Impact of stretching on the performance and injury risk of long distance runners

Journal:	*Research in Sports Medicine*
Manuscript ID:	GSPM-2015-0077.R1
Manuscript Type:	Review Paper
Keywords:	performance, flexibility, injury

Impact of stretching on the performance and injury risk of long distance runners

Claire Baxter, Lars R Mc Naughton, Andy Sparks, Lynda Norton and David Bentley

Correspondence to:

Professor Lars R. Mc Naughton

Edge Hill University

St Helen's Road

Ormskirk L39 4QP

United Kingdom

Abstract

Stretching, either prior to exercise or at the end, or both, is typically carried out by all individuals undertaking sporting activity whether they be elite or recreational athletes. The many forms of stretching available to the athlete, either passive or active, have long been thought to improve performance, decrease injury and generally be advantageous to the athlete. This review examines the current state of the literature and evaluates what athletes can and should do with respect to this controversial topic.

Introduction

Stretching has long been considered an integral part of the training routine for athletes and is used across all disciplines as a tool of preparation, performance enhancement and injury prevention (Trehearn & Buresh, 2009). In recent years however, it has been suggested that the tendency to incorporate stretching into the regimes of athletes was based not on science but assumption (Thacker et al., 2003; Herbert et al., 2011; Shrier, 2004).

Stretching performed prior to exercise (acutely) or as a long term intervention has traditionally been thought to improve the performance of endurance runners (Herbert & Gabriel, 2007). However, inconsistency across the literature has suggested this is not necessarily the case and may have different implications for various sports disciplines. DOMS can occur after single bouts of high intensity running and/or unfamiliar activity (Herbert et al., 2011). The occurrence of DOMS can result in fatigue, pain and reduction in performance, effects usually lasting 24-48 hours (Cheung et al., 2003) and can be hindering for long distance athletes. Stretching has been considered to influence the incidence of DOMS in endurance runners. Chronic overuse injuries are also frequent and devastating for long distance athletes. Common running related injuries include medial tibial stress syndrome, plantar fasciitis, achilles tendonitis, stress fractures and various knee related injuries (Gallo et al, 2012). Stretching has been considered a tool for reducing the risk of injury for endurance athletes and is an additional reason stretching is often used by endurance runners. This narrative review will report on the evidence available surrounding the effects of acute and chronic stretching in relation to its effects on performance, DOMS and injury risk in endurance runners.

Does stretching improve flexibility?

Stretching is a broad term used to describe an array of passive and active movements used to increase flexibility (Woods et al., 2012). Although there are various types of stretching, this review primarily investigates static stretching. In contrast to the dynamic movement associated with the other variations of stretching, static stretching involves elongating a muscle to the point at which a gentle tension is felt and remaining in this position for a given amount of time. Typically, multiple stretches are performed on a single muscle group with a minimum of thirty seconds per stretch (Woods et al., 2012). Bandy & Irion (1994) investigated the duration of static stretching and reported that thirty seconds is the optimal period for static stretching and that increasing this duration provides no additional advantage. It is largely unknown as to the optimal frequency (days per week) or dimensions of stretching on improvements in range of motion of a joint. Each variation of stretching has speculated to provide an assortment of advantages to athletes of varying disciplines, however the literature has primarily examined the effects of static stretching as this is the variation most commonly recommended to and performed by endurance athletes (Shrier, 2004; Wallmann et al., 2012). The second distinction in stretching referenced in this review is the acute or chronic nature of the activity. Acute stretching refers to a temporary activity that is performed in a discrete capacity immediately before exercise (Wallmann et al., 2012). In contrast, chronic stretching is defined as that which is performed outside of the warm up regime as a tool of increasing long term flexibility (Stone et al., 2006).

Flexibility is a recognized fitness component and is considered a result of regular stretching practices (Wilson et al., 2010; Shrier, 2004). However, a preliminary point to the stretching debate is whether or not stretching does in fact improve flexibility. This is a question that has been raised to determine whether or not the dispute surrounding the relationship between performance and injury for athletes is central to stretching or flexibility. Is flexibility the factor that is under scrutiny or is it simply that the common stretching methods engaged by athletes are not increasing flexibility? The research has demonstrated that when simple static stretching is executed regularly over a minimum of six weeks, flexibility is significantly increased (Thacker et al., 2003; Bandy & Irion, 1994). This leads to the distinction between acute stretching (single bout immediately before exercise) and long term chronic stretching (performed regularly and exclusive to the warm up regime of athletes). This is an important difference and as a result research has been conducted on both variations in relation to its affect on performance, DOMS and chronic injury in endurance runners.

Are endurance runners flexible?

There is evidence to suggest that typically, elite endurance runners are less flexible than their non-elite counterparts (Saunders et al., 2004). Posthumus et al. (2011) completed a survey that investigated the presence of the gene COL5A1 in endurance runners, a gene associated with inflexibility, which demonstrated that endurance runners who possess this gene had a considerably higher running economy than the other athletes participating in the study. Running economy is a recognized determinant of the performance of endurance runners and is measured by the energy demand of a runner at a specified velocity (Nelson et al., 2001). This gene also had a substantially greater presence among the endurance athletes subgroup then is estimated across the general population (Posthumus et al., 2011). It has also been postulated that hypertrophy of muscle can reduce the range of motion of a joint and this also could contribute to the reduced flexibility seen in endurance runners (Wilson & Flanagan, 2008). Gleim et al. (1990) conducted a study on untrained individuals and found that the participants with the lowest flexibility consistently had the most economical running styles. These results were justified by demonstrating that the decrease in range of motion of the transverse and frontal physiological planes led to stabilization in the pelvic region when the foot connected with the ground. This resulted in a reduction in excessive range of motion and therefore an increase in the energy required to stabilize muscular activity. It was also suggested that tightness in the muscles and tendons could increase elastic storage and therefore reduce the oxygen demand. Thacker et al. (2003) commented that the likeliness of injury is also influenced and that there is an optimal flexibility for endurance runners. The research proposes that inflexibility can be compared to that of hyperflexibility when considering injury risk (Thacker et al., 2003). A base range of flexibility will neither improve nor decrease likeliness of developing running related injuries, however extreme cases outside the normal range of flexibility might be problematic. Future research may be directed to quantifying this optimal level of flexibility for both performance and injury risk in the endurance running population compared to athletes of other disciplines.

