



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

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

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For Peer Review Only

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.

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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

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3 associated with the other variations of stretching, static stretching involves elongating a
4 muscle to the point at which a gentle tension is felt and remaining in this position for a given
5 amount of time. Typically, multiple stretches are performed on a single muscle group with a
6 minimum of thirty seconds per stretch (Woods et al., 2012). Bandy & Irion (1994)
7 investigated the duration of static stretching and reported that thirty seconds is the optimal
8 period for static stretching and that increasing this duration provides no additional
9 advantage. It is largely unknown as to the optimal frequency (days per week) or dimensions
10 of stretching on improvements in range of motion of a joint. Each variation of stretching has
11 speculated to provide an assortment of advantages to athletes of varying disciplines,
12 however the literature has primarily examined the effects of static stretching as this is the
13 variation most commonly recommended to and performed by endurance athletes (Shrier,
14 2004; Wallmann et al., 2012). The second distinction in stretching referenced in this review
15 is the acute or chronic nature of the activity. Acute stretching refers to a temporary activity
16 that is performed in a discrete capacity immediately before exercise (Wallmann et al., 2012).
17 In contrast, chronic stretching is defined as that which is performed outside of the warm up
18 regime as a tool of increasing long term flexibility (Stone et al., 2006).

19 Flexibility is a recognized fitness component and is considered a result of regular stretching
20 practices (Wilson et al., 2010; Shrier, 2004). However, a preliminary point to the stretching
21 debate is whether or not stretching does in fact improve flexibility. This is a question that
22 has been raised to determine whether or not the dispute surrounding the relationship
23 between performance and injury for athletes is central to stretching or flexibility. Is flexibility
24 the factor that is under scrutiny or is it simply that the common stretching methods engaged
25 by athletes are not increasing flexibility? The research has demonstrated that when simple
26 static stretching is executed regularly over a minimum of six weeks, flexibility is significantly
27 increased (Thacker et al., 2003; Bandy & Irion, 1994). This leads to the distinction between
28 acute stretching (single bout immediately before exercise) and long term chronic stretching
29

(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 than 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

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3 will neither improve nor decrease likelihood of developing running related injuries, however
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5 extreme cases outside the normal range of flexibility might be problematic. Future research
6
7 may be directed to quantifying this optimal level of flexibility for both performance and
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9 injury risk in the endurance running population compared to athletes of other disciplines.
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11 **Stretching and Performance**

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13 Long distance runners, considered to be athletes that participate in events 5km or longer,
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15 (Cosca & Navazio, 2007) are a population that are heavily influenced by the outcome of the
16
17 stretching debate (Wilson et al., 2010). The ability of endurance running can be divided into
18
19 two main subsections. Firstly, performance potential, which is impacted by physiological
20
21 parameters such as aerobic capacity (VO_2 max) and lactate threshold (Joyner & Coyle, 2008;
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23 Wilson et al., 2010; Godges et al., 1989). The VO_2 max represents a number of physiological
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25 aspects including cardiac output (Spurway et al., 2012), haemoglobin levels (Ferretti, 2014),
26
27 blood flow and muscle oxygen extraction (Joyner & Coyle, 2008). Lactate threshold is the
28
29 percentage of the VO_2 max where lactic acid levels rise sharply in the blood (Marcell et al.,
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31 2003). The higher the percentage of the VO_2 max in which the lactate threshold occurs
32
33 equates to the athletes increased potential for performance. The second variable is
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35 efficiency, which runs parallel to performance and varies about 30-40% among athletes
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37 (Joyner & Coyle, 2008). Running efficiency refers to how the body composition of an athlete
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39 impacts how effective muscles are at using available energy (Saunders et al., 2004) and is
40
41 dependent on factors such as muscle morphology, elastic elements and joint mechanics
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43 (Engeroff et al., 2014). The efficiency of movement is primarily due to anatomical and
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45 physiological factors of the body and methods to improve it are largely unknown (Joyner &
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47 Coyle, 2008). The efficiency variable of running ability is where stretching practices have the
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49 potential to impact an athlete's success (Barnes & Kilding, 2015). This raises the question of
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51 whether acute or chronic stretching is influencing running efficiency and whether it should
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53 remain an assumed aspect of training.
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3 Running economy is a multifactorial determinant that results from a number of metabolic,
4 cardiorespiratory and biomechanical characteristics including VO_2 max, lactate threshold
5 and running efficiency (Barnes & Kilding, 2015). Running economy is defined as the steady
6 state of oxygen consumption at a given running velocity, reflecting the energy demand of
7 running at a constant submaximal speed (Allison et al., 2008; Barnes & Kilding, 2015). It has
8 been considered the standard measurement for the overall competency of runners.
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10
11 Over the past twenty years, the literature on stretching and performance has expanded and
12 argued three standpoints, some studies providing evidence that stretching increases
13 performance, some arguing it decreases performance, and some stating it does not impact it
14 at all. Running economy was the primary indicator of performance for the studies
15 investigating the effect of stretching on the performance of long distance runners (Allison et
16 al., 2008; Joyner & Coyle, 2008; Barnes & Kilding, 2015; Wilson et al., 2010; Saunders et al.,
17 2004). The debate surrounding the effects of stretching surfaced after it was suggested that
18 acute stretching immediately before exercise had the ability to significantly inhibit
19 performance on short, explosive events including the leg press one repetition max (Bacurau
20 et al., 2009), 20m sprint performance (Nelson et al., 2005) and vertical jump height (Young
21 et al., 2001) due to the physiological changes seen in the muscle and the decreased ability to
22 store elastic energy (Wilson et al., 2010). As performance in long distance running events
23 relies on factors such as VO_2 max, lactate threshold and biomechanical factors in contrast to
24 the explosive, power oriented variables seen in anaerobic activities, a number of subsequent
25 studies analyzed the effects of acute stretching on endurance running (Wilson et al., 2010;
26 Gleim et al, 1990; Kyrolainen & Komi, 1994). Although some research demonstrated that
27 pre-exercise stretching has the potential to reduce explosive actions (Wilson et al., 2010), a
28 contrasting study reported that increased flexibility meant a reduction in musculo-tendinous
29 stiffness which by enhancing the use of elastic energy was able to improve the results of
30 rebound bench press (Wilson et al., 1992). However, this study (Wilson et al. 1992) is not
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3 relevant to endurance running. No additional studies have shown that acute stretching has
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5 the ability to improve the performance of athletes and notably no studies have reported
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7 positive effects for endurance runners. As a result, the debate has since evolved into
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9 whether stretching decreases running economy for endurance runners or simply does not
10
11 affect it.
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13 **Acute stretching and Performance**

