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Invited Review

Effects of acute and chronic stretching on pain control

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Abstract

While muscle stretching has been commonly used to alleviate pain, reports of its effectiveness have been conflicting. The objective of this review was to investigate the acute and chronic effects of stretching on pain, including delayed onset muscle soreness. The few studies implementing acute stretching protocols have reported small to large magnitude decreases in quadriceps and anterior knee pain as well as reductions in headache pain. Chronic stretching programs have demonstrated more consistent reductions in pain from a wide variety of joints and muscles, which has been ascribed to an increased sensory (pain) tolerance. Other mechanisms underlying acute and chronic pain reduction have been proposed to be related to Gate Control Theory, Diffuse Noxious Inhibitory Control, myofascial meridians, and reflex-induced increases in parasympathetic nervous activity. By contrast, the acute effects of stretching on delayed onset muscle soreness (DOMS) are conflicting. Reports of stretch-induced reductions in DOMS may be attributed to increased pain tolerance or alterations in the muscle's parallel elastic component or extracellular matrix properties providing protection against tissue damage. Further research evaluating the effect of various stretching protocols on different pain modalities is needed to clarify conflicts within the literature.

Keywords: flexibility; static stretching; proprioceptive neuromuscular facilitation; delayed onset muscle soreness; exercise-induced muscle soreness.

Major takeaways on stretch-induced pain reduction

1. Acute stretching protocols (static and PNF) have reported small to large magnitude decreases in musculoskeletal and headache pain. However, the literature is sparse.
2. Chronic stretching programs report more consistent alleviation or reduction of pain.
3. Proposed stretching-induced pain reduction mechanisms include increased sensory (pain) tolerance, Gate Control Theory, Diffuse Noxious Inhibitory Control, myofascial meridians, and reflex-induced increases in parasympathetic nervous activity.
4. The effect of stretching on delayed onset muscle soreness (DOMS) is generally conflicting, although chronic stretching (i.e., 3-6 weeks) prior to the exercise may reduce DOMS.

Introduction

Musculoskeletal pain is ubiquitous throughout the population. In general, musculoskeletal disorders have increased by 30% from 1990-2019 according to the Global Burden of Disease Study (1). The World Health Organization (WHO) (2) reports the following key facts regarding musculoskeletal conditions: "1) Approximately 1.71 billion people have musculoskeletal conditions worldwide. 2) Among musculoskeletal disorders, low back pain causes the highest burden with a prevalence of 568 million people. 3) Musculoskeletal conditions are the leading contributor to disability worldwide, with low back pain being the single leading cause of disability in 160 countries." It has been suggested that a combination of flexibility training, muscle strengthening and movement re-education may reduce musculoskeletal pain and discomfort (3, 4).

The impact of spinal flexibility on low back pain incidence is controversial. It seems that both restricted spinal flexibility or mobility (5-7) and excessive mobility (8) can

contribute to back problems. However, tight hip flexors (9) and lack of lumbar or hip (9) or thoracic (10) mobility were not related to low back pain. Nonetheless, it has been frequently suggested that adequate flexibility can attenuate the incidence and severity of low back pain (4, 11-17).

However, low back pain is not the only common disorder among the musculoskeletal disorders. Neck pain episodes, with a prevalence of 222 million (1), have remained the same from 1990-2017 despite numerous interventions (18). One reason could be the increase in the number of office and computer workers compared to manual workers, as they are more stationary due to their job requirements (19). Muscle stretching is one of many treatments recommended to address the musculoskeletal pain (20). However, the origin and cause of pain can influence the benefits expected from performing such interventions.

For this reason, research regarding the acute effects of stretching on delayed onset muscle soreness (DOMS) is equivocal. Whilst one study indicated that stretching reduced DOMS (21), a meta-analysis by Herbert et al. (22) reported no significant overall effect (10 studies) of pre- or post-exercise stretching on DOMS. Hence, the objective of this paper is to review the literature regarding the possible effectiveness of acute and chronic stretching for pain modulation of the affected (local) and non-local regions as well as with delayed onset muscle soreness (DOMS) and to suggest possible mechanisms of action.