Stretching and Performance

Long distance runners, considered to be athletes that participate in events 5km or longer, (Cosca & Navazio, 2007) are a population that are heavily influenced by the outcome of the stretching debate (Wilson et al., 2010). The ability of endurance running can be divided into two main subsections. Firstly, performance potential, which is impacted by physiological parameters such as aerobic capacity (VO_2 max) and lactate threshold (Joyner & Coyle, 2008; Wilson et al., 2010; Godges et al., 1989). The VO_2 max represents a number of physiological aspects including cardiac output (Spurway et al., 2012), haemoglobin levels (Ferretti, 2014), blood flow and muscle oxygen extraction (Joyner & Coyle, 2008). Lactate threshold is the percentage of the VO_2 max where lactic acid levels rise sharply in the blood (Marcell et al., 2003). The higher the percentage of the VO_2 max in which the lactate threshold occurs equates to the athletes increased potential for performance. The second variable is efficiency, which runs parallel to performance and varies about 30-40% among athletes (Joyner & Coyle, 2008). Running efficiency refers to how the body composition of an athlete impacts how effective muscles are at using available energy (Saunders et al., 2004) and is dependent on factors such as muscle morphology, elastic elements and joint mechanics (Engeroff et al., 2014). The efficiency of movement is primarily due to anatomical and physiological factors of the body and methods to improve it are largely unknown (Joyner & Coyle, 2008). The efficiency variable of running ability is where stretching practices have the potential to impact an athlete's success (Barnes & Kilding, 2015). This raises the question of whether acute or chronic stretching is influencing running efficiency and whether it should remain an assumed aspect of training.

Running economy is a multifactorial determinant that results from a number of metabolic, cardiorespiratory and biomechanical characteristics including VO_2 max, lactate threshold and running efficiency (Barnes & Kilding, 2015). Running economy is defined as the steady state of oxygen consumption at a given running velocity, reflecting the energy demand of running at a constant submaximal speed (Allison et al., 2008; Barnes & Kilding, 2015). It has been considered the standard measurement for the overall competency of runners.

Over the past twenty years, the literature on stretching and performance has expanded and argued three standpoints, some studies providing evidence that stretching increases performance, some arguing it decreases performance, and some stating it does not impact it at all. Running economy was the primary indicator of performance for the studies investigating the effect of stretching on the performance of long distance runners (Allison et al., 2008; Joyner & Coyle, 2008; Barnes & Kilding, 2015; Wilson et al., 2010; Saunders et al., 2004). The debate surrounding the effects of stretching surfaced after it was suggested that acute stretching immediately before exercise had the ability to significantly inhibit performance on short, explosive events including the leg press one repetition max (Bacurau et al., 2009), 20m sprint performance (Nelson et al., 2005) and vertical jump height (Young et al., 2001) due to the physiological changes seen in the muscle and the decreased ability to store elastic energy (Wilson et al., 2010). As performance in long distance running events relies on factors such as VO_2 max, lactate threshold and biomechanical factors in contrast to the explosive, power oriented variables seen in anaerobic activities, a number of subsequent studies analyzed the effects of acute stretching on endurance running (Wilson et al., 2010; Gleim et al, 1990; Kyrolainen & Komi, 1994). Although some research demonstrated that pre-exercise stretching has the potential to reduce explosive actions (Wilson et al., 2010), a contrasting study reported that increased flexibility meant a reduction in musculo-tendinous stiffness which by enhancing the use of elastic energy was able to improve the results of rebound bench press (Wilson et al., 1992). However, this study (Wilson et al. 1992) is not relevant to endurance running. No additional studies have shown that acute stretching has the ability to improve the performance of athletes and notably no studies have reported positive effects for endurance runners. As a result, the debate has since evolved into whether stretching decreases running economy for endurance runners or simply does not affect it.

Acute stretching and Performance

Athletes commonly use acute stretching during their warm up regime prior to both training and competition (Shrier, 2004). However, the majority of the literature that has investigated acute stretching and endurance running argues that stretching causes a decrease in running economy (Thacker et al., 2003; Saunders et al., 2004; Shrier, 2004). The central idea behind this phenomenon is that stretching before an endurance event reduces mechanical efficiency of the lower body (Kyrolainen & Komi, 1994) primarily through the reduction of musculotendinous stiffness (Thacker et al., 2003). A musculotendinous unit is defined as the contractile muscle and the attached tendinous structures (McLachlan et al., 2006), and musculotendinous stiffness refers specifically refers to the units ability to resist an applied change in length (Kuitunen et al., 2002). Although this stiffness has traditionally been considered a factor that has the potential to increase the risk of injury and inhibit athlete's performance in the early stages of a race, it appears it is a desirable trait for long distance runners (Wilson & Flanagan, 2008). The reduction in mechanical efficiency stems directly from the decrement in muscle stiffness that appears as a result of static stretching. The specific reasoning behind why a decrease in musculotendinous stiffness leads to reduced mechanical efficiency varied throughout the literature however all reported that acute stretching before endurance based events does not assist athletes performance and in fact can diminish it (Wilson et al., 2010; Kyrolainen & Komi, 1994; Craib et al., 1996). One study suggested that stiffer muscles surrounding the ankle and knee joints causes an increase in force potentiation when transitioning from the braking to push off phase of running

(Kyrokainen & Komi, 1994) and proposed that stiffer muscles provide the best running economy and results. Craib et al. (1996) investigated the effect of short and rapid stretching on running economy and found that inflexibility in the hip and calf regions were associated with improved running economy as less energy was required for muscle stabilization. The improved running economy may be a result of increased pelvis stability and a reduction in required muscle activation at foot strike to maintain stability. An additional study described that acute stretching may result in an increase in the number of motor units recruited to perform the same amount of mechanical work that is required without stretching. Activation of a larger number of motor units means an increase in both oxygen consumption and energy expenditure (Wilson et al., 2010). Additionally, Gleim et al. (1990) argues that efficient elastic energy storage and return is favoured for endurance athletes with a tighter musculotendinous system. Furthermore, acute stretching has the ability to strain the muscle, causing a decrease in force development, and an increase in oxygen requirement within the hour following the stretching regime (Shrier, 2004).

