i.e., the mean of the individual subject percentages is not mathematically equivalent to the percentage calculated based on the mean changes across individuals).

included MVC, contraction velocity, both eccentric and concentric contraction force, counter-movement jump height, and 50-yard dash.

Negative Studies

There were no studies that suggested that regular stretching diminishes performance.

Equivocal Studies

There were 2 studies suggesting neither an improvement nor a diminished performance.[41,42] Both of these studies were randomized cross-over studies, and both examined economy of motion. A third study that had found an increase in force also did not find an increase in running or walking economy.[35]

Summary of Clinical Evidence

Overall, the evidence strongly suggested that regular stretching increases isometric force production and velocity of contraction. The 3 studies investigating running economy found no effect. In the 1 study measuring 50-yard dash time, regular stretching improved performance. This suggests that contraction velocity or force is more important than running economy for short sprints. Whether this is also true for longer distances remains to be determined. The wide variety of patients and measures suggests that the performance benefits of regular stretching are robust. Populations included high school students to seniors, competitive athletes, recreational athletes, and males and females. Similar results were found across study designs.

DISCUSSION

A review of the clinical evidence strongly suggests that pre-exercise stretching decreases force production and velocity of contraction for at least part of the range of motion (ROM), and that running economy is improved. The effect on running speed remains to be determined, with 1 study suggesting that stretching is beneficial, 1 suggesting that stretching is detrimental, and 2 equivocal small studies. The effects of regular stretching are exactly opposite: regular stretching improves force production and velocity of contraction but has no effect on economy of motion. These results are consistent with the basic science evidence and mirror the results observed with respect to stretching and injury.

Acute Stretching

An acute bout of stretching decreases the visco-elastic behavior of muscle and tendon.[43–46] Because the stiffness is decreased, it requires less energy to move the muscle. This is consistent with the clinical finding that running economy is improved with an acute bout of stretching.

The mechanism by which stretching would be detrimental in tests of performance related to force produced is most likely related to damage caused at the time of the stretch. The basic science literature suggests that strains as little as 20%

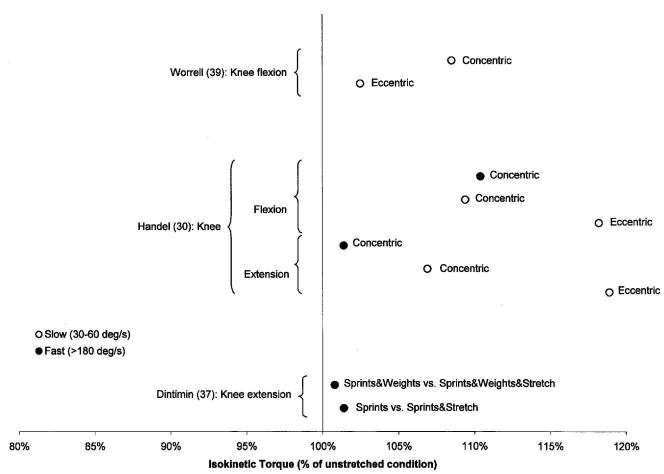

FIGURE 5. Isokinetic torque of the stretched leg as a percentage of the unstretched leg is plotted for all studies investigating a regular stretching over a period of days to weeks for which it could be calculated. Studies are divided according to whether the isokinetic testing speed was slow or fast. In studies in which the results were not presented as a percentage of the unstretched leg, the means were used to estimate the true value (i.e., the mean of the individual subject percentages is not mathematically equivalent to the percentage calculated based on the mean changes across individuals).

beyond resting fiber length can cause muscle damage, resulting in decreased force. A 20% strain occurs in some sarcomeres with regular walking[47] and therefore is certainly to be exceeded by normal stretching routines. Further, Black and Stevens[48] found that an acute bout of stretching (5% beyond resting length) in mice results in approximately 5% decline in isometric force (control group). However, there was no work deficit when the muscles were stimulated to contract and allowed to shorten. Finally, EMG was affected in most studies, and this may suggest that a neurologic mechanism is possible. More experiments using similar methodology and varying the parameters are needed.

The mechanism by which stretching would affect running speed is more complicated. Running speed is dependent on running economy, force produced, and velocity of contraction. This review found that running economy is improved (most likely due to decrease in visco-elasticity[43,49]), but force and velocity of contraction are decreased (most likely due to minor muscle damage[47,48]). The overall effect on running speed is therefore likely to be dependent on the balance of these factors within any particular individual. That being said, the 1 article that found that stretching improved running speed found that dynamic stretching was superior to static stretching.[29] Although the authors of this study did not measure ROM, previous studies found that dynamic stretching increased ROM much less than static stretching (4.3° vs. 11.4°).[50] This strongly suggests that the effects seen were not due to increased ROM and therefore were not due to improved visco-elastic properties or running economy. Because dynamic stretching also requires the muscles to contract, other possible mechanisms include central programming of muscle contraction/coordination and decreased fatigue through increased warm-up activity.