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15 Athletes commonly use acute stretching during their warm up regime prior to both training
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17 and competition (Shrier, 2004). However, the majority of the literature that has investigated
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19 acute stretching and endurance running argues that stretching causes a decrease in running
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21 economy (Thacker et al., 2003; Saunders et al., 2004; Shrier, 2004). The central idea behind
22
23 this phenomenon is that stretching before an endurance event reduces mechanical
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25 efficiency of the lower body (Kyrolainen & Komi, 1994) primarily through the reduction of
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27 musculotendinous stiffness (Thacker et al., 2003). A musculotendinous unit is defined as the
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29 contractile muscle and the attached tendinous structures (McLachlan et al., 2006), and
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31 musculotendinous stiffness refers specifically refers to the units ability to resist an applied
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33 change in length (Kuitunen et al., 2002). Although this stiffness has traditionally been
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35 considered a factor that has the potential to increase the risk of injury and inhibit athlete's
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37 performance in the early stages of a race, it appears it is a desirable trait for long distance
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39 runners (Wilson & Flanagan, 2008). The reduction in mechanical efficiency stems directly
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41 from the decrement in muscle stiffness that appears as a result of static stretching. The
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43 specific reasoning behind why a decrease in musculotendinous stiffness leads to reduced
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45 mechanical efficiency varied throughout the literature however all reported that acute
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47 stretching before endurance based events does not assist athletes performance and in fact
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49 can diminish it (Wilson et al., 2010; Kyrolainen & Komi, 1994; Craib et al., 1996). One study
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51 suggested that stiffer muscles surrounding the ankle and knee joints causes an increase in
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53 force potentiation when transitioning from the braking to push off phase of running
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3 (Kyrokaianen & Komi, 1994) and proposed that stiffer muscles provide the best running
4 economy and results. Craib et al. (1996) investigated the effect of short and rapid stretching
5 on running economy and found that inflexibility in the hip and calf regions were associated
6 with improved running economy as less energy was required for muscle stabilization. The
7 improved running economy may be a result of increased pelvis stability and a reduction in
8 required muscle activation at foot strike to maintain stability. An additional study described
9 that acute stretching may result in an increase in the number of motor units recruited to
10 perform the same amount of mechanical work that is required without stretching. Activation
11 of a larger number of motor units means an increase in both oxygen consumption and
12 energy expenditure (Wilson et al., 2010). Additionally, Gleim et al. (1990) argues that
13 efficient elastic energy storage and return is favoured for endurance athletes with a tighter
14 musculotendinous system. Furthermore, acute stretching has the ability to strain the
15 muscle, causing a decrease in force development, and an increase in oxygen requirement
16 within the hour following the stretching regime (Shrier, 2004).

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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

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2
3 Godges et al., (1989) conducted a follow up study on a larger population, it was reported
4
5 that no effect on running economy was seen (Bonacci et al., 2009).
6

7
8 In conclusion, stretching does not possess properties that warrant it a useful or effective
9
10 tool in the warm up regime of long distance runners. Although the data is not entirely
11
12 conclusive and the literature demonstrates some disparity, there is little to suggest that
13
14 acute stretching has properties that can enhance performance for endurance athletes and in
15
16 fact may have the opposite effect. This research suggests that endurance athletes may be
17
18 best reducing their warm up routine to a low intensity, progressive run and removing
19
20 stretching practices completely.
21

22 **Chronic effects of Stretching and Performance**

23
24 It has been argued that provided that stretching is not completed immediately before
25
26 exercise - as is generally the case for athletes engaging in chronic stretching - increased
27
28 flexibility as a result of regular stretching will not inhibit performance or decrease running
29
30 economy (Nelson et al., 2001; Godges et al., 1993). Nelson et al. (2001) conducted a study
31
32 involving 32 participants over 10 weeks and noted that although flexibility was significantly
33
34 increased over the study duration, it did not appear to effect running economy. The study
35
36 makes specific mention that the exercise was not performed immediately following the
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38 stretching regime and although running economy was not reduced it also did not show
39
40 improvement. There was no studies found that reported that running economy would either
41
42 improve or decline from long term stretching programs. However, as previously reported,
43
44 the literature does suggest that an increased running economy has a high association with
45
46 inflexibility in endurance runners (Gleim et al., 1990; Posthumus et al., 2011; Saunders et al.,
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48 2004) As a result, unless stretching possesses other health or performance related benefits,
49
50 it appears to have little purpose in an endurance runner's preparation. The research
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52 suggests that there may be an optimal level of flexibility for running economy, in which a
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54 balance between muscle stiffness in order to maximize elastic energy storage and return is
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3 achieved while allowing enough movement for optimal stride length at high running speeds
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5 (Saunders et al., 2004).
6

