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# THE CONTROVERSIAL CONTRIBUTION OF STRETCHING AND THE DILEMMA OF PREPARATION FOR SPORTS REQUIRING MAXIMUM FORCE PRODUCTION AND LARGE RANGE OF MOTION

**MICHAELA MILO[1]*, GHEORGHE MONEA[1], NAVOT MILO[1]**

**ABSTRACT.** The advantage of long static stretching is in the increasing of range of joint motion (ROM). However, the effect of static stretching on injury prevention has been found debatable while generally, most of the studies regarding this issue, claim for no effect. In addition, long static stretching has been found reducing maximum muscle voluntary contraction (MVC). The reasons for reduced MVC due to static stretching are both neural and mechanical: reduction of stretching effect, reduction in stretch shortening cycle (SSC) and reduction in musculotendinous stiffness. The contradictory effects of static stretching are creating a dilemma in sports that integrate MVC and large ROM. Therefore, the purpose of this article is to consolidate the information about the advantages and disadvantages of the stretching and to review the proposed solutions for this dilemma: Not to perform long static stretching immediately before the main activity, dynamic stretching are recommended instead; Intensive dynamic activity between the stretching and the main activity, may eliminates the impairing effect; Vibration or rolling a foam roller along the muscle may be a substitute for static stretching in term of increasing ROM without impairing MVC; And finally, it is best to perform static stretching as a separate training unit.

**Keywords:** *Static Stretching, Dynamic Stretching, Dynamic Warm-Up, Range of Motion, Maximum Voluntary Contraction*.

## Introduction

Long static stretching of the muscles on the one hand are increasing range of joint motion (ROM), and on the other hand reduces force production and maximum muscle voluntary contraction (MVC) of the muscles in which

[1] Babeş-Bolyai Universiry, Cluj-Napoca, Romania
*Corresponding Author: milomn@gmail.com*

stretching were performed. This creates a dilemma for athletes who engaged with sports that require a combination of large ROM and MVC (i.e. gymnastics, ballet, various fields in athletics, martial arts and more). The problem is how these athletes can increase ROM during warm-up process or at least not limiting muscle's force production by static stretching (Kinser et al., 2008)? Therefore, the purpose of this article is to consolidate the information about the advantages and disadvantages of stretching and to review the proposed solutions for the dilemma in which physical performances are integrating MVC and large ROM.

Muscle stretching has traditionally been part of the activity routine of many who engage in physical activity, either in physical activity for health purposes or in sports. Yet among many, stretching is part of the warm-up process before exercise, and for decades it has been considered as helping to improve performance (Behm & Chaouachi, 2011) and preventing injuries (Herbert & Gabriel, 2002). As part of the overall warm-up routine, the stretching usually takes place after a few minutes of light activity (usually jogging), followed by specific exercises that simulate the designated activity. Usually the warm-up aims are raising the body temperature, increasing the amount of synovial fluid in the joints, adjusting the neural system to the designated activity, injecting blood stream and oxygen into the muscles, increasing ROM and reducing the risk of injury (Young & Behm, 2002). However, it is unclear whether stretching contribute to the warm-up process.

The literature distinguishes between three types of stretching: **long static stretching**, which is performed by stretching the muscle to discomfort or pain zone, and staying there for 30 seconds or more - without movement or with light movement. These stretches are the only ones that improve range of movement in the joints (Behm & Chaouachi, 2011; Young & Behm, 2002); **Dynamic stretching**, which are carried out in the same way as static stretching, but last only a few seconds while performing several repetitions in slow movement (Fletcher & Jones, 2004); **Ballistic stretching**, which are carried out by a quick stretching that activates a reflex of defensive mechanism - which in turn contracting the muscle (Eldred, 1953).

## The benefits of long static stretching

The benefit of long static stretching, lasting longer than 30 seconds per set, is the chronic increase in ROM. Static stretching has an important health value and a primary value in sports where the ROM is an achievement component (Behm & Chaouachi,. 2011). The static stretching technique that is considered most effective is the Proprioceptive Neuromuscular Facilitation (PNF)

(Sharman et al., 2006; Marek et al., 2005; Bradley et al., 2007; Church et al., 2001). This technique is also considered the best for increasing ROM in a short period of time. There are two ways to accomplish this technique. One is stretching the muscle to the area of discomfort, In this area, a contraction of about three seconds should be performed with a force of about 20% of the maximum strength of the stretched muscle and then continue stretching the muscle further. The second, which is even considered to have better results, does not contract the stretched muscle but the antagonist muscle or the antagonistic muscle group. In order to achieve an effect over time, this protocol should be performed twice a week (Hindle et al., 2012).

