Static stretching (SS) is commonly practiced by athletes, both as a part of a pre-exercise routine and part of an ongoing exercise programme. While different types of stretching can be used for slightly different reasons, the aims of SS are typically to:

• improve flexibility,
• enhance physical performance,
• prevent injury to the musculotendinous unit (MTU) and/or
• improve the speed of return to sport after injury.

Research suggests that other forms of training and rehabilitation (e.g. strength training) can achieve many of these aims as effectively, or even more effectively, than SS. However, SS has remained an integral part of athletic preparation. We recently published a systematic review which showed that eccentric strength training programmes consistently increase flexibility, which might have been considered the primary benefit of SS and called into question whether SS has an additional benefit among athletic populations. In this article we wish to discuss whether there is evidence that SS is worth including in athlete management for each of these proposed aims. For each aim, the supporting evidence will be contrasted with the evidence for a graded strength training programme.

STATIC STRETCHING AND FLEXIBILITY

There is consistent evidence that SS increases flexibility in the short-term, although the gains in flexibility decrease relatively quickly, such that they are lost within 30 minutes. There is also consistent evidence that SS performed regularly for several weeks results in meaningful improvements in range of motion (ROM).

Mechanism of increasing flexibility with SS

The mechanism of how this increased ROM occurs is subject to debate, with changes in neurophysiological (e.g. changes in stretch tolerance) and mechanical (e.g. viscoelastic changes, sarcomerogenesis) factors proposed. There is little doubt from animal studies that sustained SS, or immobilisation, can induce mechanical tissue changes, with tissues adapting and remodelling in response to the stress they are placed under. Interpreting this animal research must acknowledge that some studies examine SS being applied continuously for days or even weeks. This may not reflect the effect of SS being performed for just a few minutes.
times per week. For example, even among animals, intermittent SS every few days (3 times/week for 40 minutes)\textsuperscript{15} may not prevent reductions in length caused by immobilisation.

Determining whether ROM changes are due to mechanical changes in the MTU among humans typically requires examining whether SS reduces the passive resistance to torque (PRT) when producing a specified ROM or whether SS reduces tendon stiffness (e.g. measured using elastography) during contraction. Several studies have shown that sustained SS does not change MTU mechanical properties\textsuperscript{11,16–22}, with no change in the PRT following SS despite increases in ROM. This would suggest that the increased ROM is due to increased stretch tolerance, rather than any mechanical alteration in the tissues. However, several other studies\textsuperscript{23–27} have reported changes in PRT after SS, with the degree of increase in ROM being correlated with the decrease in PRT\textsuperscript{25,26}. While the disagreement on changes in PRT is confusing, there is agreement on the lack of change in tendon stiffness following sustained SS, irrespective of whether studies have\textsuperscript{23,24,26} or have not\textsuperscript{21} reported a change in PRT. This discrepancy suggests that if structural changes occur following SS they may be more likely to occur in the parallel elastic component of the musculature or even the joint capsule rather than within the tendon itself. While tendon stiffness does not appear to change following sustained SS, there does appear to be changes in the viscoelastic properties of tendons in the long-term, as evidenced in changes in the hysteresis loop in tendons\textsuperscript{24}.