7 The literature suggests acute stretching regimes do not help endurance runner's
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9 performance, and may in fact decrease running economy. Specifically, by decreasing
10
11 musculotendinous stiffness, acute stretching reduces stability and force production, in turn
12
13 decreasing mechanical efficiency and increasing oxygen demand (Wilson & Flanagan, 2008).
14
15 Therefore, if individuals feel it necessary to include stretching in their daily routine, it is
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17 suggested that it is not performed immediately before running. Further research is required
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19 to clarify the effects of chronic stretching on endurance running performance. Furthermore,
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21 the evidence on dynamic stretching is limited and requires further examination. Although no
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23 studies were able to provide evidence that acute stretching positively impacts performance
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25 for endurance runners the effects of chronic stretching on endurance running performance
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27 is unknown and is an area requiring further investigation. A notable weakness that is seen
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29 across all relevant literature examining the relationship between stretching and
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31 performance is the lack of explanation and are primarily speculative in nature. There are
32
33 limited evidence based claims which describe why acute and chronic stretching effects
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35 performance.
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39 **Stretching and Delayed Onset Muscle Soreness**

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41 Delayed onset muscle soreness (DOMS) is common and debilitating for endurance runners
42
43 (Cheung et al., 2003). DOMS can cause discomfort in the muscle and is the leading cause of
44
45 reduced performance in subsequent exercise, decreased muscle strength and range of
46
47 motion (High et al., 1989). The specific cause of DOMS is unknown, however it is thought to
48
49 be triggered by a series of biochemical changes that occur as a result of muscle damage
50
51 (Friden, 2008). It is often seen when individuals are exposed to high force eccentric
52
53 contractions repeatedly and/or unaccustomed exercise (Kim & Lee, 2014). Running has a
54
55 significant eccentric component which has been implicated in the manifestation of DOMS
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2
3 (Cheung et al., 2003). As a result, DOMS is prevalent following bouts of high intensity or
4
5 downhill running exercise (Kim & Lee, 2014). Therefore a reduction in the incidence of
6
7 DOMS and therefore an improvement in recovery would be such a quality to encourage
8
9 endurance athletes to leave stretching in their daily routine.
10

11
12 The use of stretching to prevent DOMS was supported by the idea that muscle soreness was
13
14 a result of unfamiliar exercise causing muscle spasm (de Vries, 1961). Muscle spasm was
15
16 thought to reduce blood flow to the muscle and conversely, stretching was thought to
17
18 restore blood to the muscle, interrupting the pain-spasm-pain cycle (Herbert et al., 2011).
19
20 High et al. (1989) conducted a study that investigated the effect of stretching on DOMS of 62
21
22 healthy participants in order to investigate these claims. Results were compared among the
23
24 individuals in the experimental (static stretching) and control (non-stretching) conditions
25
26 and the results demonstrated that there was no significant difference between muscle
27
28 soreness over the following five days. These findings were supported by a number of
29
30 additional studies, reporting that acute stretching does not provide a significant impact on
31
32 DOMS following exhaustive exercise (Buroker & Schwane, 1989; Johansson et al., 1999;
33
34 McGlynn et al., 1979; Wessel & Wan, 1994). Furthermore, Herbert & Gabriel (2007) reported
35
36 that although a small amount of improvement may be seen in DOMS following stretching, it
37
38 is too insignificant to warrant athletes including it into their warm up regime. Herbert et al.
39
40 (2011) reported that there was no evidence that suggested static or dynamic stretching
41
42 performed before or after exercise or in an acute or chronic capacity had the ability to
43
44 reduce the severity or duration of DOMS. Jamtvedt et al. (2010) supported these claims
45
46 surveying over 2,000 individuals and concluding that no variation of stretching has the ability
47
48 to alter DOMS.
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53 Similarly to the effects on performance, there is no evidence found which suggests that
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55 stretching has the ability to reduce either the presence of DOMS or the prevalence of
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57 chronic injury in long distance runners. A number of studies have investigated the
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3 relationship between stretching and the presence of DOMS following exercise and the
4
5 unanimous response is that the duration and intensity of DOMS cannot be influenced by
6
7 stretching (Herbert et al., 2011; Dannecker et al., 2002). There was no evidence to suggest
8
9 stretching could assist in the reduction of DOMS across the literature for athletes of any
10
11 discipline (Herbet el al., 2011). It is recommended that athletes suffering from DOMS
12
13 investigate other prevention methods, such as massaging, icing or hot and cold therapy
14
15 (Snyder et al., 2011; Sforzo et al., 2011).
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18 **Stretching and Chronic Injury**