### Stretching and injury prevention

Traditionally muscle stretching has been considered to prevent injuries. Despite this belief, studies have found that there is no direct link between stretching and preventing injuries (Rubini et al., 2007; Black et al., 2002; Herbert & Gabriel, 2002; Thacker et al., 2004; Pereles et al., 2012). Pope et al (2000), examined whether there is an effect of static stretching for legs muscles, as part of the warm-up of 1538 young recruits for the Australian army, on the prevention or reduction of legs injuries. The study argues for no impact on the reduction of injuries.

In contrast, Hartig & Henderson (1999) found that during 13-week infantry basic training course, troops that added three hamstring stretching sessions to their already scheduled fitness program, increased significantly hamstring flexibility and decreased significantly number of injuries resulting from an overuse and stiffness of lower limbs extremity. In addition, Amako et al (2003), found no significant difference in overall injuries among army recruits who performed static stretching by comparison to those who did not performed. However, among the recruits who did performed stretching, there were significantly less muscle/tendon injuries and low back pain. Stone et al (2006) summarize that acute stretching seems to have little effect on injury and chronic flexibility may have some injury reduction potential. Although most of the literature claims for no relation between stretching and injury prevention, further research is needed.

### The disadvantages of the static stretching

For many years, many athletes from various sports and physical activities have been using long static stretching as part of the preparation and warm up process for physical activities that require power. It turns out that this habit reduces MVC of the stretched muscle (Behm & Chaouachi, 2011). In measuring force production of the quadriceps, using interpolated twitch technique (Shield & Zhou, 2004) and surface integrated EMG, found 12% and 20% respectively, a reduction in MVC, after 20 minutes of static stretching to quadriceps muscle, versos quadriceps force production when no stretching performed before measurement (Behm et al., 2001). Fowles et al (2000), found that a bout of more than 30 minutes long static stretching, are impairment MVC immediately after long static stretching (28% reduction comparing to pre-force production test), after 5 minutes (21%), after 15 minutes (13%), after 30 minutes (12%), after 45 minutes (10%) and even after 1 hour (9% reduction) after the stretching.

In many of the field tests that examine leg's MVC, we measure and compare vertical jumps performed after different types of stretching. This is a simple and effective way, in addition to the fact that the vertical jump characterizes many sports. In many of the studies dealing with leg's MVC and those described below, it is customary to examine three types of high jumps from standing position: Squat-Jump (SJ), usually performed from a knee bending angle of °90, without the eccentric phase of the jump; Counter movement (CMJ), regular standing vertical jump, usually performed with arm kept on the waist; Drop jump (DJ), like CMJ but while jumping downward from height of 40cm usually. The CMJ and DJ jumps testing in addition to muscle's MVC, also the effect of stretching reflex that is affected by the muscles and tendon censors: Muscle spindles and Golgi tendon organs.

The stretching reflex occurs in muscles and tendons that are involved in jumping and at the end of the eccentric phase. The reflex is the beginning of the stretch shortening cycle (SSC). This effect also enables increased recruitment of the strong and fast muscle fibers of (FTb) and also the use of elastic energy, which is found in the elastic components that are part of muscles and tendons structure. These elastic components create a "spring" effect that contributes to the jump height. In contrast, SJ neutralizes SSC and isolate force production only, to determine height jump (Bosco et al.,1982; Bosco et al., 1986).

Young & Behm (2003), found decline in SJ and DJ immediately after a bout of long static stretching for the leg muscles involved in vertical jump. On the other hand, they found incline of SJ and DJ after running only and after long static stretching when between the stretching and the jumps, an explosive dynamic activity was performed. The researchers conclude that the explosive dynamic activity had a stimulating effect after the negative effect of the static stretching. Robbins & Scheuermann (2008), tested whether short static stretching, 15 seconds per set, will not impair SJ height. They found that two sets of short static stretching did not have any effect on SJ height but the more the stretching sets were multiplied, jumping capacity has decreased. The researchers conclude that if still a static stretching before a force-like activity such as vertical jump is desired, they should be carried out in one or two times only, for a short period of time for each set. This implies that even if the stretching is short and does not adversely affect the force production in the legs, it still does not have a positive effect on muscle force production.

Sim et al (2009), examined combinations of dynamic activity and static stretching before a repeat sprint test (20m X 6 times). The results of the slowest sprints were found when stretches were performed before and close to the sprints and the fastest sprints tests were achieved, whether before the sprints a dynamic activity only was performed or whether before the dynamic activity a bout of static stretches were performed. The researchers point out, therefore, that long static stretches may not impair the speed of a repeated sprint test if dynamic, extended, structured, and gradual activity was performed between them. This indicates that the weakening effect of static stretching is not chronic.