Strength training has more consistently been shown to influence the mechanical and neurophysiological properties of the MTU. Both animal\textsuperscript{18,29} and human\textsuperscript{10–32} studies consistently demonstrate that eccentric strength training results in increased flexibility, measured using indirect measures such as joint ROM\textsuperscript{30,33} and direct measurement of fascicle length\textsuperscript{31,32,34}. This is thought to reflect the addition of sarcomeres in series (sarcomereogenesis), as documented in different muscle groups\textsuperscript{30–32}. This hypothesis is further supported by the fact that increases in ROM\textsuperscript{30} and fascicle length\textsuperscript{34} closely parallel changes in the muscle length-tension curve\textsuperscript{16}. Numerous authors have shown that strength training increases the PRT of muscle\textsuperscript{17,21}, increases tendon stiffness\textsuperscript{27–30} and increases stiffness of the MTU\textsuperscript{30,41}. This increased stiffness is associated with increased flexibility, where eccentric strength training for as little as 6 weeks significant increases flexibility\textsuperscript{10,33}. The magnitude of increase in flexibility reported after eccentric training\textsuperscript{23,30,31,32,34} appears to be similar to that achieved after SS\textsuperscript{11,16,41} and sufficient to address deficits observed among those with recurrent pain/injury\textsuperscript{6,44,45}. However, it is important to highlight that the precise type of eccentric training performed varies a lot between studies. For example, while all studies in our recent review\textsuperscript{1} showed increased flexibility after eccentric training, the largest increase was seen in a study\textsuperscript{30} which incorporated a static hold in the elongated position. Therefore, the improvements in flexibility after some eccentric training may not be as large as those obtained by SS. There is some inconsistency in the literature regarding the effect of other strength training programmes on flexibility. Most studies suggest that eccentric-only programmes result in greater flexibility gains than concentric-only\textsuperscript{32,46} or isometric-only\textsuperscript{47} training programmes. However, some research has reported findings suggesting that there may be no difference in flexibility gains dependent on the mode of strength training, with the ROM through which the muscle is exercised possibly being more critical than the mode of exercise\textsuperscript{34}. Further research is therefore needed to clarify whether flexibility can be effectively increased with non-eccentric strength training.

**In summary**
- SS increases flexibility in both the short- and long-term.
• The precise mechanism(s) through which SS achieves increased flexibility is still debatable. While enhanced stretch tolerance is likely and changes in tendon stiffness are very unlikely, mechanical changes in PRT have been reported inconsistently.

• Flexibility is also increased by strength training, especially eccentric training. The magnitude of increase achieved appears to be close to that achieved through SS. Interestingly, strength training appears to increase both tendon stiffness and overall MTU stiffness, while simultaneously increasing ROM.

• Neither SS nor strength training appears to consistently decrease the stiffness of the joints.

STATIC STRETCHING AND PERFORMANCE

Acute SS

Effect on strength, power and explosive muscle performance

Several recent reviews and meta-analyses\(^ {46-50} \) have agreed that SS maintained for greater than 45 seconds immediately before performance either:

- negatively influences maximal strength, power, muscular explosive performance (e.g. jumping and sprinting), balance and agility or
- has no effect on performance.

In other words, none of the reviews showed a beneficial effect of SS on performance! There is an apparent dose-response relationship with shorter duration SS being less commonly associated with decrements in performance\(^ {59} \). Maximal strength appears to be more commonly negatively affected by SS than explosive muscular performance or power\(^ {48,50} \).

Effect on endurance performance

The influence of acute SS on activities such as running and cycling is less clear cut. A recent review\(^ {62} \) described how several studies\(^ {53-56} \) show a negative influence while others\(^ {52,57-59} \) show no change in performance. Very few studies\(^ {56} \) report improvements in endurance performance following acute SS.

Sustained SS

Effect on strength, power and explosive muscular performance

Overall, fewer studies have assessed the influence of sustained SS on performance. While several studies have shown some improvements in some of these performance measures after sustained SS\(^ {25,61-63} \), this is not observed on all measures in these studies\(^ {64} \) or at all in many other studies\(^ {17,25,64} \). Typically, the studies which have shown improvements in performance after SS have compared to an inactive control group, rather than another exercise group. For the most part SS does not appear to impair performance. In marked contrast, far superior and more consistent improvements in muscular performance are evident after strength training\(^ {22,65} \). The addition of SS to strength training does not appear to provide additional benefits nor to influence the passive properties of the MTU\(^ {17,65,66} \). However a recent study\(^ {67} \) showed that SS which was consistently performed immediately before strength training actually reduced the gains in strength achieved compared to strength training alone.

Effect on endurance performance

Sustained SS does not appear to enhance running or walking efficiency\(^ {55,66,69} \) even when ROM is increased\(^ {69} \). Results are equivocal with SS and endurance performance\(^ {58,69} \). In contrast, strength training consistently improves endurance performance\(^ {66,70-72} \).