Hayes & Walker (2007) suggested that a ten minute sub maximal warm up run prior to performance testing could reverse the reduction in active peak force and rate of force development while retaining the improved stretch-absorbing capacity and therefore not impact running economy. Furthermore, Allison et al. (2008) reported that changes in neuromuscular function due to stretching were evident in participants but had no effect on running economy. However, no studies were able to suggest that stretching immediately before an endurance running event could improve running economy (Thacker et al., 2003; Shrier, 2004). A small number of studies that investigated the performance of isolated muscle groups demonstrated that stretching before performance testing can increase the strength of that muscle group at specific isokinetic degrees (Godges et al., 1989; Akagi & Takahashi, 2014), however these results did not provide evidence to suggest that the same results could be applied to endurance running (Worrell et al., 1994). Furthermore, when

Godges et al., (1989) conducted a follow up study on a larger population, it was reported that no effect on running economy was seen (Bonacci et al., 2009).

In conclusion, stretching does not possess properties that warrant it a useful or effective tool in the warm up regime of long distance runners. Although the data is not entirely conclusive and the literature demonstrates some disparity, there is little to suggest that acute stretching has properties that can enhance performance for endurance athletes and in fact may have the opposite effect. This research suggests that endurance athletes may be best reducing their warm up routine to a low intensity, progressive run and removing stretching practices completely.

Chronic effects of Stretching and Performance

It has been argued that provided that stretching is not completed immediately before exercise - as is generally the case for athletes engaging in chronic stretching - increased flexibility as a result of regular stretching will not inhibit performance or decrease running economy (Nelson et al., 2001; Godges et al., 1993). Nelson et al. (2001) conducted a study involving 32 participants over 10 weeks and noted that although flexibility was significantly increased over the study duration, it did not appear to effect running economy. The study makes specific mention that the exercise was not performed immediately following the stretching regime and although running economy was not reduced it also did not show improvement. There was no studies found that reported that running economy would either improve or decline from long term stretching programs. However, as previously reported, the literature does suggest that an increased running economy has a high association with inflexibility in endurance runners (Gleim et al., 1990; Posthumus et al., 2011; Saunders et al., 2004) As a result, unless stretching possesses other health or performance related benefits, it appears to have little purpose in an endurance runner's preparation. The research suggests that there may be an optimal level of flexibility for running economy, in which a balance between muscle stiffness in order to maximize elastic energy storage and return is achieved while allowing enough movement for optimal stride length at high running speeds (Saunders et al., 2004).

The literature suggests acute stretching regimes do not help endurance runner's performance, and may in fact decrease running economy. Specifically, by decreasing musculotendinous stiffness, acute stretching reduces stability and force production, in turn decreasing mechanical efficiency and increasing oxygen demand (Wilson & Flanagan, 2008). Therefore, if individuals feel it necessary to include stretching in their daily routine, it is suggested that it is not performed immediately before running. Further research is required to clarify the effects of chronic stretching on endurance running performance. Furthermore, the evidence on dynamic stretching is limited and requires further examination. Although no studies were able to provide evidence that acute stretching positively impacts performance for endurance runners the effects of chronic stretching on endurance running performance is unknown and is an area requiring further investigation. A notable weakness that is seen across all relevant literature examining the relationship between stretching and performance is the lack of explanation and are primarily speculative in nature. There are limited evidence based claims which describe why acute and chronic stretching effects performance.

Stretching and Delayed Onset Muscle Soreness

Delayed onset muscle soreness (DOMS) is common and debilitating for endurance runners (Cheung et al., 2003). DOMS can cause discomfort in the muscle and is the leading cause of reduced performance in subsequent exercise, decreased muscle strength and range of motion (High et al., 1989). The specific cause of DOMS is unknown, however it is thought to be triggered by a series of biochemical changes that occur as a result of muscle damage (Friden, 2008). It is often seen when individuals are exposed to high force eccentric contractions repeatedly and/or unaccustomed exercise (Kim & Lee, 2014). Running has a significant eccentric component which has been implicated in the manifestation of DOMS

(Cheung et al., 2003). As a result, DOMS is prevalent following bouts of high intensity or downhill running exercise (Kim & Lee, 2014). Therefore a reduction in the incidence of DOMS and therefore an improvement in recovery would be such a quality to encourage endurance athletes to leave stretching in their daily routine.

The use of stretching to prevent DOMS was supported by the idea that muscle soreness was a result of unfamiliar exercise causing muscle spasm (de Vries, 1961). Muscle spasm was thought to reduce blood flow to the muscle and conversely, stretching was thought to restore blood to the muscle, interrupting the pain-spasm-pain cycle (Herbert et al., 2011). High et al. (1989) conducted a study that investigated the effect of stretching on DOMS of 62 healthy participants in order to investigate these claims. Results were compared among the individuals in the experimental (static stretching) and control (non-stretching) conditions and the results demonstrated that there was no significant difference between muscle soreness over the following five days. These findings were supported by a number of additional studies, reporting that acute stretching does not provide a significant impact on DOMS following exhaustive exercise (Buroker & Schwane, 1989; Johansson et al., 1999; McGlynn et al., 1979; Wessel & Wan, 1994). Furthermore, Herbert & Gabriel (2007) reported that although a small amount of improvement may be seen in DOMS following stretching, it is too insignificant to warrant athletes including it into their warm up regime. Herbert et al. (2011) reported that there was no evidence that suggested static or dynamic stretching performed before or after exercise or in an acute or chronic capacity had the ability to reduce the severity or duration of DOMS. Jamtvedt et al. (2010) supported these claims surveying over 2,000 individuals and concluding that no variation of stretching has the ability to alter DOMS.

Similarly to the effects on performance, there is no evidence found which suggests that stretching has the ability to reduce either the presence of DOMS or the prevalence of chronic injury in long distance runners. A number of studies have investigated the relationship between stretching and the presence of DOMS following exercise and the unanimous response is that the duration and intensity of DOMS cannot be influenced by stretching (Herbert et al., 2011; Dannecker et al., 2002). There was no evidence to suggest stretching could assist in the reduction of DOMS across the literature for athletes of any discipline (Herbet el al., 2011). It is recommended that athletes suffering from DOMS investigate other prevention methods, such as massaging, icing or hot and cold therapy (Snyder et al., 2011; Sforzo et al., 2011).

