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REVIEW ARTICLE

Acute Effects of Stretching on Flexibility and Performance: A Narrative Review

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Abstract
Passive and active stretching techniques have been shown to increase both chronic and acute range of motion (ROM). Acute ROM improvements can be countered by decreases in muscle performance, primarily after prolonged static stretching (SS) and proprioceptive neuromuscular facilitation (PNF) techniques when not incorporated into a full warm up procedure. In contrast, ballistic stretching and dynamic stretching techniques typically induce either an increase or no change in muscular force and power. This review explores studies that have investigated stretching responses on ROM, muscle functionality and performance. Collectively, the literature demonstrates that prolonged acute SS and PNF stretching can elicit the greatest changes in flexibility, but without additional dynamic activities (i.e. full warm up) can induce neuromuscular force and power output impairments, while increasing ROM and some sports specific performance. Muscle response to stretching may be determined by the manipulation of confounding variables such as duration, population, volume, test specificity and frequency. An increased dosage of some of these variables during stretching in isolation, augments ROM increases while attenuating muscle force output, except for stretching intensity which may lead to similar responses. Populations with high flexibility may have positive effects from stretching when tested on their sport specific performance, while general population may suffer greater negative effects. Not controlling these variables during stretching protocols may lead to misleading information regarding its effects on muscle performance.

Keywords Passive stretching · Active stretching · Range of motion · Performance

Introduction

Stretching is a technique used to increase muscle joint range of motion (ROM) [1–3]. Passive and active static, and dynamic stretching techniques were developed to increase levels of ROM and improve specific sport techniques [4–6]. Although, passive and active static stretching (SS) techniques seem to provide the greatest changes in ROM, it is also well documented that they can acutely induce impairments in muscle performance [1, 7]. Therefore, dynamic stretching techniques have preferably been added to athletes' routines since it consists of more sport or action specific dynamic movements and leads to increases in body temperature [1, 8, 9], which can decrease tissue viscosity and increase neural conduction velocity [1, 2, 10, 11]. It has also been suggested that dynamic stretching does not induce impairments or may even increase muscle power output [2, 4, 8, 12, 13]. However, coaches need to consider a variety of complex variables in order to decide what technique is more beneficial for performance, as intensity, duration, volume, athletic background, task specificity and frequency may play a major role in these stretching responses.

Longer periods of SS (> 45–60 s) may induce greater decrements in muscle force output, which may be due to neurological impairments such as decrements in spinal excitability, increased pre-synaptic inhibition or disfacilitation of reflex-induced afferent excitability [14–18]. These

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negative effects generally last only for short periods of time before there is a return to baseline values [19]. Conversely, there are reports of static stretch-induced impairments persisting for 2 h [20] and up to 24 h [21].

However, duration may not be the only factor to influence stretching effects. Some studies have reported that performing daily stretching exercises compared to 3 times per week lead to greater ROM achievements [6, 22]. Therefore, participants who have been well familiarized with stretching exercises and have been performing them in their daily routines for years may have induced plastic (semi-permanent) changes in their elastic structures. These changes in their elastic structures may protect their muscles from stretching induced decrements when the task is specific to their training.

However, a plethora of research investigating stretching effects in muscle tendon passive structures does not support the idea of morphological changes [23–26]. These morphological adaptations to elastic structures, such as ligaments, tendon, muscle, fascia and skin, may only be seen after long stretch training interventions (> 8 weeks) [26, 27]. These changes are also not supported by the idea of sex differences, as females and males seem to respond similarly to stretching interventions. Nevertheless, a similar stretching response curve exists between sexes, as females have a greater tolerance to stretching exercises [28]. Additionally, populations that have been exposed to stretching interventions since an early age, such as dancers, figure skaters and gymnasts, may respond differently to stretching effects in muscle performance [3, 29]. There are also some studies that support the idea that stretching techniques provided no negative effect in specific testing task. Therefore, the stretching effects may have a carry-over effect according to the condition that is performed, intensity, duration, background and stretching mode [30].