Wilson et al (2010), examined the effect of static stretching on distance runners. In a 30-minute run on a treadmill, the runners could follow the running time, increase or decrease the speed but not knowing the speed and the distance they have already run. In a different day, the same runners performed the same 30-minute run, under the same limitations but before the run they performed 16-minute static stretching. The running distance after the stretching was shorter. Cramer et al (2007), add that the static stretching performed before physical activity, weaken the muscle's MVC among all types of athletes, both those that are required for MVC and those are required for aerobic capacity.

In contrast to the findings that strongly suggest a decrease in muscle's MVC after long static stretching, a decline in balance functions after long static stretching is not unequivocal, although balance does not improve after these stretches. Behm et al, (2004), found a light decrease (9.2%) in balance test of standing on one leg, between pretest and posttest performed after static stretching of 45 seconds for major leg muscles. On the other hand, there was an increase of 17.3% in the balance test when between the two tests there was no-work interval. Costa et al (2009), also examined the effect of static stretching on balance functions, but compared the balance after sets of 45-seconds static stretching to the major leg muscles and the balance after sets of 15 seconds only. In contrast to the previous study, no balance effect was found after 45-second stretching test, however, short 15-second stretching sets resulted in an 18% improvement in balance test, a similar improvement to stretching after no-work interval in the study of Behm et al (2004).

Long static stretching in PNF technique is not different in their effect on muscle's MVC than all the long static stretching. They were also followed by a decrease in MVC (Marek et al., 2005; Sharman et al., 2006; Church et al., 2001; Bradley et al., 2007). Young & Behm (2003) recommend not to perform static stretching before an activity that requires MVC, such as jumping. They argue that one of the reasons for static stretching is reducing risk of injury, however, they say, a more significant factor in reducing the risk of injury during warm-up is raising muscle temperature, therefore, apart from increasing range of motion, the additional contribution of the stretching is questionable. Simic et al (2013), summarize dozens of studies of the immediate impact of static stretching on force production, noting the negative impact of these stretching. However, the effect of static stretching lasting less than 30 seconds should also be examined. The authors assume that the lengthening time in a state of muscle-stretching position of discomfort is a significant factor in the reduction of MVC.

**The reasons for reducing muscular force production as a result of prolonged static stretching**

The reasons for stretching induces muscle's force production impairment, can be divided into the mechanics of muscle activation and neuronal activation. Several researchers explain the mechanical reasons for reducing the ability: Kokkonen et al (1998), found that MVC of knee flexion and extension is decreased immediately after long static stretching quadriceps and hamstrings. These researchers find similarity between the results of their study and the findings of Wilson et al (1994), that indicate that the stiffer the musculo tendinous, the greater the ability to produce force.

Wilson et al (1994) and Fletcher & Bethan (2004), hypothesize that stretching exercises stimulate the elasticity of the elastic components in musculotendinous, resulting in increased compliance of these tissues, thereby moderating muscle force. This is similar to two identical engines that lift the same load in a very short time, but one connects directly to the load and the other connects to a spring that connects to the load. The first motor will probably lift the load faster. Herda et al (2008), hypothesize that reducing MVC due to static stretching is caused by an increase in muscle length beyond the optimal level of rest before the contraction of the sarcomeres, which prevents them from effectively extracting the force of contraction.

The neural factors for stretching induces muscle's force production impairment, associate with the mechanical factors: Fletcher & Bethan (2004); Behm et al (2001); Cramer et al (2007) and Herda et al (2008), note that increased compliance in muscle and tendons also impairs neural conduction to muscle cells and for this reason, reduces MVC. Evetovich et al (2003), measured MVC output in the biceps brachii in an action preceded by static stretching versus an action that did not precede stretching. The results of the Mechanomeography (MMG) showed insignificant differences between a biceps brachii MVC pretest and MVC posttest, when long static stretching performed between them. A significant increase in MVC was observed when between the pretest and the posttest there was a resting time instead of stretching. In this study, the researchers concluded that stretching reduces the recruitment of motor units (neural effect). Rosenbaum & Hennig (1995), found that static stretching slows down the stretching reflex, which stimulates the muscle spindles that under normal condition increases MVC in gastrocnemius, which actives in many physical activities including running and jumping. Moor (1984), also notes that stretching also inhibits the neuronal response of the Golgi system in the Achilles tendon, which has a similar role to the muscle spindles but in tendons.