Stretching and Chronic Injury

The bulk of the literature investigating the relationship between stretching and injury for long distance runners has focused on chronic, long term, degenerative injuries – which are seen most commonly in this population. Although competitive endurance runners are most frequently in their 20s and 30s, the majority of participants are within the 35-50 years bracket (Cosca & Navazio, 2007). As a result, this population is at a high risk for running related chronic injuries such as illiotibial band friction, achilles tendinopathy and plantar fasciitis (Cosca & Navazio, 2007; Gallo et al., 2012). Marti et al. (1984) conducted a study on over 4,000 male runners and reported that 45% sustained an injury over a one year period with inflammation to the achilles tendon and calf muscle injuries among the most common.

The majority of studies suggest that stretching has no impact of the risk of chronic injury in endurance runners (Thacker et al., 2003; Cosca & Navazio, 2007; Witvrouw et al., 2004). It has shown that long term stretching can potentially increase the compliance of the muscle-tendon unit (Toft et al., 1989) and may allow greater force production at longer muscle lengths (McHugh & Nesse, 2008) which may be relevant to other sporting disciplines however Witvrouw et al. (2004) highlights that for endurance running these potential benefits are not clinically beneficial. When participating in a long distance running event, the lower limbs engage in a repetitive motion at a submaximal intensity. This means the tendons in the legs are unlikely to require maximum energy absorption and elastic stability to perform the exercise (Witvrouw et al., 2004). This applies to all endurance events which include repetitive motion such as long distance cycling and swimming. As a result of this, the likeliness that the endurance athletes will encounter muscle strain injuries is low in comparison to highly explosive sports which require maximum effort out of the musculo-tendinous structures.

Dutch researchers (van Mechelen et al. 1993) studied the effect of stretching on injury over a 10 week program and reported that stretching made no impact on the prevalence of overuse injuries. Furthermore, the study did not report any muscle or tendon strain related injuries supporting the idea that overuse injuries are the most frequent for endurance runners. This also supports that although there is potential advantages for a subset of sporting activities, due to the nature of the injuries generally experienced by endurance runners, stretching provides no assistance in reducing the risk of injury (McHugh & Cosgrave, 2010). Pope et al. (2000) conducted a study which reinforced these claims, surveying over 1,000 military recruits and concluding that stretching did not affect the prevalence of chronic overuse injuries in their population.

Bonacci et al. (2009) has commented that although stretching has not demonstrated any ability to reduce the risk of injury in endurance runners, it can be an important tool in the maintenance and promotion of range of motion in hip, knee and ankle joints after injury. An additional study investigated the effect of flexibility on vertical jump technique and suggested that stretching has both advantageous and disadvantageous properties depending on the activities that individuals are participating in and what the athlete is trying to achieve (Hunter & Marshall, 2002). This highlights that the relationship between the effects of stretching and sporting activities generally is not clear and some athletes may benefit from incorporating chronic stretching into their routine from an injury risk standpoint.

When investigating the relationship between stretching and chronic injury, the literature shows a higher degree of discrepancy. Stretching may possess qualities that will help reduce the likeliness of muscle and tendon strain injuries however this is unrelated to the subset of injuries most experienced by endurance runners (McHugh & Cosgrave, 2010). As a result it can be concluded that stretching provides no significant assistance in the reduction of chronic overuse injuries and therefore is not a useful injury preventative strategy for endurance athletes. Further research is required to determine whether stretching has the ability to reduce the prevalence of muscle strain injuries and should remain incorporated into the warm up regime of athletes of different areas.

Practical Implications

The available research suggests neither acute nor chronic static stretching has clinically beneficial effects for endurance runners on performance, incidence of DOMS or to prevent injury. Therefore other strategies could be used to assist a runner with preparation and recovery. Bazyler et al. (2011) conducted a study to investigate the benefit of a sub-maximal warm up for endurance performance and found no significant improvements in performance. Similarly, investigations involving dynamic stretching techniques have shown little evidence to suggest it provides any advantage to endurance athletes (Dalleck et al., 2007). However, the research outside of static stretching is limited (Dalleck et al., 2007) and is an area requiring further research. From the current literature, it can be concluded that stretching is an ineffective way of altering performance or injury risk and endurance athletes are advised to direct their efforts to other strategies. In terms of pre-exercise activities, this may include a progressive warm up prior to exercise which incorporates graded intensity. Athletes are also recommended to individualize their training programs in order to promote performance responses and reduce injury risk. Aside from the improvement of an athletes lactate threshold and VO_2 max, supplementary efforts such as resistance training (Dean et al., 2013) have reported to assist in the performance of endurance runners and may be a useful incorporation into the training schedule of athletes. Endurance runners experiencing common overuse injuries are advised to treat each injury individually and acknowledge that risk factors such as extensive mileage can impact the risk of developing a chronic injury in the lower limbs (Warden et al., 2014). Therefore, progressive and planned training in combination with over recovery modalities may be the most effective way to reduce injury risk and promote recovery during period of high running volume. Cross and interval training may be techniques used to reduce weekly mileage and the likeliness of overuse injuries (Millet et al., 2011).

Conclusion

In conclusion, the literature suggests that stretching poses no significant advantage to endurance runners. Acute stretching can reduce running economy and performance for up to an hour by diminishing the musculotendinous stiffness and elastic energy potential. Chronic stretching additionally appears to have no advantageous effects. In regards to DOMS, it has been reported consistently in the literature that stretching cannot reduce its longevity or intensity. In relation to injury risk, stretching shows little significance for endurance runners to chronic injury. Endurance athletes are at high risk of overuse injuries such as illiotibial band syndrome, stress fractures and plantar fasciitis, and the literature suggests that stretching cannot reduce the prevalence of these injuries. It appears stretching may hold significance for certain exercise disciplines however it can be concluded that it holds no advantage for endurance runners and is not the solution to improving performance or reducing injury prevalence.