The objective of this narrative review is to highlight the effects of different stretching modes on muscle performance output, as well as all the variables that influence these changes, such as volume, intensity and frequency, which may be different depending on the population being tested.

Stretching Modes

Stretching is a technique that involves lengthening musculotendinous and other elastic structures over the joint for a short period of time (30–60 s), thus aiming to enhance joint flexibility [2, 7, 31]. Many different stretching techniques have been performed within different populations. These stretching techniques can be classified as passive, and active static, dynamic, and ballistic stretching.

Passive and Active Static Stretching

Passive SS is defined as elastic structures being stretched by an external force with no rate change for a period of time. Active SS is similar except the individual exerts their own force (i.e. antagonist muscles, use the arms to pull the lower limbs or use body mass to help elongate musculotendinous tissues). SS consists of lengthening the muscle towards the end of range of motion (ROM) till experiencing near or maximal point of discomfort and holding this position for an extended period of time (i.e. 15–60 s) with no additional forces applied [2, 7]. This technique has been incorporated as one of the most popular warm-up routines and can be performed individually to improve joint flexibility.

Proprioceptive Neuromuscular Facilitation (PNF)

There is a body of research showing that proprioceptive neuromuscular facilitation (PNF) may be a more efficient technique for achieving greater levels of ROM [5, 32, 33]. This involves two main techniques; contract relax (CR) and contract relax antagonist contract (CRAC) [5, 34]. CR consists of a pre-muscle contraction while the muscle is held at a lengthened position, followed by a passive stretch. The CRAC technique includes the same principle as the CR, however this is performed over a cycle of two or more times [34].

Dynamic Stretching (DS)

Dynamic stretching (DS) involves performing movements over a full or nearly full ROM [1, 6]. These movements are typically performed under controlled conditions (moderate to relatively rapid angular velocities). However, the emphasis is on a controlled motion. Although SS techniques lead to positive and significant ROM improvements, it is well documented that prolonged SS leads to decrements in muscular performance and muscle force output [7, 35, 36]. Therefore, many coaches and exercise professionals have opted for prescribing active DS techniques rather than SS, since some studies show similar ROM improvements with no changes in muscle performance between both techniques [37, 38]. Chow et al. compared the effects of active, passive and PNF stretching techniques in the ROM of the knee flexion movement. They found that all the stretching techniques increased knee ROM, with no differences between these techniques. Due to the reports of SS- and PNF-induced performance impairments over the last 20 years, DS has experienced a surge in popularity especially with athletic warm-ups that do not have high levels of flexibility as the main training focus.

Ballistic Stretching (BS)

Ballistic stretching (BS) involves rapid and active movements throughout the entire joint ROM [1, 6]. This technique is typically a highly sport specific related activity. However, there are some misunderstanding in the literature when differentiating DS versus BS effects on ROM and muscle performance [6]. BS consists of repetitive and fast movements at the end of the ROM [3, 39]. However, there seem to exist a greater risk of injuries with this technique with individuals that are not well familiarized or have low flexibility levels [40].

Stretching and Performance

Stretching Effects on Force

SS has been incorporated in warm up routines as one of the most popular stretching techniques for years in athletic and non-athletic populations who aim to increase ROM and muscle performance [5, 41]. However, a consistent body of research has agreed that longer periods of SS (> 60 s) cause impairments in muscle performance, such as decreases in maximal force output, explosive force, power, balance, reaction and movement time in trained, untrained and recreationally active populations [7, 31, 35, 42]. Studies investigating PNF stretching have demonstrated that this technique can induce similar decrements in force and power output compared to SS [43, 44]. Myahara et al. [45] reported that whereas PNF provided greater ROM improvements than SS, both stretching techniques led to lower isometric maximal voluntary contraction (MVC) forces. Therefore, dynamic stretching techniques have become more popular since some studies have reported that BS and DS lead to less muscle performance impairments with similar ROM improvements as SS and PNF [3, 46]. A systematic review by Kay and Blazevich showed strength impairments from SS following longer periods (> 45 s) of SS. However, some studies have shown similarities in strength decrements between SS and BS. Lima et al. found similar decrements in hamstrings peak torque after more than 60 s of BS and SS stretching. However, SS has been reported to provide greater ROM than DS or BS by several studies [5, 35, 47].