**The dilemma of stretching in sports requiring large ranges of motion and maximum force production**

Because of the accumulated information about the acute impairing effect of long static stretching on MVC and force production, and because long static stretching are the only ones among other types of stretching that positively affect the increasing of ROM, the following dilemma arises: How long does this impairing effect continue? Are there any interventions (activities), placed between the long static stretching to the designated activity, which have the potential to eliminate the static stretching impairing effect? Is there a way to warm-up and yet to increase ROM without impairing MVC (Stone et al., 2006)? The continuation of the review will be focused on the dilemma and the solution suggested in sports that integrating ROM and MVC.

By comparison to no-stretching warm-up, McNeal & Sands (2001), found reduction of 8.2% in DJ height in female gymnasts, immediately after long static stretching for the extensor legs muscles. Costa et al (2010), found reduction of 8.75% in force production among jiu-jitsu athletes in 1 RM horizontal bench press, immediately after total 180s of stretching for the main muscle groups involved in the bench press. The authors indicate that static stretching is beneficial and important for gymnasts, jiu-jitsu and other martial arts athletes' flexibility. However, stretch training should not be placed before performance that integrates flexibility and force-like activity, which characterizes these sports.

Donti et al (2014), found that among artistic and rhythmic gymnasts, performing long static stretching for the legs, does not impair MVC performance, if after the stretching there is a potentiating activity like a series of tuck jumps. Moreover, after three sets of five tuck jumps, elite gymnasts can improve their ROM and CMJ average height. These finding corresponding the findings of Young & Behm (2003) which claim that in order to eliminate the weakening effect of the long static stretching, it is vital to perform between stretching and the next force-like activity, a series of dynamic and potentiating exercises.

By comparison to a concentrated rhythmic gymnastics warm-up exercises (i.e. 4-minute jogging warm-up period; 4minutes of plyometric training and hopping; 10 minutes of ballistic stretching for leg and back flexibility; 2 minutes of abdominal and dorsal muscle strength training). Di Cagno et al (2010), found a reduction in flight time (7.2%) among rhythmic gymnasts, immediately after a warm-up that consisted of multiple sets of long static stretching only. Because of the flight time reduction, judges graded lower a technical leap, which is also a combination of vertical jump and high-level flexibility.

These authors suggest that a warm-up before explosive gymnastic movements combined with high ROM level, should not be performed immediately prior to the gymnastics exercise. To maintain the high level of the gymnasts' flexibility during rhythmic gymnastics training session, ballistic stretching could be more appropriated (Di Cagno et al., 2010). Usually a warm-up for rhythmic gymnastics competition starts 30-60 before competition, by 15 seconds long static stretching. In the middle until the end of the warm-up, in addition to specific exercises, static stretching is alternated with dynamic stretching (Guidetti et al., 2009). The use of dynamic stretching will be detailed below.

One of the solutions for the decrease of muscle's MVC as a result of long static vibration, may be exposure the muscle to vibration. Rohmert et al (1989), found that the arm and shoulder muscles, respond to vibration by increasing MVC. RøNNESTAD (2004) found also that performing 1RM in squat on a vibration platform, followed by maximum CMJ, resulted by higher CMJ then performing CMJ after no-vibration with the same 1RM squat. Cochrane & Stannard (2005), found increase in ROM and vertical jump in female field hockey players, after a bout of vibration by standing on a vibration platform. A combination of vibration and long static stretching helps to increase ROM in highly trained male gymnasts (Sands et al., 2006). With the aim to find a method for integrating long static stretching in warm-up for gymnastics routines without impairing MVC, Kinser et al (2008) found that a combination of vibration and long static stretching helps to increase acute ROM in forward split position and not impairing vertical jump. SJ and CMJ, that performed immediately after bout of long static stretching with vibration, achieved similar jump height results as achieved in pretest.

Another alternative method for long static stretching in an aim to improve acute ROM without impairing maximum force activity, is rolling a foam roller in high-pressure along the muscle, instead of stretching it. MacDonald et al (2013), found that foam rolling for only 2 minutes enhances quadriceps muscle ROM to a similar degree as previously reported in other static stretching studies, and more importantly, the authors claim, it had no significant impact on quadriceps muscle force. Sullivan et al (2013) also found an increase in ROM and increase in MVC in hamstrings, immediately after rolling the foam roller along the hamstring muscle.