In summary

- Acute SS for greater than 45 seconds should be avoided immediately before participation in activities where strength or power are important, as performance is likely to be reduced without any clear benefits to justify its continued use.
- Shorter durations of SS are also hard to justify immediately before participation in activities where strength or power are important given the potential for decreased performance and lack of clear benefits.
- In endurance activities, acute SS is hard to justify immediately before participation as performance may be reduced with no clear benefits to justify its continued use.
- Sustained SS is not associated with as clear a decline in performance as acute SS and may in fact enhance strength and power compared to not performing any exercise programme. However, since SS is far less effective than strength training in enhancing strength and power and it is unclear whether adding SS might reduce the strength gains achieved, it is hard to justify its continued use.
- Sustained SS does not appear to enhance gait economy, nor consistently enhance endurance performance. In contrast, strength training enhances endurance performance.

STATIC STRETCHING AND INJURY PREVENTION OR TREATMENT

It seems to make sense intuitively that SS should help prevent injury, or help hasten return to activity. For example, athletes with a previous injury often remain less flexible in that limb\(^ {56,64} \) and often report ‘tightness’ prior to injury, or intermittently in a previously injured region. In addition, the degree to which flexibility is reduced in the early days post-injury appears to be linked to the speed of return to activity\(^ {73} \). Finally, several studies have suggested that decreased flexibility at baseline, or stretching less often, may predispose to injury\(^ {74-80} \).

However, the relationship between baseline flexibility and future injury risk is complex, with many studies\(^ {81,82} \) demonstrating no relationship between the two. In fact, several systematic reviews have now evaluated the effect of SS on risk
of injury\textsuperscript{83-85}. These reviews conclude that: “There is not sufficient evidence to endorse or discontinue routine stretching before or after exercise to prevent injury among competitive or recreational athletes\textsuperscript{83}” and “In light of these findings, routine stretching exercises before initiation of sport activities are not a proven, effective method for reducing injury rates\textsuperscript{86}.” This scientific literature contradicts long-held beliefs about the proposed benefits of SS for injury prevention. It could be argued that many studies have typically included SS as part of a multimodal intervention, making it difficult to pronounce definitive conclusions about the specific contribution of SS. A recent meta-analysis\textsuperscript{87} addressed this concern, by investigating the effectiveness of exercise interventions at preventing sports injuries while allowing for multimodal exposures and calculating the relative risk of each intervention. Unsurprisingly, their findings “do not support the use of stretching for injury prevention purposes, neither before or after exercise\textsuperscript{87}” Therefore, at least in in terms of injury prevention, it appears SS has very little to offer and should not be used.

In contrast, a wide range of other interventions can reduce injury rates, with Laursen et al\textsuperscript{87} stating that “consistently favourable estimates were obtained for all injury prevention measures except for stretching.” For example, consider the strong evidence that gradually progressive strength training programmes which are maintained after return to sport and/or throughout the season can greatly reduce the occurrence and, in particular, recurrence of a range of musculoskeletal pains and/or injuries\textsuperscript{88-94}. The aforementioned meta-analysis\textsuperscript{87} showed that strength training reduced incidence of sports injuries to less than one third. Thus while there is substantial evidence to suggest a negligible protective effect of SS on sports injury, strength training – and in particular eccentric strength training – positively influences injury rates.

In terms of hastening return to sport, the relatively weak support for the role of SS in reviews of injury management\textsuperscript{95,96} is based on a single randomised controlled trial\textsuperscript{97} which showed that performing SS four times per day instead of just once per day reduces the time until return to sport. However, performing SS less frequently only delayed return to sport by less than 2 days, such that this may not be a clinically significant finding. In contrast, another randomised controlled trial\textsuperscript{98} showed that an eccentric-based strength training programme reduced the time to return to sport significantly more than a ‘conventional’ training programme which included a mix of SS, concentric and eccentric exercises. In this case, the mean difference between groups for time to return to sport was a huge 23 days! It should be acknowledged that the latter study did not allow return to sport until athletes were able to complete the ‘H-test’ satisfactorily, meaning that athletes in both groups did not return to sport as quickly as in the other study\textsuperscript{99}. Unfortunately, there has been no randomised controlled trial comparing either SS or strength training to natural recovery, which is needed to conclusively demonstrate that either of these approaches is better than no treatment.

**In summary**

- SS does not appear to reduce injury risk and any effect on earlier return to sport is of marginal clinical significance.
- In contrast, a graduated strength training programme appears to significantly reduce injury risk and significantly reduce the time to return to sport after injury.