Stretching Effects on Power

A few studies have shown performance decreases after DS and BS [13, 35, 36]. Behm et al. [31] reviewed 184 studies showing a decrease in squat power performance after DS stretching. They suggested that these impairments occurred due to the lack of specificity between the task and the DS stretching exercises. Although some studies have shown similar increases in ROM for SS, BS and DS [3, 5, 46], typically only trivial to small changes or increases in muscle power after BS and DS have been found [31]. Fletcher et al. [8] examined 2 sets of 10 repetitions of slow vs. fast DS on both countermovement jump (CMJ) and drop jump (DJ) heights in recreationally trained participants. They found that fast DS led to greater increases of CMJ and DJ performance and both stretching velocities led to 9.07%, 7.67%, 11.78% and 13.27% increases of knee ROM during CMJ and DJ, respectively. However, the DS exercises used in this research protocol seemed to be more focused on preparing the participants for the following exercises than for increasing ROM. Nevertheless, Unick et al. [48] found no changes of vertical jump height scores after 3 sets of 15 s of 4 SS and BS stretching exercises for gastrocnemius, hamstrings and quadriceps muscles in resistance trained women.

Behm et al. (2016), in a comprehensive meta-analysis, demonstrated that SS performed for long periods of time negatively impacts force production and power. This plethora of research evidence has influenced coaches to reorganize exercise routines avoiding the inclusion of SS [7, 27, 49]. Wallman et al. [50] compared the effects of SS, DS and BS on 40-yard sprint performance. They found a similar increase in the performance time. However, there is some evidence showing increases in ROM, power and strength after SS. Shrier et al. [51] in a review of 23 studies regarding the SS effects on performance, showed that SS improved force, speed and power. However, they did not provide information regarding the SS duration. Therefore, although a few studies have shown SS-induced improvements on performance [52], it seems to be well established that prolonged periods of SS decreases muscle performance [7, 31]. Stretching effects depend on a complex combination of factors, such as participants with different sporting backgrounds [3, 53], stretch intensity, volume, type, structure, progression and control [31]. All these variables can cause specific acute and chronic effects on muscle performance.

Stretching Within a Full Warm-up

One of the most important conclusions of the Behm et al. [1] meta-analysis was that although prolonged (> 60 s per muscle group) SS and PNF stretching when performed in isolation typically induce performance impairments, there is little evidence for these deficits when the stretching is a component of a full warm-up. The few studies that include post-SS dynamic activity do not report significant impairments [4, 54]. Recent studies incorporating all aspects of a full warm-up (i.e. aerobic activity, SS, DS, and dynamic sport specific activity) have not shown any performance deficits with a moderate duration of SS either [55, 56]. Although 60 s of SS per muscle group did not result in performance decreases with a full warm-up, more excessive SS of 2 min per muscle group could still induce some deficits [56]. Furthermore, while the inclusion of SS within a full warm-up did not enhance physical performance (nor impair it), there was a positive psychological effect as the individuals felt more confident of achieving high performance in the ensuing sports-related tests [55]. The meta-analysis from Behm et al. [1] also highlighted a number of common limitations of the typical stretching and subsequent performance studies published in the literature. Due to the expansive literature expounding on the SS and PNF-induced performance impairments, there could be participant bias as typically, the experimental subjects are often exercise science students who have read the literature and thus have an expectation of stretch-induced impairments. Janes et al. [57] tested this hypothesis by informing (deceiving) one of their experimental groups that SS enhanced performance and did find some small magnitude positive effects (increased leg extension force) after 3 repetitions of 30 s each of SS. Other limitations included the use of a non-stretch rest control condition [57]. This control period is not valid to determine whether stretching should be done as part of a pre-activity routine, because an individual would instead move to their activity and not remain inactive. Another listed limitation was that the details of non-significant changes were commonly not reported, and thus effects estimates would be biased towards the statistically significant results in the literature (i.e. SS-induced impairments). Finally, testing is often conducted immediately after the stretching intervention, whereas the typical routine would have a substantial period of time between the warm-up and the sport activity (i.e. equipment adjustments, final coaching tips, tactics or strategies, national anthem etc.) [1].