**Dynamic stretching as a substitute for static stretching**

In contrast to the ballistic stretching that stretches the muscle in a quick movement and activates the muscle spindles, which in a reflex arch, as a defense mechanism, creates fast contraction of the stretched muscle (Eldred, 1953), The dynamic stretching is performed as very short static stretching lasting about a second or two, then a slight relaxation, and so forth. Dynamic stretching takes about 12-15 repetitions per stretching set. The dynamic stretching leads to short stays in the muscle discomfort / pain situation, as opposed to the long and continuous stretch of the static stretching (Fletcher & Bethan (2004). Numerous studies have examined the effect of dynamic stretching in comparison to static stretching. In contrast to the unequivocal findings regarding the reduction in MVC after long static stretching, the findings of the effect of dynamic stretching are not unequivocal.

With regard to MVC, some of the researches claim for no change after performing dynamic stretching (Fletcher & Bethan, 2004; Herda et al, 2008) and more researches claim for MVC enhancement after dynamic stretching (Needham et al, 2009; Yamaguchi & Ishii 2005; Yamaguchi et al., 2007; Behm & Chaouachi, 2011; Hough et al, 2009; Cornwell et al., 2001; Kokkonen et al., 1998; Wallmann, et al., 2005). However, Pearce et al (2009); Fletcher & Bethan (2004) and Siatras et al (2003), claim for better improvement in MVC after dynamic activity and dynamic activity with large ROM respectively.

In an attempt to find a solution to increase ROM without impairing force production, Harper (2011), found that dynamic stretching can be beneficial before a performance of split jump, which is a combination of high vertical jump and large ROM. However, Behm & Chaouachi (2011), indicating that the purpose of dynamic stretching is increasing force production, while the increasing of ROM, as a result of dynamic stretching, is negligible. Artistic Gymnastics considered one of the important ROM and force-like sports. Siatras et al (2003), tested three different warm-ups before a handspring vault:

1) integrated long static legs stretching; 2) integrated dynamic stretching; 3) only dynamic warm-up. Among the three they found the slowest run speed before jump, measured after static stretching and the fastest run speed achieved after no stretching and dynamic warm-up.

## Discussion

Stretching muscles as part of the preparation for physical activity where maximum and sub-maximum force production are required is controversial. On the one hand, long static stretching, lasting more than 30 seconds per set, including PNF, significantly increases ROM (Sharman et al., 2006; Marek et al., 2005; Bradley et al., 2007; Church et al., 2001). This is important in terms of long-term health and because of the importance of large ROM that characterize sports and physical activities such as branches of gymnastics, ballet, various fields in athletics, martial arts and more (Behm & Chaouachi, 2011).

On the other hand, when static stretching is lengthening, or more sets of stretching are performed in close proximity to the main activity, then the more reduces the ability to produce maximum force in the stretched muscle. This is particularly significant in activities characterized by MVC and explosive force (i.e. jumping and sprinting) and even when generating sub-maximum force production, such as long-distance run (Behm et al., 2001; Young and Behm, 2003; Cramer et al., 2007; Sim et al., 2009; Kokkonen et al., 1998; Bradley et al., 2007; Wilson et al., 2010).

Most of the sports that engage with the combination of ROM and MVC are engage also with balance. It turns out that the static stretching, when carried out before and close to balance performance, have no beneficial effect. Although long sets of static stretching lasting more than 30 seconds did not significantly impair these functions but they also did not improve them. However, when static stretching of only 15 seconds per set was performed prior to balance exercise, balance enhancement was achieved, but similarly to enhancement achieved after no-stretching preparation (Behm et al., 2004; Costa et al., 2009). These findings raise the question of the necessity of static stretching in close proximity to activity requiring balance and proprioceptive functions (Evangelos et al., 2012), which are essential in the branches of gymnastics and other large ROM and MVC sports.

Unlike the traditional approach of stretching before exercise reduces risk of muscle or tendon injury, there is no unanimity regarding to injury prevention. Many researchers claim that the risk of muscle injury is the same whether or not stretching has been integrated in warm-up (Pope et al., 2000; Thacker et al., 2004; Pereles et al., 2012) and even under certain conditions, a risk of injury may be increased as a result of routine performance of static stretching before activity that requiring MVC (Gabbe et al., 2006). In contrast, some researchers claim for positive effect of stretching on injury prevention (Hartig & Henderson, 1999; Amako et al., 2003). The contrast of the findings implies that further research, regarding to the issue of stretching and injury prevention, is needed. This is because muscle or joint injury has variety of reasons. It is suggested that performing long static stretching as a training unit that is not integrated in warm-up for activity (Stone et al., 2006), possibly reduce the likelihood of certain injuries in certain sports (McHugh et al., 2010).