19
20 The bulk of the literature investigating the relationship between stretching and injury for
21
22 long distance runners has focused on chronic, long term, degenerative injuries – which are
23
24 seen most commonly in this population. Although competitive endurance runners are most
25
26 frequently in their 20s and 30s, the majority of participants are within the 35-50 years
27
28 bracket (Cosca & Navazio, 2007). As a result, this population is at a high risk for running
29
30 related chronic injuries such as illiotibial band friction, achilles tendinopathy and plantar
31
32 fasciitis (Cosca & Navazio, 2007; Gallo et al., 2012). Marti et al. (1984) conducted a study on
33
34 over 4,000 male runners and reported that 45% sustained an injury over a one year period
35
36 with inflammation to the achilles tendon and calf muscle injuries among the most common.
37
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39 The majority of studies suggest that stretching has no impact of the risk of chronic injury in
40
41 endurance runners (Thacker et al., 2003; Cosca & Navazio, 2007; Witvrouw et al., 2004). It
42
43 has shown that long term stretching can potentially increase the compliance of the muscle-
44
45 tendon unit (Toft et al., 1989) and may allow greater force production at longer muscle
46
47 lengths (McHugh & Nesse, 2008) which may be relevant to other sporting disciplines
48
49 however Witvrouw et al. (2004) highlights that for endurance running these potential
50
51 benefits are not clinically beneficial. When participating in a long distance running event, the
52
53 lower limbs engage in a repetitive motion at a submaximal intensity. This means the tendons
54
55 in the legs are unlikely to require maximum energy absorption and elastic stability to
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3 perform the exercise (Witvrouw et al., 2004). This applies to all endurance events which
4
5 include repetitive motion such as long distance cycling and swimming. As a result of this, the
6
7 likeliness that the endurance athletes will encounter muscle strain injuries is low in
8
9 comparison to highly explosive sports which require maximum effort out of the musculo-
10
11 tendinous structures.

12
13 Dutch researchers (van Mechelen et al. 1993) studied the effect of stretching on injury over
14
15 a 10 week program and reported that stretching made no impact on the prevalence of
16
17 overuse injuries. Furthermore, the study did not report any muscle or tendon strain related
18
19 injuries supporting the idea that overuse injuries are the most frequent for endurance
20
21 runners. This also supports that although there is potential advantages for a subset of
22
23 sporting activities, due to the nature of the injuries generally experienced by endurance
24
25 runners, stretching provides no assistance in reducing the risk of injury (McHugh & Cosgrave,
26
27 2010). Pope et al. (2000) conducted a study which reinforced these claims, surveying over
28
29 1,000 military recruits and concluding that stretching did not affect the prevalence of
30
31 chronic overuse injuries in their population.

32
33 Bonacci et al. (2009) has commented that although stretching has not demonstrated any
34
35 ability to reduce the risk of injury in endurance runners, it can be an important tool in the
36
37 maintenance and promotion of range of motion in hip, knee and ankle joints after injury. An
38
39 additional study investigated the effect of flexibility on vertical jump technique and
40
41 suggested that stretching has both advantageous and disadvantageous properties
42
43 depending on the activities that individuals are participating in and what the athlete is trying
44
45 to achieve (Hunter & Marshall, 2002). This highlights that the relationship between the
46
47 effects of stretching and sporting activities generally is not clear and some athletes may
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49 benefit from incorporating chronic stretching into their routine from an injury risk
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51 standpoint.
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3 When investigating the relationship between stretching and chronic injury, the literature
4 shows a higher degree of discrepancy. Stretching may possess qualities that will help reduce
5 the likeliness of muscle and tendon strain injuries however this is unrelated to the subset of
6 injuries most experienced by endurance runners (McHugh & Cosgrave, 2010). As a result it
7 can be concluded that stretching provides no significant assistance in the reduction of
8 chronic overuse injuries and therefore is not a useful injury preventative strategy for
9 endurance athletes. Further research is required to determine whether stretching has the
10 ability to reduce the prevalence of muscle strain injuries and should remain incorporated
11 into the warm up regime of athletes of different areas.
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22 **Practical Implications**

23
24 The available research suggests neither acute nor chronic static stretching has clinically
25 beneficial effects for endurance runners on performance, incidence of DOMS or to prevent
26 injury. Therefore other strategies could be used to assist a runner with preparation and
27 recovery. Bazylar et al. (2011) conducted a study to investigate the benefit of a sub-maximal
28 warm up for endurance performance and found no significant improvements in
29 performance. Similarly, investigations involving dynamic stretching techniques have shown
30 little evidence to suggest it provides any advantage to endurance athletes (Dalleck et al.,
31 2007). However, the research outside of static stretching is limited (Dalleck et al., 2007) and
32 is an area requiring further research. From the current literature, it can be concluded that
33 stretching is an ineffective way of altering performance or injury risk and endurance athletes
34 are advised to direct their efforts to other strategies. In terms of pre-exercise activities, this
35 may include a progressive warm up prior to exercise which incorporates graded intensity.
36 Athletes are also recommended to individualize their training programs in order to promote
37 performance responses and reduce injury risk. Aside from the improvement of an athletes
38 lactate threshold and VO₂ max, supplementary efforts such as resistance training (Dean et
39 al., 2013) have reported to assist in the performance of endurance runners and may be a
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3 useful incorporation into the training schedule of athletes. Endurance runners experiencing
4
5 common overuse injuries are advised to treat each injury individually and acknowledge that
6
7 risk factors such as extensive mileage can impact the risk of developing a chronic injury in
8
9 the lower limbs (Warden et al., 2014). Therefore, progressive and planned training in
10
11 combination with over recovery modalities may be the most effective way to reduce injury
12
13 risk and promote recovery during period of high running volume. Cross and interval training
14
15 may be techniques used to reduce weekly mileage and the likeliness of overuse injuries
16
17 (Millet et al., 2011).
18
19

20 **Conclusion**

21
22 In conclusion, the literature suggests that stretching poses no significant advantage to
23
24 endurance runners. Acute stretching can reduce running economy and performance for up
25
26 to an hour by diminishing the musculotendinous stiffness and elastic energy potential.
27
28 Chronic stretching additionally appears to have no advantageous effects. In regards to
29
30 DOMS, it has been reported consistently in the literature that stretching cannot reduce its
31
32 longevity or intensity. In relation to injury risk, stretching shows little significance for
33
34 endurance runners to chronic injury. Endurance athletes are at high risk of overuse injuries
35
36 such as illiotibial band syndrome, stress fractures and plantar fasciitis, and the literature
37
38 suggests that stretching cannot reduce the prevalence of these injuries. It appears stretching
39
40 may hold significance for certain exercise disciplines however it can be concluded that it
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42 holds no advantage for endurance runners and is not the solution to improving performance
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44 or reducing injury prevalence.
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Impact of stretching on the performance and injury risk of long distance runners

For Peer Review Only

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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.