Stretching and Different Populations

High Flexibility Populations (*Dancers, Gymnasts and Figure Skaters)*

The majority of studies mentioned in this literature review may have a population bias. Whereas most studies use college aged, recreationally active populations, few studies have examined populations that are interested in stretching to achieve high levels of flexibility and ability to perform sport specific exercises. However, the acute negative effects from stretching may differ when performed by a highly flexible population [3]. Morrin and Redding [29] found no SS impairments on balance, vertical jump and ROM variables in dancers. They concluded that combining SS and DS can enhance performances of jump height and balance. Fletcher [8] and Lima et al. (2016) also found similar ROM increases and hamstrings peak torque decreases after BS and SS for both ballet dancers and resistance trained women [48]. Additionally, a review of different stretching techniques for dancers showed that the emphasis of DS was to prepare the joints and elastic tissues for the following exercises that would be performed during their routines [40]. It also often includes the same exercises performed during athletic routine and it can increase muscle and core (body) temperature [4]. BS is usually recommended for advanced dancers since it can help them achieve extreme levels of muscle length [40], however coaches may feel more comfortable in prescribing DS to their athletes, as BS may increase the risk of injuries such as muscle strains [5]. Although prolonged SS can cause acute muscle performance impairments in populations that do not stretch very often it may still be one of the superior techniques to improve flexibility in populations that stretch on a daily basis [47, 58]. More research is needed to examine the SS and DS dose response relationship of high flexible athletes compared to the average population in terms of ROM and possible subsequent performance impairments. However, as a reminder, there are no studies showing performance impairments when stretching is incorporated into a full warm-up [31, 55, 56].

Recreationally and Strength Trained Athletes

Nevertheless, for some sports, flexibility may not be the main training focus, as the main training aim is to achieve high levels of force, power and endurance. In these cases, it may be more suitable to perform a dynamic warm up rather than SS exercises [12]. However, the literature has not thoroughly examined athletic populations that start stretching at a young age with high volumes and intensities to attain the more extreme ROM needed for competition, such as gymnasts, ballet dancers, figure skaters, among others. Coaches select and classify their athletes for competitions based on many factors that are related to their anthropometric data, performance and psychological aspects [59–61]. However, in some specific sports, athletes can be selected to represent their institution or progress to a higher category according to their level of flexibility [60]. Therefore, performing only DS or simple stretching exercises during warm up routines may not be sufficient to achieve their desired levels of flexibility.

According to the concept of training specificity, strength and power training generate the greatest improvements when training is specific to the tasks performed in the sport or activity [62, 63]. For instance, Allison et al. [64] investigated the effects of prolonged static stretching on running economy and neuromuscular function in male runners. They found that maximal oxygen consumption values were not affected during the running tasks after 8 stretching exercises of 40 s each for quadriceps, hamstrings and plantar flexors. However, SS decreased isometric maximal voluntary contraction and CMJ by 5.5% and 5.6%, respectively. The disparity with these results may be attributed to the task specificity of the maximal oxygen consumption test for runners' performance versus a non-specific isometric MVC test. In contrast, Babault et al. [65] showed that general populations with either low or high flexibility levels decreased hamstrings peak torque after stretching [66]. However, the population that had high flexibility returned to the baseline peak torque levels faster than the population with low flexibility. Behm et al. [67] also investigated a short period of SS (3 × 30 s) in 9 males and 9 females. They did not find any correlation between changes in ROM and stretch impairments of CMJ, DJ and quadriceps and hamstrings MVCs. They also performed a short period of SS training (4 weeks 5 days per week) for quadriceps, hamstrings and gastrocnemius in 12 males not engaged in flexibility training. Participants performed the same SS volume as the acute study (3 × 30 s) and were similarly tested. The magnitude of stretching impairments on muscle performance remained the same even after the short stretching training protocol. The authors concluded that the extent of flexibility is not correlated to stretch-induced impairments. However, the stretch training protocol was performed for a short period (4 weeks), and previous studies have shown that this training period is insufficient to induce morphological changes [26]. Lima et al. (2016) also found that ballerinas, who are highly flexible, after performing BS stretching had greater endurance thus inducing less fatigue, which shows that task specificity seems to play a major role in the stretching responses.