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Impact of stretching on the performance and injury risk of long distance runners

Abstract

Stretching, either prior to exercise or at the end, or both, is typically carried out by all individuals undertaking sporting activity whether they be elite or recreational athletes. The many forms of stretching available to the athlete, either passive or active, have long been thought to improve performance, decrease injury and generally be advantageous to the athlete. This review examines the current state of the literature and evaluates what athletes can and should do with respect to this controversial topic.

Introduction

Stretching has long been considered an integral part of the training routine for athletes and is used across all disciplines as a tool of preparation, performance enhancement and injury prevention (Trehearn & Buresh, 2009). In recent years however, it has been suggested that the tendency to incorporate stretching into the regimes of athletes was based not on science but assumption (Thacker et al., 2003; Herbert et al., 2011; Shrier, 2004).

Stretching performed prior to exercise (acutely) or as a long term intervention has traditionally been thought to improve the performance of endurance runners (Herbert & Gabriel, 2007). However, inconsistency across the literature has suggested this is not necessarily the case and may have different implications for various sports disciplines. **Delayed onset muscle soreness or** DOMS, can occur after single bouts of high intensity running and/or unfamiliar activity (Herbert et al., 2011). The occurrence of DOMS can result in fatigue, pain and reduction in performance, effects usually lasting 24-48 hours (Cheung et al., 2003) and can be hindering for long distance athletes. Stretching has been considered to influence the incidence of DOMS in endurance runners. Chronic overuse injuries are also frequent and devastating for long distance athletes. Common running related injuries include medial tibial stress syndrome, plantar fasciitis, achilles tendonitis, stress fractures and various knee related injuries (Gallo et al, 2012). Stretching has been considered a tool for reducing the risk of injury for endurance athletes and is an additional reason stretching is often used by endurance runners. This narrative review will report on the evidence available surrounding the effects of acute and chronic stretching in relation to its effects on performance, DOMS and injury risk in endurance runners.

Does stretching improve flexibility?

Stretching is a broad term used to describe an array of passive and active movements used to increase flexibility (Woods et al., 2012). Although there are various types of stretching, this review primarily investigates static stretching. In contrast to the dynamic movement associated with the other variations of stretching, static stretching involves elongating a muscle to the point at which a gentle tension is felt and remaining in this position for a given amount of time. Typically, multiple stretches are performed on a single muscle group with a minimum of thirty seconds per stretch (Woods et al., 2012). Bandy & Irion (1994) investigated the duration of static stretching and reported that thirty seconds is the optimal period for static stretching and that increasing this duration provides no additional advantage. It is largely unknown as to the optimal frequency (days per week) or dimensions of stretching on improvements in range of motion of a joint. Each variation of stretching has speculated to provide an assortment of advantages to athletes of varying disciplines, however the literature has primarily examined the effects of static stretching as this is the variation most commonly recommended to and performed by endurance athletes (Shrier, 2004; Wallmann et al., 2012). The second distinction in stretching referenced in this review is the acute or chronic nature of the activity. Acute stretching refers to a temporary activity that is performed in a discrete capacity immediately before exercise (Wallmann et al., 2012). In contrast, chronic stretching is defined as that which is performed outside of the warm up regime as a tool of increasing long term flexibility (Stone et al., 2006).

Flexibility is a recognized fitness component and is considered a result of regular stretching practices (Wilson et al., 2010; Shrier, 2004). However, a preliminary point to the stretching debate is whether or not stretching does in fact improve flexibility. This is a question that has been raised to determine whether or not the dispute surrounding the relationship between performance and injury for athletes is central to stretching or flexibility. Is flexibility the factor that is under scrutiny or is it simply that the common stretching methods engaged by athletes are not increasing flexibility? The research has demonstrated that when simple static stretching is executed regularly over a minimum of six weeks, flexibility is significantly increased (Thacker et al., 2003; Bandy & Irion, 1994). This leads to the distinction between acute stretching (single bout immediately before exercise) and long term chronic stretching (performed regularly and exclusive to the warm up regime of athletes). This is an important difference and as a result research has been conducted on both variations in relation to its affect on performance, DOMS and chronic injury in endurance runners.

Are endurance runners flexible?

Running economy is a recognized determinant of the performance of endurance runners and is measured by the energy demand of a runner at a specified velocity (Nelson et al., 2001). There is evidence to suggest that typically, elite endurance runners are less flexible than their non-elite counterparts (Saunders et al., 2004). Posthumus et al. (2011) completed a survey that investigated the presence of the gene COL5A1 in endurance runners, a gene associated with inflexibility, which demonstrated that endurance runners who possess this gene had a considerably higher running economy than the other athletes participating in the study. **The COL5A1 gene has been associated with type V collagen, with the varying genotypes correlating with different ranges of motion (Posthumus et al., 2011).** This gene also had a substantially greater presence among the endurance athletes subgroup then is estimated across the general population (Posthumus et al., 2011). It has also been postulated that hypertrophy of muscle can reduce the range of motion of a joint and this also could contribute to the reduced flexibility seen **in athletes** (Wilson & Flanagan, 2008). Gleim et al. (1990) conducted a study on untrained individuals and found that the participants with the lowest flexibility consistently had the most economical running styles. These results were justified by demonstrating that the decrease in range of motion of the transverse and frontal physiological planes led to stabilization in the pelvic region when the foot connected with the ground. This resulted in a reduction in excessive range of motion and therefore **a decrease** in the energy required to stabilize muscular activity. It was also suggested that tightness in the muscles and tendons could increase elastic storage and therefore reduce the oxygen demand. Thacker et al. (2003) commented that the likeliness of injury is also influenced and that there is an optimal flexibility for endurance runners. The research proposes that inflexibility can be compared to that of hyperflexibility when considering injury risk (Thacker et al., 2003). A base range of flexibility will neither improve nor decrease likeliness of developing running related injuries, however extreme cases outside the normal range of flexibility might be problematic. Future research may be directed to quantifying this optimal level of flexibility for both performance and injury risk in the endurance running population compared to athletes of other disciplines.