For Peer Review Only

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

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3 associated with the other variations of stretching, static stretching involves elongating a
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5 muscle to the point at which a gentle tension is felt and remaining in this position for a given
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7 amount of time. Typically, multiple stretches are performed on a single muscle group with a
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9 minimum of thirty seconds per stretch (Woods et al., 2012). Bandy & Irion (1994)
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11 investigated the duration of static stretching and reported that thirty seconds is the optimal
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13 period for static stretching and that increasing this duration provides no additional
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15 advantage. It is largely unknown as to the optimal frequency (days per week) or dimensions
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17 of stretching on improvements in range of motion of a joint. Each variation of stretching has
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19 speculated to provide an assortment of advantages to athletes of varying disciplines,
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21 however the literature has primarily examined the effects of static stretching as this is the
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23 variation most commonly recommended to and performed by endurance athletes (Shrier,
24
25 2004; Wallmann et al., 2012). The second distinction in stretching referenced in this review
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27 is the acute or chronic nature of the activity. Acute stretching refers to a temporary activity
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29 that is performed in a discrete capacity immediately before exercise (Wallmann et al., 2012).
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31 In contrast, chronic stretching is defined as that which is performed outside of the warm up
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33 regime as a tool of increasing long term flexibility (Stone et al., 2006).
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37 Flexibility is a recognized fitness component and is considered a result of regular stretching
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39 practices (Wilson et al., 2010; Shrier, 2004). However, a preliminary point to the stretching
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41 debate is whether or not stretching does in fact improve flexibility. This is a question that
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43 has been raised to determine whether or not the dispute surrounding the relationship
44
45 between performance and injury for athletes is central to stretching or flexibility. Is flexibility
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47 the factor that is under scrutiny or is it simply that the common stretching methods engaged
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49 by athletes are not increasing flexibility? The research has demonstrated that when simple
50
51 static stretching is executed regularly over a minimum of six weeks, flexibility is significantly
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53 increased (Thacker et al., 2003; Bandy & Irion, 1994). This leads to the distinction between
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55 acute stretching (single bout immediately before exercise) and long term chronic stretching
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3 (performed regularly and exclusive to the warm up regime of athletes). This is an important
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5 difference and as a result research has been conducted on both variations in relation to its
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7 affect on performance, DOMS and chronic injury in endurance runners.
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9 10 **Are endurance runners flexible?**

11 Running economy is a recognized determinant of the performance of endurance runners
12 and is measured by the energy demand of a runner at a specified velocity (Nelson et al.,
13 2001). There is evidence to suggest that typically, elite endurance runners are less flexible
14 than their non-elite counterparts (Saunders et al., 2004). Posthumus et al. (2011) completed
15 a survey that investigated the presence of the gene COL5A1 in endurance runners, a gene
16 associated with inflexibility, which demonstrated that endurance runners who possess this
17 gene had a considerably higher running economy than the other athletes participating in the
18 study. **The COL5A1 gene has been associated with type V collagen, with the varying**
19 **genotypes correlating with different ranges of motion (Posthumus et al., 2011).** This gene
20 also had a substantially greater presence among the endurance athletes subgroup than is
21 estimated across the general population (Posthumus et al., 2011). It has also been
22 postulated that hypertrophy of muscle can reduce the range of motion of a joint and this
23 also could contribute to the reduced flexibility seen **in athletes** (Wilson & Flanagan, 2008).
24 Gleim et al. (1990) conducted a study on untrained individuals and found that the
25 participants with the lowest flexibility consistently had the most economical running styles.
26 These results were justified by demonstrating that the decrease in range of motion of the
27 transverse and frontal physiological planes led to stabilization in the pelvic region when the
28 foot connected with the ground. This resulted in a reduction in excessive range of motion
29 and therefore **a decrease** in the energy required to stabilize muscular activity. It was also
30 suggested that tightness in the muscles and tendons could increase elastic storage and
31 therefore reduce the oxygen demand. Thacker et al. (2003) commented that the likeliness of
32 injury is also influenced and that there is an optimal flexibility for endurance runners. The
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3 research proposes that inflexibility can be compared to that of hyperflexibility when
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5 considering injury risk (Thacker et al., 2003). A base range of flexibility will neither improve
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7 nor decrease likeliness of developing running related injuries, however extreme cases
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9 outside the normal range of flexibility might be problematic. Future research may be
10
11 directed to quantifying this optimal level of flexibility for both performance and injury risk in
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13 the endurance running population compared to athletes of other disciplines.
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15 **Stretching and Performance**