**The dilemma, how athletes can prepare themselves for optimal performance in optimal ROM and optimal MVC?**

- If long static stretching, including PNF, are necessary as part of preparation, it is recommended to perform it about an hour before the designated activity. In order to maintain flexibility during the rest warm-up time, it is recommended to perform ether ballistic or more important, dynamic stretching (McNeal & Sands, 2001; Costa et al., 2010; Guidetti et al., 2009; Di Cagno et al., 2010).
- Performing a bout of explosive force activities to the stretched muscles, for five/ten minutes between long static stretching and the designated activity, may eliminate the impairing effect of the static stretching (Donti et al., 2014; Young & Behm, 2003). However, it is not known whether carrying out the explosive activity reduces ROM in an acute manner.
- A combination of long static stretching with vibration or even vibration only, in preparation for designated performance may enhance ROM without impairing or even increasing MVC (Rohmert et al., 1989; RøNNESTAD, 2004; Sands et al., 2006; Kinser et al.,2008) and even reinforcing it (Cochrane & Stannard, 2005).
- Rolling a foam roller in high-pressure along the muscle is an effective substitute for stretching in relation to ROM as part of warm-up and preparation for designated activity, without impairing MVC (MacDonald et al., 2013), and even reinforcing it (Sullivan et al., 2013).
- Dynamic stretching is not increasing ROM but performing dynamic stretching as part of the preparation for designated performance may maintain ROM which achieved in different training unit or approximately an hour before the designated performance (Guidetti et al., 2009; Sands et al., 2006; Siatras et al., 2003).

- Dynamic stretching may also increase MVC (Needham et al, 2009; Yamaguchi & Ishii 2005; Yamaguchi et al., 2007; Behm & Chaouachi, 2011; Hough et al, 2009; Cornwell et al., 2001; Kokkonen et al., 1998; Wallmann, et al., 2005). However, dynamic activity and dynamic activity with large ROM may increase MVC to the same extant or even more (Pearce et al., 2009; Fletcher & Bethan, 2004; Siatras et al., 2003).

For summary, this data revealed that in order to achieve the benefits of the long static stretching, with regard to flexibility, it is best to perform it as a separate training unit and this is true for all sports and physical activity. With regard to the dilemma of sports and physical activity that integrate large ROM with maximum force production, although several solutions are proposed, little research has dealt with this dilemma and further research is needed.

## REFERENCES

Amako, M., Oda, T., Masuoka, K., Yokoi, H., & Campisi, P. (2003). Effect of static stretching on prevention of injuries for military recruits. *Military medicine*, *168*(6), 4 42.

Behm, D.G., Bambury, A., Cahill, F., & Power, K. (2004). Effect of acute static stretching on force, balance, reaction time, and movement time. *Medicine and science in sports and exercise*, *36*, 1397-1402.

Behm, D.G., Button, D.C., & Butt, J.C. (2001). Factors affecting force loss with prolonged stretching. *Canadian Journal of Applied Physiology*, *26*(3), 262-272.

Behm, D.G., & Chaouachi, A. (2011). A review of the acute effects of static and dynamic stretching on performance. *European journal of applied physiology*, *111*(11), 2633-2651.

Black, J.D., Freeman, M., & Stevens, E.D. (2002). A 2 week routine stretching program did not prevent contraction induced injury in mouse muscle. *The Journal of physiology*, *544*(1), 137-147.

Bradley, P.S., Olsen, P.D., & Portas, M.D. (2007). The effect of static, ballistic, and proprioceptive neuromuscular facilitation stretching on vertical jump performance. *The Journal of Strength & Conditioning Research*, *21*(1), 223-226.

Church, J.B., Wiggins, M.S., Moode, F.M., & Crist, R. (2001). Effect of warm-up and flexibility treatments on vertical jump performance. *The Journal of Strength & Conditioning Research*, *15*(3), 332-336.

Cramer, J.T., Beck, T.W., Housh, T.J., Massey, L.L., Marek, S.M., Danglemeier, S., ... & Egan, A.D. (2007). Acute effects of static stretching on characteristics of the isokinetic angle–torque relationship, surface electromyography, and mechanomyography. *Journal of sports sciences*, *25*(6), 687-698.

Cochrane, D.J., & Stannard, S.R. (2005). Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. *British journal of sports medicine*, *39*(11), 860-865.

Cornwell, A., Nelson, A.G., Heise, G.D., & Sidaway, B. (2001). Acute effects of passive muscle stretching on vertical jump performance. *Journal of Human Movement Studies*, *40*(4), 307-324.