Stretching and Performance

Long distance runners, considered to be athletes that participate in events 5km or longer, (Cosca & Navazio, 2007) are a population that are heavily influenced by the outcome of the stretching debate (Wilson et al., 2010). The ability of endurance running can be divided into two main subsections. Firstly, performance potential, which is impacted by physiological parameters such as aerobic capacity (VO_2 max) and lactate threshold (Joyner & Coyle, 2008; Wilson et al., 2010; Godges et al., 1989). The VO_2 max represents a number of physiological aspects including cardiac output (Spurway et al., 2012), haemoglobin levels (Ferretti, 2014), blood flow and muscle oxygen extraction (Joyner & Coyle, 2008). Lactate threshold is the percentage of the VO_2 max where lactic acid levels rise sharply in the blood (Marcell et al., 2003). The higher the percentage of the VO_2 max in which the lactate threshold occurs equates to the **athlete's** increased potential for performance. The second variable is efficiency, which runs parallel to performance and varies about 30-40% among athletes (Joyner & Coyle, 2008). Running efficiency refers to how the body composition of an athlete impacts how effective muscles are at using available energy (Saunders et al., 2004) and is dependent on factors such as muscle morphology, elastic elements and joint mechanics (Engeroff et al., 2014). The efficiency of movement is primarily due to anatomical and physiological factors of the body and methods to improve it are largely unknown (Joyner & Coyle, 2008). The efficiency variable of running ability is where stretching practices have the potential to impact an athlete's success (Barnes & Kilding, 2015). This raises the question of whether acute or chronic stretching is influencing running efficiency and whether it should remain an assumed aspect of training.

Running economy is a multifactorial determinant that results from a number of metabolic, cardiorespiratory and biomechanical characteristics including VO_2 max, lactate threshold and running efficiency (Barnes & Kilding, 2015). Running economy is defined as the steady state of oxygen consumption at a given running velocity, reflecting the energy demand of running at a constant submaximal speed (Allison et al., 2008; Barnes & Kilding, 2015). It has been considered the standard measurement for the overall competency of runners.

Over **approximately the past decade**, the literature on stretching and performance has expanded and argued three standpoints, some studies providing evidence that stretching increases performance, some arguing it decreases performance, and some stating it does not impact it at all. Running economy was the primary indicator of performance for the studies investigating the effect of stretching on the performance of long distance runners (Allison et al., 2008; Joyner & Coyle, 2008; Barnes & Kilding, 2015; Wilson et al., 2010; Saunders et al., 2004). The debate surrounding the effects of stretching surfaced after it was suggested that acute stretching immediately before exercise had the ability to significantly inhibit performance on short, explosive events including the leg press one repetition max (Bacurau et al., 2009), 20m sprint performance (Nelson et al., 2005) and vertical jump height (Young et al., 2001) due to the physiological changes seen in the muscle and the decreased ability to store elastic energy (Wilson et al., 2010). As performance in long distance running events relies on factors such as VO_2 max, lactate threshold and biomechanical factors in contrast to the explosive, power oriented variables seen in anaerobic activities, a number of subsequent studies analyzed the effects of acute stretching on endurance running (Wilson et al., 2010; Gleim et al, 1990; Kyrolainen & Komi, 1994). Although some research demonstrated that pre-exercise stretching has the potential to reduce explosive actions (Wilson et al., 2010), a contrasting study reported that increased flexibility meant a reduction in musculo-tendinous stiffness which by enhancing **elasticity, and possibly re-bound mechanics, was then** able to improve the results of rebound bench press (Wilson et al., 1992). However, this study (Wilson et al. 1992) is not relevant to endurance running. No additional studies have shown that acute stretching has the ability to improve the performance of athletes and notably no studies have reported positive effects for endurance runners. As a result, the debate has since evolved into whether stretching decreases running economy for endurance runners or simply does not affect it.

Acute stretching and Performance

Athletes commonly use acute stretching during their warm up regime prior to both training and competition (Shrier, 2004). However, the majority of the literature that has investigated acute stretching and endurance running argues that stretching causes a decrease in running economy (Thacker et al., 2003; Saunders et al., 2004; Shrier, 2004). The central idea behind this phenomenon is that stretching before an endurance event reduces mechanical efficiency of the lower body (Kyrolainen & Komi, 1994) primarily through the reduction of musculotendinous stiffness (Thacker et al., 2003). A musculotendinous unit is defined as the contractile muscle and the attached tendinous structures (McLachlan et al., 2006), and musculotendinous stiffness refers specifically to the **unit's** ability to resist an applied change in length (Kuitunen et al., 2002). Although this stiffness has traditionally been considered a factor that has the potential to increase the risk of injury and inhibit athlete's performance in the early stages of a race, it appears it is a desirable trait for long distance runners (Wilson & Flanagan, 2008). The reduction in mechanical efficiency stems directly from the decrement in muscle stiffness that appears as a result of static stretching. The specific reasoning behind why a decrease in musculotendinous stiffness leads to reduced mechanical efficiency varied throughout the **literature. However, all** reported that acute stretching before endurance based events does not assist **athlete's** performance and in fact can diminish it (Wilson et al., 2010; Kyrolainen & Komi, 1994; Craib et al., 1996). One study suggested that stiffer muscles surrounding the ankle and knee joints causes an increase in force potentiation when transitioning from the braking to push off phase of running (Kyrokainen & Komi, 1994) and proposed that stiffer muscles provide the best running economy and results. Craib et al. (1996) investigated the effect of short and rapid stretching on running economy and found that inflexibility in the hip and calf regions were associated with improved running economy as less energy was required for muscle stabilization. The improved running economy may be a result of increased pelvis stability and a reduction in required muscle activation at foot strike to maintain stability. An additional study **conducted by Wilson et al. (2010) suggested** that acute stretching may result in an increase in the number of motor units recruited to perform the same amount of mechanical work that is required without stretching. Activation of a larger number of motor units means an increase in both oxygen consumption and energy expenditure (Wilson et al., 2010). Additionally, Gleim et al. (1990) argues that efficient elastic energy storage and return is favoured for endurance athletes with a tighter musculotendinous system. Furthermore, acute stretching has the ability to strain the muscle, causing a decrease in force development, and an increase in oxygen requirement within the hour following the stretching regime (Shrier, 2004).