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17 Long distance runners, considered to be athletes that participate in events 5km or longer,
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19 (Cosca & Navazio, 2007) are a population that are heavily influenced by the outcome of the
20
21 stretching debate (Wilson et al., 2010). The ability of endurance running can be divided into
22
23 two main subsections. Firstly, performance potential, which is impacted by physiological
24
25 parameters such as aerobic capacity (VO_2 max) and lactate threshold (Joyner & Coyle, 2008;
26
27 Wilson et al., 2010; Godges et al., 1989). The VO_2 max represents a number of physiological
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29 aspects including cardiac output (Spurway et al., 2012), haemoglobin levels (Ferretti, 2014),
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31 blood flow and muscle oxygen extraction (Joyner & Coyle, 2008). Lactate threshold is the
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33 percentage of the VO_2 max where lactic acid levels rise sharply in the blood (Marcell et al.,
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35 2003). The higher the percentage of the VO_2 max in which the lactate threshold occurs
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37 equates to the **athlete's** increased potential for performance. The second variable is
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39 efficiency, which runs parallel to performance and varies about 30-40% among athletes
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41 (Joyner & Coyle, 2008). Running efficiency refers to how the body composition of an athlete
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43 impacts how effective muscles are at using available energy (Saunders et al., 2004) and is
44
45 dependent on factors such as muscle morphology, elastic elements and joint mechanics
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47 (Engeroff et al., 2014). The efficiency of movement is primarily due to anatomical and
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49 physiological factors of the body and methods to improve it are largely unknown (Joyner &
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51 Coyle, 2008). The efficiency variable of running ability is where stretching practices have the
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53 potential to impact an athlete's success (Barnes & Kilding, 2015). This raises the question of
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3 whether acute or chronic stretching is influencing running efficiency and whether it should
4 remain an assumed aspect of training.
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7 Running economy is a multifactorial determinant that results from a number of metabolic,
8 cardiorespiratory and biomechanical characteristics including VO_2 max, lactate threshold
9 and running efficiency (Barnes & Kilding, 2015). Running economy is defined as the steady
10 state of oxygen consumption at a given running velocity, reflecting the energy demand of
11 running at a constant submaximal speed (Allison et al., 2008; Barnes & Kilding, 2015). It has
12 been considered the standard measurement for the overall competency of runners.
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20 Over **approximately the past decade**, the literature on stretching and performance has
21 expanded and argued three standpoints, some studies providing evidence that stretching
22 increases performance, some arguing it decreases performance, and some stating it does
23 not impact it at all. Running economy was the primary indicator of performance for the
24 studies investigating the effect of stretching on the performance of long distance runners
25 (Allison et al., 2008; Joyner & Coyle, 2008; Barnes & Kilding, 2015; Wilson et al., 2010;
26 Saunders et al., 2004). The debate surrounding the effects of stretching surfaced after it was
27 suggested that acute stretching immediately before exercise had the ability to significantly
28 inhibit performance on short, explosive events including the leg press one repetition max
29 (Bacurau et al., 2009), 20m sprint performance (Nelson et al., 2005) and vertical jump height
30 (Young et al., 2001) due to the physiological changes seen in the muscle and the decreased
31 ability to store elastic energy (Wilson et al., 2010). As performance in long distance running
32 events relies on factors such as VO_2 max, lactate threshold and biomechanical factors in
33 contrast to the explosive, power oriented variables seen in anaerobic activities, a number of
34 subsequent studies analyzed the effects of acute stretching on endurance running (Wilson et
35 al., 2010; Gleim et al, 1990; Kyrolainen & Komi, 1994). Although some research
36 demonstrated that pre-exercise stretching has the potential to reduce explosive actions
37 (Wilson et al., 2010), a contrasting study reported that increased flexibility meant a
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3 reduction in musculo-tendinous stiffness which by enhancing **elasticity, and possibly re-**
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5 **bound mechanics, was then** able to improve the results of rebound bench press (Wilson et
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7 al., 1992). However, this study (Wilson et al. 1992) is not relevant to endurance running. No
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9 additional studies have shown that acute stretching has the ability to improve the
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11 performance of athletes and notably no studies have reported positive effects for endurance
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13 runners. As a result, the debate has since evolved into whether stretching decreases running
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15 economy for endurance runners or simply does not affect it.
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18 **Acute stretching and Performance**

19
20 Athletes commonly use acute stretching during their warm up regime prior to both training
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22 and competition (Shrier, 2004). However, the majority of the literature that has investigated
23
24 acute stretching and endurance running argues that stretching causes a decrease in running
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26 economy (Thacker et al., 2003; Saunders et al., 2004; Shrier, 2004). The central idea behind
27
28 this phenomenon is that stretching before an endurance event reduces mechanical
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30 efficiency of the lower body (Kyrolainen & Komi, 1994) primarily through the reduction of
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32 musculotendinous stiffness (Thacker et al., 2003). A musculotendinous unit is defined as the
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34 contractile muscle and the attached tendinous structures (McLachlan et al., 2006), and
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36 musculotendinous stiffness refers specifically to the **unit's** ability to resist an applied change
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38 in length (Kuitunen et al., 2002). Although this stiffness has traditionally been considered a
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40 factor that has the potential to increase the risk of injury and inhibit athlete's performance
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42 in the early stages of a race, it appears it is a desirable trait for long distance runners (Wilson
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44 & Flanagan, 2008). The reduction in mechanical efficiency stems directly from the
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46 decrement in muscle stiffness that appears as a result of static stretching. The specific
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48 reasoning behind why a decrease in musculotendinous stiffness leads to reduced mechanical
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50 efficiency varied throughout the **literature. However, all** reported that acute stretching
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52 before endurance based events does not assist **athlete's** performance and in fact can
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54 diminish it (Wilson et al., 2010; Kyrolainen & Komi, 1994; Craib et al., 1996). One study
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3 suggested that stiffer muscles surrounding the ankle and knee joints causes an increase in
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5 force potentiation when transitioning from the braking to push off phase of running
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7 (Kyrokainen & Komi, 1994) and proposed that stiffer muscles provide the best running
8
9 economy and results. Craib et al. (1996) investigated the effect of short and rapid stretching
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11 on running economy and found that inflexibility in the hip and calf regions were associated
12
13 with improved running economy as less energy was required for muscle stabilization. The
14
15 improved running economy may be a result of increased pelvis stability and a reduction in
16
17 required muscle activation at foot strike to maintain stability. An additional study **conducted**
18
19 **by Wilson et al. (2010) suggested** that acute stretching may result in an increase in the
20
21 number of motor units recruited to perform the same amount of mechanical work that is
22
23 required without stretching. Activation of a larger number of motor units means an increase
24
25 in both oxygen consumption and energy expenditure (Wilson et al., 2010). Additionally,
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27 Gleim et al. (1990) argues that efficient elastic energy storage and return is favoured for
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29 endurance athletes with a tighter musculotendinous system. Furthermore, acute stretching
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31 has the ability to strain the muscle, causing a decrease in force development, and an
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33 increase in oxygen requirement within the hour following the stretching regime (Shrier,
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35 2004).