**CLINICAL IMPLICATIONS**

It is difficult to justify the use of SS for any of the aims examined in this article:

- **Flexibility**: SS is very effective in both the short-term and long-term. However, (i) flexibility is not as important a factor in performance and injury prevention as once thought and (ii) other methods of increasing flexibility such as gradually progressive strength training are available. It remains unclear whether increases in flexibility after strength training are equivalent to those after SS, however they appear greatest after eccentric programmes.

- **Short-term performance**: SS may diminish performance, especially when performed immediately before explosive activities. While the effect of chronic SS is equivocal, strength training programmes are associated with improvements in performance and adding SS to strength training may actually reduce the strength gains achieved.

- **Injury prevention or return to sport after injury**: there is very little evidence that SS is effective. In contrast, there is considerable evidence
that progressive strength training programmes, which typically include an eccentric component, reduce injury risk, pain and disability in a range of musculotendinous conditions, as well as hastening return to sport.

Therefore, the only area in which SS might seem to offer a specific advantage is in the area of increasing flexibility. There may be times when the most important goal is enhancing flexibility (e.g. ballet) and in these isolated circumstances SS may be justifiable. However, there remains a lack of evidence that gains are superior to those of a strength training programme. Even if strength training is eventually confirmed as being inferior to SS at increasing flexibility, the fact that strength training improves performance, pain, disability, injury and return to sport rates mean strength training must be a mainstay of athletic development and training, in contrast to SS.

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1. Does this apply to areas which are commonly reported as being ‘tight’ e.g. hip flexors?
   In short, yes. While there is evidence that some specific restrictions in hip mobility may be related to future injury69, such changes are likely to be strongly related to underlying bony architecture99 and there is little or no evidence that SS modifies such deficits.

2. If flexibility is not important, why do evidence-based tests capable of predicting the likely duration of absence post-injury98 or the safety of returning to sport100 examine flexibility?
   These tests, which do appear very useful, are actually indicators of pain intensity98 and ability to tolerate eccentric load100 rather than tests of flexibility.

3. Athletes commonly report symptoms of ‘tightness’ in advanced of, or after, an injury. Is there a role for monitoring and/or stretching, this tightness?
   Monitoring – yes, SS – probably not! There is emerging evidence98 that symptoms of ‘tightness’ may simply be one manifestation of muscle micro-damage rather than restricted tissue length. Management which addresses the ability of the MTU to withstand load86,87,89,94,95 and the external load placed on the athlete49,101,102 would appear to be more justifiable than SS to address this ‘tightness’. Therefore, there may still be a role of ongoing monitoring of flexibility, but on the basis that decreasing flexibility in an athlete may act as a marker of an athlete being over-reached, similar to monitoring performance measures (e.g. counter-movement jump) intermittently. In such a case, initial moderation of training load86,94,102, managing a gradual return to normal training loads and consideration of an athlete’s systemic health105,106 are probably more worthwhile than SS to target a perceived restriction in muscle extensibility.

4. How long should a strength training programme last to achieve flexibility and performance gains and injury reduction?
   Benefits from strength training are seen very quickly. However, like all successful rehabilitation programmes, this should be maintained even after the athlete has returned to full participation to continue appropriate MTU loading and to improve functional capacity, as gains from all such programmes are temporary.

5. How does this apply to other forms of stretching e.g. dynamic stretching?
   Dynamic stretching as part of an athletic warm-up does not always improve flexibility as effectively as SS44. However, it appears to less frequently have a negative effect on performance than SS54. Consequently, it may be acceptable for dynamic stretching to be completed immediately before participation. In terms of injury prevention, dynamic stretching does not have the degree of supporting evidence that a gradually progressive strength training programme does, similar to SS.

6. How do we clarify the questions which remain, such as the mechanism through which SS increases flexibility and the effect of SS on return to play time?
   Firstly, greater consistency in definitions of flexibility and SS between studies might enhance understanding. Secondly, more accurate in vivo measurements of human MTU are needed. Finally, more studies are required to determine if SS offers any additional benefit for return to play durations after injury over either natural recovery alone or strength training.