Sex Differences

There is little evidence for sex specific ROM and morphological responses to stretching. Although there are some studies reporting that females may have greater levels of flexibility than males, these findings are attributed to females having greater tolerance to stretching than males. Marshall and Singer [68] evaluated hamstrings extensibility effects on stretch tolerance and passive stiffness between males and females. They did not find any differences between the sexes and passive stiffness. However, females had greater hamstrings extensibility values and lower pain scale values. There are many studies supporting the idea that females may have higher pain tolerance than males. In agreement with these findings, Hoge et al. [28] did not find any sex difference in passive stiffness. However, Ciprani et al. [69] investigated an 8 week stretching intervention and found that the individuals that stretched 6 times per week had greater hip ROM increases than the participants stretching 3 times per week, however there was no differences between sex. Therefore, stretching responses seem to be more dependent on training variables and background than sex-related.

Stretching Critical Variables

Some of the major variables underlying stretching effects are intensity, duration, frequency and volume. In a meta-analysis, Behm et al. (2016) concluded that these variables had a direct impact on the acute stretching effects. Unfortunately, many studies reported results of stretching effects without considering the control of some of these variables, which may lead to confounding effects. Therefore, it is still not known if there are any superior effects from one variable over the other. Therefore, manipulating duration, frequency and volume may induce different stretching responses.

Stretching Duration

Whereas Roberts and Wilson [70] showed that 9 SS of 5 s each provided similar increases in passive ROM as 3 SS of 15 s, the 15 s SS had significantly greater effects on active ROM than the 5 s SS. Bandy et al. [47] compared the effects of SS on hamstrings flexibility, which involved SS for 30 vs. 60 s, and 1 time vs. 3 times per day, and found that managing either duration or frequency led to similar results for increasing hamstrings ROM. In agreement with these results, Ogura et al. [71] found similar increases for hamstrings ROM between 30 s vs. 60 s of SS. However, they also reported a decrease of hamstrings maximal voluntary contraction (MVC) after 60 s of SS, although 30 s of SS did not impair hamstrings MVC. The literature seems to consistently agree that prolonged SS without a full warm-up acutely causes some decrements on muscle performance for general population [7, 31, 42]. Thomas et al. [6], in their meta-analysis, recommended a minimum duration of 5 min per week for each muscle group. In the meta-analysis from Behm et al. [1], the authors summarized the literature by stating "whereas single static stretches of 5 s can improve ROM, it is generally recommended that longer durations of 30–60 s provide optimal improvements in flexibility". However, stretching volumes and frequencies used in the typical research protocols are low compared to what athletes with high flexibility levels (e.g. gymnasts and dancers) usually perform. These recommendations may be more applicable to the general population. More research is needed to study the exceptional needs and demands of extreme flexibility athletes.