Costa, E.C., dos Santos, C.M., Prestes, J., da Silva, J.B., & Knackfuss, M.I. (2009). Acute effect of static stretching on the strength performance of Jiu-Jitsu athletes in horizontal bench press. *Fitness & Performance Journal (Online Edition)*, *8*(3).

Di Cagno, A., Baldari, C., Battaglia, C., Gallotta, M.C., Videira, M., Piazza, M., & Guidetti, L. (2010). Preexercise static stretching effect on leaping performance in elite rhythmic gymnasts. *The Journal of Strength & Conditioning Research*, *24*(8), 1995-2000.

Donti, O., Tsolakis, C., & Bogdanis, G.C. (2014). Effects of baseline levels of flexibility and vertical jump ability on performance following different volumes of static stretching and potentiating exercises in elite gymnasts. *Journal of sports science & medicine*, *13*(1), 105.

Eldred, E., Granit, R., & Merton, P.A. (1953). Supraspinal control of the muscle spindles and its significance. *The Journal of physiology*, *122*(3), 498.

Fletcher, I.M., & Jones, B. (2004). The effect of different warm-up stretch protocols on 20 meter sprint performance in trained rugby union players. *The Journal of Strength & Conditioning Research*, *18*(4), 885-888.

Fowles, J.R., Sale, D.G., & MacDougall, J.D. (2000). Reduced strength after passive stretch of the human plantar flexors. *Journal of applied physiology*, *89*(3), 1179-1188.

Gabbe, B.J., Bennell, K.L., Finch, C.F., Wajswelner, H., & Orchard, J.W. (2006). Predictors of hamstring injury at the elite level of Australian football. *Scandinavian journal of medicine & science in sports*, *16*(1), 7-13.

Guidetti, L., Di Cagno, A., Gallotta, M.C., Battaglia, C., Piazza, M., & Baldari, C. (2009). Precompetition warm-up in elite and sub elite rhythmic gymnastics. *The Journal of Strength & Conditioning Research*, *23*(6), 1877-1882.

Harper, E.N. (2011). The effect of static and dynamic stretching on competitive gymnasts' split jump performance. (Doctoral dissertation, Miami University).

Hartig, D.E., & Henderson, J.M. (1999). Increasing hamstring flexibility decreases lower extremity overuse injuries in military basic trainees. *The American journal of sports medicine*, *27*(2), 173-176.

Herbert, R.D., & Gabriel, M. (2002). Effects of stretching before and after exercising on muscle soreness and risk of injury: systematic review. *Bmj*, *325*(7362), 468.

Herbert, R.D., de Noronha, M., & Kamper, S.J. (2011). Stretching to prevent or reduce muscle soreness after exercise. *The Cochrane Library*.

Herda, T.J., Cramer, J.T., Ryan, E.D., McHugh, M.P., & Stout, J.R. (2008). Acute effects of static versus dynamic stretching on isometric peak torque, electromyography, and mechanomyography of the biceps femoris muscle. *The Journal of Strength & Conditioning Research*, *22*(3), 809-817.

Hough, P.A., Ross, E.Z., & Howatson, G. (2009). Effects of dynamic and static stretching on vertical jump performance and electromyographic activity. *The Journal of Strength & Conditioning Research*, *23*(2), 507-512.

Kinser, A.M., Ramsey, M.W., O'bryant, H.S., Ayres, C.A., Sands, W.A., & Stone, M.H. (2008). Vibration and stretching effects on flexibility and explosive strength in young gymnasts. *Medicine & Science in Sports & Exercise*, *40*(1), 133-140.

Kokkonen, J., Nelson, A.G., & Cornwell, A. (1998). Acute muscle stretching inhibits maximal strength performance. *Research quarterly for exercise and sport*, *69*(4), 411-415.

MacDonald, G.Z., Penney, M.D., Mullaley, M.E., Cuconato, A.L., Drake, C.D., Behm, D.G., & Button, D.C. (2013). An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. *The Journal of Strength & Conditioning Research*, *27*(3), 812-821.

Marek, S.M., Cramer, J.T., Fincher, A.L., & Massey, L.L. (2005). Acute effects of static and proprioceptive neuromuscular facilitation stretching on muscle strength and power output. *Journal of Athletic Training*, *40*(2), 94.

McHugh, M.P., & Cosgrave, C.H. (2010). To stretch or not to stretch: the role of stretching in injury prevention and performance. *Scandinavian journal of medicine & science in sports*, *20*(2), 169-181.

McNeal, J.R., & Sands, W.A. (2001). Static stretching reduces power production in gymnasts. *Technique*, *21*(10), 5-6.