Hayes & Walker (2007) suggested that a **ten-minute** sub maximal warm up run prior to performance testing could reverse the reduction in active peak force and rate of force development while retaining the improved stretch-absorbing capacity and therefore not impact running economy and reverse the negative effects of stretching. Furthermore, Allison et al. (2008) reported that changes in neuromuscular function due to stretching were evident in participants but had no effect on running economy. However, no studies were able to suggest that stretching immediately before an endurance running event could improve running economy (Thacker et al., 2003; Shrier, 2004). A small number of studies that investigated the performance of isolated muscle groups demonstrated that stretching before performance testing can increase the strength of that muscle group at specific isokinetic degrees (Godges et al., 1989; Akagi & Takahashi, 2014), however these results did not provide evidence to suggest that the same results could be applied to endurance running (Worrell et al., 1994). Furthermore, when Godges et al., (1989) conducted a follow up study on a larger population, it was reported that no effect on running economy was seen (Bonacci et al., 2009).

In conclusion, **static** stretching does not possess properties that warrant it a useful or effective tool in the warm up regime of long distance runners. Although the data is not entirely conclusive and the literature demonstrates some disparity, there is little to suggest that acute stretching has properties that can enhance performance for endurance athletes and in fact may have the opposite effect. This research suggests that endurance athletes may be best reducing their warm up routine to a low intensity, progressive run and removing stretching practices completely.

Chronic effects of Stretching and Performance

It has been argued that provided that stretching is not completed immediately before exercise - as is generally the case for athletes engaging in chronic stretching - increased flexibility as a result of regular stretching will not inhibit performance or decrease running economy (Nelson et al., 2001; Godges et al., 1993). Nelson et al. (2001) conducted a study involving 32 participants over 10 weeks and noted that although flexibility was significantly increased over the study duration, it did not appear to **affect** running economy. The study makes specific mention that the exercise was not performed immediately following the stretching regime and although running economy was not reduced it also did not show improvement. There **were** no studies **that were** found **which** reported that running economy would **either be positively or negatively affected from** long term stretching programs. However, as previously reported, the literature does suggest that an increased running economy has a high association with inflexibility in endurance runners (Gleim et al., 1990; Posthumus et al., 2011; Saunders et al., 2004) As a result, unless stretching possesses other health or performance related benefits, it appears to have little purpose in an endurance runner's preparation. The research suggests that there may be an optimal level of flexibility for running economy, in which a balance between muscle stiffness in order to maximize elastic energy storage and return is achieved while allowing enough movement for optimal stride length at high running speeds (Saunders et al., 2004).

The literature suggests acute stretching regimes do not help endurance runner's performance, and may in fact decrease running economy. Specifically, by decreasing musculotendinous stiffness, acute stretching reduces stability and force production, in turn decreasing mechanical efficiency and increasing oxygen demand (Wilson & Flanagan, 2008). Therefore, if individuals feel it necessary to include stretching in their daily routine, it is suggested that it is not performed immediately before running. Further research is required to clarify the effects of chronic stretching on endurance running performance. Furthermore, the evidence on dynamic stretching is limited and requires further examination. Although no studies were able to provide evidence that acute stretching positively impacts performance for endurance runners the effects of chronic stretching on endurance running performance is unknown and is an area requiring further investigation. A notable weakness that is seen across all relevant literature examining the relationship between stretching and performance is the lack of explanation and are primarily speculative in nature. There are limited evidence based claims which describe why acute and chronic stretching **affects** performance.

Stretching and Delayed Onset Muscle Soreness

Delayed onset muscle soreness (DOMS) is common and debilitating for endurance runners (Cheung et al., 2003). DOMS can cause discomfort in the muscle and is the leading cause of reduced performance in subsequent exercise, decreased muscle strength and range of motion (High et al., 1989). The specific cause of DOMS is unknown, however it is thought to be triggered by a series of biochemical changes that occur as a result of muscle damage (Friden, 2008). **It is often seen when individuals are exposed to repeated high-force eccentric contractions and/or unaccustomed exercise** (Kim & Lee, 2014). Running has a significant eccentric component which has been implicated in the manifestation of DOMS (Cheung et al., 2003). As a result, DOMS is prevalent following bouts of high intensity or downhill running exercise (Kim & Lee, 2014).

The use of stretching to prevent DOMS was supported by the idea that muscle soreness was a result of unfamiliar exercise causing muscle spasm (de Vries, 1961). Muscle spasm was thought to reduce blood flow to the muscle and conversely, stretching was thought to restore blood to the muscle, interrupting the pain-spasm-pain cycle (Herbert et al., 2011). High et al. (1989) conducted a study that investigated the effect of stretching on DOMS of 62 healthy participants in order to investigate these claims. Results were compared among the individuals in the experimental (static stretching) and control (non-stretching) conditions and the results demonstrated that there was no significant difference between muscle soreness over the following five days. These findings were supported by a number of additional studies, reporting that acute stretching does not provide a significant impact on DOMS following exhaustive exercise (Buroker & Schwane, 1989; Johansson et al., 1999; McGlynn et al., 1979; Wessel & Wan, 1994). Furthermore, Herbert & Gabriel (2007) reported that although a small amount of improvement may be seen in DOMS following stretching, it is too insignificant to warrant athletes including it into their warm up regime. Herbert et al. (2011) reported that there was no evidence that suggested static or dynamic stretching performed before or after exercise or in an acute or chronic capacity had the ability to reduce the severity or duration of DOMS. Jamtvedt et al. (2010) supported these claims surveying over 2,000 individuals and concluding that no variation of stretching has the ability to alter DOMS.

Similarly to the effects on performance, there is no evidence found which suggests that stretching has the ability to reduce either the presence of DOMS or the prevalence of chronic injury in long distance runners. A number of studies have investigated the relationship between stretching and the presence of DOMS following exercise and the unanimous response is that the duration and intensity of DOMS cannot be influenced by stretching (Herbert et al., 2011; Dannecker et al., 2002; **Johansson et al., 1999; Engbretson et al., 1999**). In conclusion, there was no evidence to suggest stretching could assist in the reduction of DOMS for athletes of any discipline. It is recommended that athletes suffering from DOMS investigate other prevention methods, such as massaging, icing or hot and cold therapy (Snyder et al., 2011; Sforzo et al., 2011).