Regular Long-Term Stretching

Although the immediate effects of stretching decrease visco-elasticity and increase stretch tolerance, the effect of stretching over 3 to 4 weeks appears to affect only stretch tolerance, with no change in visco-elasticity.[51,52] Therefore, one would not expect to see a change in running economy; the clinical evidence supports the basic science evidence.

The mechanism by which regular long-term stretching improves performance is likely related to stretch-induced hypertrophy. When a muscle is stretched 24 hours per day, some hypertrophy occurs even though the muscle has not been contracting.[53–55] If stretching a muscle group for 30 to 60 s/d over months also results in hypertrophy, one would predict an increase in force and contraction velocity; this was observed in every study that investigated these outcomes. That being said, Black et al[56] stretched mouse hindlimbs for 1 minute every second day for 12 days and did not find any difference in peak force between stretched and unstretched legs (data obtained prior to the eccentric contraction-induced injury in the study). As the effect on running speed is a combination of force (increased), velocity of contraction (increased), and running economy (no change), the overall effect should be an increase in running speed. This was observed in the 2 studies that used running speed as the outcome.

Limitations

All of the studies in this review used human data. Although most studies used a randomized cross-over design (the strongest evidence of causality), some studies used a pre-post design. Results were generally consistent across designs.

There are many different ways to stretch. Static stretching was used in most of the studies, but the effects were observed with PNF stretching as well. Dynamic stretching is a combination of both stretching and warm-up (i.e., muscle is contracting). This review found that the effects were consistent across different modes of stretching for isometric force, isokinetic torque, and jump height. Although different modes of stretching in running produced conflicting results, another methodological difference was the duration of stretch, with the longer stretch producing worse results.

It is not possible to blind a subject as to whether they stretched or not. However, in the 1 study in which subjects were asked, all believed that an acute bout of stretching would improve performance.[14] Where the results were in the opposite direction of the prior beliefs, lack of blinding could only mean that the effect was even greater than we observed, and that it is likely that an acute bout of stretching affects performance through physiological and not psychologic mechanisms.

The subject population is a very important variable to consider. These studies found similar results across gender, age, and level of athletic talent. This also suggests the results are due to basic physiological changes that occur in the muscle, a hypothesis that is supported by the basic science evidence on stretch-induced muscle damage and stretch-induced hypertrophy.

There were no studies using injured subjects. An acute stretch can produce an analgesic effect,[44–46] which may in itself improve performance in injured athletes. For example, the stretch-induced analgesia may minimize pain-induced muscular inhibition, and this could theoretically improve performance in an injured athlete. However, the analgesic effect of stretching may also affect other nerves aside from pain fibers (e.g., proprioceptive nerves), and the overall effect of stretching in this population remains to be determined. Finally, the improved performance, if it did occur, might be at the expense of an increased risk of injury. The advantages and disadvantages of stretching need to be weighed for each athlete, including but not limited to competition level, competition timing (e.g., early or late in the season), and nature of injury.

Although several measures of performance were used in these studies, including isometric force, isokinetic torque, jump height, jump velocity, and sprint speed, these do not cover all aspects of performance. If a hurdler cannot get his or her leg over the hurdle without stretching, then an acute bout of stretching will improve performance regardless of its effect on force or sprint speed. In addition, stretching may be a mode of relaxation for some subjects, and this may affect performance within a competition. If this were a mechanism of improved performance, then stretching should be compared with other methods of relaxation for clinical effectiveness.

Finally, the author did not systematically review the stretch-shorten cycle research. A muscle that contracts immediately after a stretch (e.g., jumping up immediately after landing from a short jump) produces more force than a muscle that was not stretched. This is an important phenomenon but unrelated to the clinical effects of pre-exercise stretching. That being said, the effect of stretching on jump height was similar in subjects who began from a stationary position (static jump height) and those who used a stretch-shorten cycle (countermovement jump and drop-jump; Fig. 3).

In summary, the evidence suggests that stretching immediately prior to exercise decreases the results on performance tests that require isolated force or power. The effect on running speed remains to be determined. On the other hand, regular stretching will improve the results for all activities. This is similar to the fact that stretching immediately prior to exercise does not reduce the risk of injury, but that regular stretching may reduce the risk of injury.[6] Therefore, if one stretches, one should stretch after exercise, or at a time not related to exercise (the relative benefit of each remains unstudied at the present time). Future research should investigate the cellular and molecular mechanisms by which the effects of stretching occur, whether the added benefit of regular stretching is as effective as other types of performance-enhancement exercises being promoted (e.g., plyometrics, increased weight training), and whether the same effects are seen in the presence of injury.

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