Needham, R.A., Morse, C.I., & Degens, H. (2009). The acute effect of different warm-up protocols on anaerobic performance in elite youth soccer players. *The Journal of Strength & Conditioning Research*, *23*(9), 2614-2620.

Pearce, A.J., Kidgell, D.J., Zois, J., & Carlson, J.S. (2009). Effects of secondary warm up following stretching. *European journal of applied physiology*, *105*(2), 175-183.

Pereles, D., Roth, A., & Thompson, D. (2012). A Large, Randomized, Prospective Study of the Impact of a Pre-Run Stretch on the Risk of Injury on Teenage and Older Runners.

Pope, R.P., Herbert, R.D., Kirwan, J.D., & Graham, B.J. (2000). A randomized trial of pre exercise stretching for prevention of lower-limb injury. *Medicine and science in sports and exercise*, *32*(2), 271-277.

Rohmert, W., Wos, H., Norlander, S., & Helbig, R. (1989). Effects of vibration on arm and shoulder muscles in three body postures. *European journal of applied physiology and occupational physiology*, *59*(4), 243-248.

RøNNESTAD, B.R. (2004). Comparing the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. *The Journal of Strength & Conditioning Research*, *18*(4), 839-845.

Rubini, E.C., Costa, A.L., & Gomes, P.S. (2007). The effects of stretching on strength performance. *Sports medicine*, *37*(3), 213-224.

Sands, W.A., McNeal, J.R., Stone, M.H., Russell, E.M., & Jemni, M. (2006). Flexibility enhancement with vibration: Acute and long-term. *Medicine & Science in Sports & Exercise*, *38*(4), 720-725.

Siatras, T., Papadopoulos, G., Mameletzi, D., Gerodimos, V., & Kellis, S. (2003). Static and dynamic acute stretching effect on gymnasts' speed in vaulting. *Pediatric Exercise Science*, *15*(4), 383-391.

Sharman, M.J., Cresswell, A.G., & Riek, S. (2006). Proprioceptive neuromuscular facilitation stretching. *Sports Medicine*, *36*(11), 929-939.

Sim, A.Y., Dawson, B.T., Guelfi, K.J., Wallman, K.E., & Young, W.B. (2009). Effects of static stretching in warm-up on repeated sprint performance. *The Journal of Strength & Conditioning Research*, *23*(7), 2155-2162.

Stone, M., Ramsey, M.W., Kinser, A.M., & O'bryant, H.S. (2006). Stretching: Acute and chronic? The potential consequences. *Strength and Conditioning Journal*, *28*(6), 66.

Sullivan, K.M., Silvey, D.B., Button, D.C., & Behm, D.G. (2013). Roller massager application to the hamstrings increases sit and reach range of motion within five to ten seconds without performance impairments. *International journal of sports physical therapy*, *8*(3), 228.

Thacker, S.B., Gilchrist, J., Stroup, D.F., & Kimsey Jr, C.D. (2004). The impact of stretching on sports injury risk: a systematic review of the literature. *Medicine & Science in Sports & Exercise*, *36*(3), 371-378.

Yamaguchi, T., & Ishii, K. (2005). Effects of static stretching for 30 seconds and dynamic stretching on leg extension power. *Journal of strength and Conditioning Research*, *19*(3), 677.

Yamaguchi, T., Ishii, K., Yamanaka, M., & Yasuda, K. (2007). Acute effects of dynamic stretching exercise on power output during concentric dynamic constant external resistance leg extension. *The Journal of Strength & Conditioning Research*, *21*(4), 1238-1244.

Young, W.B., & Behm, D.G. (2002). Should Static Stretching Be Used During a Warm-Up for Strength and Power Activities? *Strength & Conditioning Journal*, *24*(6), 33-37.

Young, W.B., & Behm, D.G. (2003). Effects of running, static stretching and practice jumps on explosive force production and jumping performance. *Journal of Sports Medicine and Physical Fitness*, *43*(1), 21.

Wallmann, H.W., Mercer, J.A., & McWhorter, J.W. (2005). Surface electromyographic assessment of the effect of static stretching of the gastrocnemius on vertical jump performance. *The Journal of Strength & Conditioning Research*, *19*(3), 684-688.

Wilson, J.M., Hornbuckle, L.M., Kim, J.S., Ugrinowitsch, C., Lee, S.R., Zourdos, M.C., ... & Panton, L.B. (2010). Effects of static stretching on energy cost and running endurance performance. *The Journal of Strength & Conditioning Research*, *24*(9), 2274-2279.