Stretching and Chronic Injury

Research investigating the relationship between stretching and injury for long distance runners has focused on chronic, long term, degenerative injuries – which are seen most commonly in this population. Although competitive endurance runners are most frequently in their 20s and 30s, the majority of participants are within the 35-50 years bracket (Cosca and Navazio, 2007). As a result, this population is at a high risk for running related chronic injuries such as illiotibial band friction, achilles tendinopathy and plantar fasciitis (Cosca and Navazio, 2007; Gallo et al., 2012). Marti et al. (1984) conducted a study on over 4,000 male runners and reported that 45% sustained an injury over a one year period with inflammation to the achilles tendon and calf muscle injuries among the most common.

The majority of studies suggest that stretching has no impact **on** the risk of chronic injury in endurance runners (Thacker et al., 2003; Cosca & Navazio, 2007; Witvrouw et al., 2004). It has shown that long term stretching can potentially increase the compliance of the muscle-tendon unit (Toft et al., 1989) and may allow greater force production at longer muscle lengths (McHugh & Nesse, 2008) which may be relevant to other sporting disciplines however Witvrouw et al. (2004) highlights that for endurance running these potential benefits are not clinically beneficial. When participating in a long distance running event, the lower limbs engage in a repetitive motion at a submaximal intensity. This means the tendons in the legs are unlikely to require maximum energy absorption and elastic stability to perform the exercise (Witvrouw et al., 2004). This applies to all endurance events which include repetitive motion such as long distance cycling and swimming. As a result of this, the likeliness that the endurance athletes will encounter muscle strain injuries is low in comparison to highly explosive sports which require maximum effort out of the musculo-tendinous structures.

Dutch researchers (van Mechelen et al. 1993) studied the effect of stretching on injury over a **10-week** program and reported that stretching made no impact on the prevalence of overuse injuries. Furthermore, the study did not report any muscle or tendon strain related injuries supporting the idea that overuse injuries are the most frequent for endurance runners. This also supports that although there is potential advantages for a subset of sporting activities, due to the nature of the injuries generally experienced by endurance runners, stretching provides no assistance in reducing the risk of injury (McHugh & Cosgrave, 2010). Pope et al. (2000) conducted a study which reinforced these claims, surveying over 1,000 military recruits and concluding that stretching did not affect the prevalence of chronic overuse injuries in their population.

Bonacci et al. (2009) has commented that although stretching has not demonstrated any ability to reduce the risk of injury in endurance runners, it can be an important tool in the maintenance and promotion of range of motion in hip, knee and ankle joints after injury. **Hunter and Marshall (2002) suggested that stretching has both advantageous and disadvantageous properties** depending on the activities that individuals are participating in and what the athlete is trying to achieve). This highlights that the relationship between the effects of stretching and sporting activities generally is not clear and some athletes may benefit from incorporating chronic stretching into their routine from an injury risk standpoint. **However, a systematic review (Shrier, 2004) concluded that an acute bout of stretching pre-exercise may improve running economy, but regular stretching over time has no effect on economy.**

When investigating the relationship between stretching and chronic injury, the literature shows a higher degree of discrepancy. Stretching may possess qualities that will help reduce the likeliness of muscle and tendon strain injuries **such as may be experienced during strength, power and plyometric training undertaken by these athletes,** however this is unrelated to the subset of injuries most experienced by endurance runners (McHugh & Cosgrave, 2010). As a result it can be concluded that stretching provides no significant assistance in the reduction of chronic overuse injuries and therefore is not a useful injury preventative strategy for endurance athletes. Further research is required to determine whether stretching has the ability to reduce the prevalence of muscle strain injuries and should remain incorporated into the warm up regime of athletes of different areas.

Practical Implications

The available research suggests neither acute nor chronic static stretching has clinically beneficial effects for endurance runners on performance, incidence of DOMS or to prevent injury. Therefore other strategies could be used to assist a runner with preparation and recovery. Bazyler et al. (2011) conducted a study to investigate the benefit of a sub-maximal warm up for endurance performance and found no significant improvements in performance. Similarly, investigations involving dynamic stretching techniques have shown little evidence to suggest it provides any advantage to endurance athletes (Dalleck et al., 2007). However, the research outside of static stretching is limited (Dalleck et al., 2007) and is an area requiring further research. From the current literature, it can be concluded that stretching is an ineffective way of altering performance or injury risk and endurance athletes are advised to direct their efforts to other strategies. **Although the effects of stretching across varying sports disciplines are not conclusive, stretching will not improve**

performance in endurance based running events. Alternative strategies may include incorporating graded intensity in the preliminary stages of a run. Athletes are also recommended to individualize their training programs in order to promote performance responses and reduce injury risk. **As well as the improvement of an athlete's lactate threshold and VO_2 max, supplementary training such as resistance training (Dean et al., 2013) have been reported to assist in the improved performance of endurance runners and may be a useful incorporation into the training schedule of athletes.** Endurance runners experiencing common overuse injuries are advised to treat each injury individually and acknowledge that risk factors such as extensive mileage can impact the risk of developing a chronic injury in the lower limbs (Warden et al., 2014). Therefore, progressive and planned training in combination with over recovery modalities may be the most effective way to reduce injury risk and promote recovery during **periods** of high running volume. Cross and interval training may be techniques used to reduce weekly mileage and the likeliness of overuse injuries (Millet et al., 2011).

Conclusion

In conclusion, the literature suggests that stretching poses no significant advantage to endurance runners. Acute stretching can reduce running economy and performance for up to an hour by diminishing the musculotendinous stiffness and elastic energy potential. Chronic stretching additionally appears to have no advantageous effects and currently no research has suggested it can be beneficial for endurance athletes. In regards to DOMS, it has been reported consistently in the literature that stretching cannot reduce its longevity or intensity. **In relation to injury risk, specifically chronic injury, stretching has not been shown to have any major effect for endurance runners.** Endurance athletes are at high risk of overuse injuries such as illiotibial band syndrome, stress fractures and plantar fasciitis, and the literature suggests that stretching cannot reduce the prevalence of these injuries. It appears stretching may hold significance for certain exercise disciplines however it can be concluded that it holds no advantage for endurance runners and is not the solution to improving performance or reducing injury prevalence.

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