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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

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3 before performance testing can increase the strength of that muscle group at specific
4 isokinetic degrees (Godges et al., 1989; Akagi & Takahashi, 2014), however these results did
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6
7 not provide evidence to suggest that the same results could be applied to endurance
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10 running (Worrell et al., 1994). Furthermore, when Godges et al., (1989) conducted a follow
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12 up study on a larger population, it was reported that no effect on running economy was
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14 seen (Bonacci et al., 2009).

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16 In conclusion, **static** stretching does not possess properties that warrant it a useful or
17
18 effective tool in the warm up regime of long distance runners. Although the data is not
19
20 entirely conclusive and the literature demonstrates some disparity, there is little to suggest
21
22 that acute stretching has properties that can enhance performance for endurance athletes
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24 and in fact may have the opposite effect. This research suggests that endurance athletes
25
26 may be best reducing their warm up routine to a low intensity, progressive run and
27
28 removing stretching practices completely.

30 31 **Chronic effects of Stretching and Performance**

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33 It has been argued that provided that stretching is not completed immediately before
34
35 exercise - as is generally the case for athletes engaging in chronic stretching - increased
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37 flexibility as a result of regular stretching will not inhibit performance or decrease running
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39 economy (Nelson et al., 2001; Godges et al., 1993). Nelson et al. (2001) conducted a study
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41 involving 32 participants over 10 weeks and noted that although flexibility was significantly
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43 increased over the study duration, it did not appear to **affect** running economy. The study
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45 makes specific mention that the exercise was not performed immediately following the
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47 stretching regime and although running economy was not reduced it also did not show
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49 improvement. There **were** no studies **that were** found **which** reported that running
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51 economy would **either be positively or negatively affected from** long term stretching
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53 programs. However, as previously reported, the literature does suggest that an increased
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55 running economy has a high association with inflexibility in endurance runners (Gleim et al.,
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3 1990; Posthumus et al., 2011; Saunders et al., 2004) As a result, unless stretching possesses
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5 other health or performance related benefits, it appears to have little purpose in an
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7 endurance runner's preparation. The research suggests that there may be an optimal level
8
9 of flexibility for running economy, in which a balance between muscle stiffness in order to
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11 maximize elastic energy storage and return is achieved while allowing enough movement for
12
13 optimal stride length at high running speeds (Saunders et al., 2004).

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

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50 Delayed onset muscle soreness (DOMS) is common and debilitating for endurance runners
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52 (Cheung et al., 2003). DOMS can cause discomfort in the muscle and is the leading cause of
53
54 reduced performance in subsequent exercise, decreased muscle strength and range of
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56 motion (High et al., 1989). The specific cause of DOMS is unknown, however it is thought to
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3 be triggered by a series of biochemical changes that occur as a result of muscle damage
4
5 (Friden, 2008). **It is often seen when individuals are exposed to repeated high-force**
6
7 **eccentric contractions and/or unaccustomed exercise** (Kim & Lee, 2014). Running has a
8
9 significant eccentric component which has been implicated in the manifestation of DOMS
10
11 (Cheung et al., 2003). As a result, DOMS is prevalent following bouts of high intensity or
12
13 downhill running exercise (Kim & Lee, 2014).
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18 The use of stretching to prevent DOMS was supported by the idea that muscle soreness was
19
20 a result of unfamiliar exercise causing muscle spasm (de Vries, 1961). Muscle spasm was
21
22 thought to reduce blood flow to the muscle and conversely, stretching was thought to
23
24 restore blood to the muscle, interrupting the pain-spasm-pain cycle (Herbert et al., 2011).
25
26 High et al. (1989) conducted a study that investigated the effect of stretching on DOMS of 62
27
28 healthy participants in order to investigate these claims. Results were compared among the
29
30 individuals in the experimental (static stretching) and control (non-stretching) conditions
31
32 and the results demonstrated that there was no significant difference between muscle
33
34 soreness over the following five days. These findings were supported by a number of
35
36 additional studies, reporting that acute stretching does not provide a significant impact on
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38 DOMS following exhaustive exercise (Buroker & Schwane, 1989; Johansson et al., 1999;
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40 McGlynn et al., 1979; Wessel & Wan, 1994). Furthermore, Herbert & Gabriel (2007) reported
41
42 that although a small amount of improvement may be seen in DOMS following stretching, it
43
44 is too insignificant to warrant athletes including it into their warm up regime. Herbert et al.
45
46 (2011) reported that there was no evidence that suggested static or dynamic stretching
47
48 performed before or after exercise or in an acute or chronic capacity had the ability to
49
50 reduce the severity or duration of DOMS. Jamtvedt et al. (2010) supported these claims
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52 surveying over 2,000 individuals and concluding that no variation of stretching has the ability
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54 to alter DOMS.
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3 Similarly to the effects on performance, there is no evidence found which suggests that
4 stretching has the ability to reduce either the presence of DOMS or the prevalence of
5 chronic injury in long distance runners. A number of studies have investigated the
6 relationship between stretching and the presence of DOMS following exercise and the
7 unanimous response is that the duration and intensity of DOMS cannot be influenced by
8 stretching (Herbert et al., 2011; Dannecker et al., 2002; **Johansson et al., 1999; Engbretson**
9 **et al., 1999**). In conclusion, there was no evidence to suggest stretching could assist in the
10 reduction of DOMS for athletes of any discipline. It is recommended that athletes suffering
11 from DOMS investigate other prevention methods, such as massaging, icing or hot and cold
12 therapy (Snyder et al., 2011; Sforzo et al., 2011).