Stretching Intensity

The intensity of a stretching exercise is thought to be an important variable that modulates the effectiveness of the stretching protocol for improving flexibility [30]. Many coaches have prescribed a high intensity stretching exercise to their athletes, causing pain and muscle soreness to the joints [72]. The most common protocol to measure stretching intensity is a discomfort scale [30]. Participants are usually asked to perform stretching exercises at their maximal point of discomfort or mid-point of discomfort. Freitas et al. [30] found greater decreases of hamstring passive torque after a combination of long duration of 180 s of passive SS and low intensity that was classified at the mid-point of discomfort (50% of their maximal). A decrease of passive torque is highly correlated to greater muscle-joint compliance which leads to increases of ROM. Freitas et al. [73], in a second study, examined the effects of high intensity-moderate duration vs. low intensity-long duration hamstrings passive stretching with university students. The high intensity-moderate duration protocol consisted of stretching at their maximal point of discomfort for 90 s without rest and the low intensity-long duration was performed by stretching at their mid-point of discomfort for 900 s. While the high intensity—moderate duration protocol induced an increase in hamstrings peak passive torque, the low intensity-long duration did not demonstrate any increases of passive torque after 1 h of passive stretching. However, after 1 min of stretching the hamstrings muscles, passive torque decreased to a greater extent after low intensity-long duration protocol compared to high intensity-moderate duration. The authors suggested that duration may play a greater role than intensity, but that increases of hamstrings passive torque after the high intensity-moderate duration protocol may have occurred due to an increase of stretch tolerance. Additionally, the authors reported that duration may play a greater role on ROM and passive torque changes when stretching is performed at the mid-point of discomfort, as it seems to be more efficient than stretching at the maximal point of discomfort. Behm et al. [74] investigated the effects of three different stretching intensities (100%, 75% and 50% of point of discomfort) on countermovement jump, drop jump and squat jump, with university students. The SS protocol consisted of 4 sets of 30 s for quadriceps, hamstrings and plantar flexors. The different intensities (mid, submaximal and maximal point of discomfort) decreased DJ, SJ and CMJ height. However, they did not investigate ROM. These studies demonstrate that using a stretching intensity at the mid-point of discomfort may be a better strategy to increase ROM and to diminish power performance impairments. High intensity stretching appears not to lead to high magnitude changes in passive muscle stiffness and ROM.

Stretching Intensity and Duration

Young et al. [75] examined the effects of a combination of running and static stretching of four different durations and 2 intensities with dancers. Running + SS was performed at their maximal point of discomfort for the subsequent durations: one min of SS, 2 min of SS and 4 min of SS. The fourth condition was performed as 2 min of SS at 90% of their maximal point of discomfort. They concluded that none of the different stretching intensities and durations changed their ROM. However, running + 4 min of stretching led to greater impairments in drop jump jump height, whereas running + 2 min of stretching at 90% did not cause any impairments on drop jump performance. This study is in agreement with past studies that showed that stretching at the maximal point of discomfort may not be the most advantageous strategy to increase muscle performance [76, 77]. It is important to point out that these variables are extremely important for improving flexibility and influences on force, power and technical sport movements. In comparison to strength and power training programs, which are progressive and modulate training variables (i.e. intensity, volume, load) throughout their duration, flexibility training tends to remain fairly static over time in terms of types of exercises, intensities and durations.

Conclusions

Collectively, the studies included in this review provide insights into the acute effects of stretching on ROM and muscle performance, as well as the underlying variables. Unfortunately, it is beyond the scope of this article to review the fundamental neurophysiological mechanisms responsible for these adaptations. Stretching responses seem to be dependent on mode, population and testing specificity. Passive SS techniques elicit the greatest changes in flexibility while inducing lower force and power output values when practiced over prolonged periods (> 60 s per muscle group) and not incorporated into a full warm-up (5–10 min of aerobic activity, SS, DS and 5–15 min of sport specific dynamic activities). Passive SS may still be advantageous for highly flexible populations that focus on achieving high levels of ROM and improving technical sport tasks. Active dynamic stretching techniques may be the most effective to increase specific performance for athletic and general populations aiming to maintain moderate levels of ROM while avoiding performance decrements. Stretching responses may be underlined by confounding variables that can change the overall stretching response output, such as managing duration, volume, intensity and frequency. Thus, performing these variables at a greater level seems to cause an inverted relationship between ROM gains and muscle performance impairments. However, manipulating different stretching intensities may not elicit any different stimulus response to the muscle, such as increases in flexibility and performance. This may also be due to the lack of technology used to test this variable or participants not being well familiarized with different stretching intensities. Therefore, these variables should be controlled in research designs and training programs in order to generate valid and sensitive responses. Therefore, special consideration should be taken regarding the athletes' training background and objectives in order to decide the most advantageous method to manipulate the confounding variables to elicit an overall benefit from the stretching exercises.

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