23 **Stretching and Chronic Injury**

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

33 The majority of studies suggest that stretching has no impact **on** the risk of chronic injury in
34 endurance runners (Thacker et al., 2003; Cosca & Navazio, 2007; Witvrouw et al., 2004). It
35 has shown that long term stretching can potentially increase the compliance of the muscle-
36 tendon unit (Toft et al., 1989) and may allow greater force production at longer muscle
37 lengths (McHugh & Nesse, 2008) which may be relevant to other sporting disciplines
38 however Witvrouw et al. (2004) highlights that for endurance running these potential
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3 benefits are not clinically beneficial. When participating in a long distance running event, the
4
5 lower limbs engage in a repetitive motion at a submaximal intensity. This means the tendons
6
7 in the legs are unlikely to require maximum energy absorption and elastic stability to
8
9 perform the exercise (Witvrouw et al., 2004). This applies to all endurance events which
10
11 include repetitive motion such as long distance cycling and swimming. As a result of this, the
12
13 likeliness that the endurance athletes will encounter muscle strain injuries is low in
14
15 comparison to highly explosive sports which require maximum effort out of the musculo-
16
17 tendinous structures.
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19
20 Dutch researchers (van Mechelen et al. 1993) studied the effect of stretching on injury over
21
22 a **10-week** program and reported that stretching made no impact on the prevalence of
23
24 overuse injuries. Furthermore, the study did not report any muscle or tendon strain related
25
26 injuries supporting the idea that overuse injuries are the most frequent for endurance
27
28 runners. This also supports that although there is potential advantages for a subset of
29
30 sporting activities, due to the nature of the injuries generally experienced by endurance
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32 runners, stretching provides no assistance in reducing the risk of injury (McHugh & Cosgrave,
33
34 2010). Pope et al. (2000) conducted a study which reinforced these claims, surveying over
35
36 1,000 military recruits and concluding that stretching did not affect the prevalence of
37
38 chronic overuse injuries in their population.
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41 Bonacci et al. (2009) has commented that although stretching has not demonstrated any
42
43 ability to reduce the risk of injury in endurance runners, it can be an important tool in the
44
45 maintenance and promotion of range of motion in hip, knee and ankle joints after injury.
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48 **Hunter and Marshall (2002) suggested that stretching has both advantageous and**
49
50 **disadvantageous properties** depending on the activities that individuals are participating in
51
52 and what the athlete is trying to achieve). This highlights that the relationship between the
53
54 effects of stretching and sporting activities generally is not clear and some athletes may
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56 benefit from incorporating chronic stretching into their routine from an injury risk
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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. Bazylar 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**

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2
3 **performance in endurance based running events.** Alternative strategies may include
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5 incorporating graded intensity in the preliminary stages of a run. Athletes are also
6
7 recommended to individualize their training programs in order to promote performance
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9 responses and reduce injury risk. **As well as the improvement of an athlete's lactate**
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11 **threshold and VO₂ max, supplementary training such as resistance training (Dean et al.,**
12
13 **2013) have been reported to assist in the improved performance of endurance runners**
14
15 **and may be a useful incorporation into the training schedule of athletes.** Endurance
16
17 runners experiencing common overuse injuries are advised to treat each injury individually
18
19 and acknowledge that risk factors such as extensive mileage can impact the risk of
20
21 developing a chronic injury in the lower limbs (Warden et al., 2014). Therefore, progressive
22
23 and planned training in combination with over recovery modalities may be the most
24
25 effective way to reduce injury risk and promote recovery during **periods** of high running
26
27 volume. Cross and interval training may be techniques used to reduce weekly mileage and
28
29 the likeliness of overuse injuries (Millet et al., 2011).
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31

32 33 **Conclusion**

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35 In conclusion, the literature suggests that stretching poses no significant advantage to
36
37 endurance runners. Acute stretching can reduce running economy and performance for up
38
39 to an hour by diminishing the musculotendinous stiffness and elastic energy potential.
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41 Chronic stretching additionally appears to have no advantageous effects and currently no
42
43 research has suggested it can be beneficial for endurance athletes. In regards to DOMS, it
44
45 has been reported consistently in the literature that stretching cannot reduce its longevity or
46
47 intensity. **In relation to injury risk, specifically chronic injury, stretching has not been**
48
49 **shown to have any major effect for endurance runners.** Endurance athletes are at high risk
50
51 of overuse injuries such as illiotibial band syndrome, stress fractures and plantar fasciitis,
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53 and the literature suggests that stretching cannot reduce the prevalence of these injuries. It
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55 appears stretching may hold significance for certain exercise disciplines however it can be
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3 concluded that it holds no advantage for endurance runners and is not the solution to
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5 improving performance or reducing injury prevalence.
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