Pain

Both muscle stretching and massage have been widely used for pain relief since before scientific confirmation of its effectiveness or appropriate application guidelines (e.g., duration, intensity, frequency) was provided (3). It is generally considered to be effective for pain relief with both acute and chronic applications of stretching being used (21, 23-44).

Effects of Acute Stretching on Pain

Few studies have directly examined the acute effects of stretching alone on pain, with many studies instead combining it with other modalities such as strengthening, manual therapy, mobilization, and immobilization (45-54). However, two studies implemented stretching-only interventions and observed significant reductions in pain. For example, contract-relax proprioceptive neuromuscular facilitation (PNF) stretching (6-s resistance, 4-s relaxation for a total of 30 s for three trials) targeting the hip flexors and knee extensors increased the pain pressure threshold in the rectus femoris (effect size: 0.28, small magnitude), vastus lateralis (effect size: 0.31, small magnitude) and vastus medialis (effect size: 0.5, moderate magnitude) of patients with anterior knee pain (23). Also, using the numeric rating scale (visual analogue scale: VAS), nurses' headache pain was attenuated after static stretching (10-s holds) of the neck with the pain subsiding at 30 min (effect size: 0.4, small magnitude) and 60 min (effect size: 0.84, large magnitude) following stretching (24). Whilst further research is clearly warranted, the current, limited data suggest a consistent positive effect of acute stretching on several forms of pain.

Different pain modulation mechanisms have been proposed to explain these effects. The gate control theory originally proposed by Melzack and Wall (55) suggests that pain sensation is modulated through a "gate" system in which activation of larger afferent fibres would "close or partially block" the gate resulting in inhibition of pain or opening the gate by activating small afferent fibres. When C (slow pain) and Aδ (fast pain) fibres are activated through a painful stimulus, they synapse with nuclei in the substantia gelatinosa of Rolando as they enter the Rexed lamina II, sending the action potential upwards and eliciting the pain sensation. As stretching is performed, sensory fibres send information to the posterior grey horn whose collaterals stimulate inhibitory interneurons that release the neurotransmitter gamma aminobutyric acid (GABA). GABA would either inhibit the nuclei of substantia gelatinosa of Rolando or the synaptic terminal between the C or Aδ and their respective

second-order neurons in the spinal cord. The inhibition would cause the action potential that is sent through the pain pathway to be reduced, thus reducing perceived pain severity (Figure 1).

The effects of acute muscle stretching on pain can also be observed more globally, with non-stretched muscles or other non-local sites being affected. PNF hamstrings stretches consisting of bilateral 8-s contractions followed by 8 s of rest followed by another 8-s contraction plus 8-s stretch (repeated twice for each leg for a total of 48 s) increased PPT and reduced VAS scores associated with masseter muscle pain (25). Similarly, another study reported increased pain pressure threshold values from the masseter muscles 5 min after a 40-s hamstrings static stretching (SS) intervention using the straight leg raise stretch (26).

Several theories may contribute to pain reduction in non-stretched areas. A kinetic chain theory was introduced by a German engineer, Franz Reuleaux (56), and later adapted to human movement and popularized by Steindler (57). They explain that limbs should be considered as rigid overlapping segments connected via links or joints by a connective tissue continuum (58-60). It is suggested that myofascial tissue meridians (e.g., superficial back line, superficial front line, lateral line) link the entire body and thus movements in a targeted segment can be transferred through the myofascial chains to other adjacent segments (61-65). Hence, the stress or strain on a distant structure may be reduced through myofascial meridians diminishing the related stress and associated pain (Figure 1). While foam rolling studies have demonstrated remote decreases in pain (or increased pain pressure thresholds), the mechanism has been attributed to an increased global pain (sensory) threshold (e.g., Diffuse Noxious Inhibitory Control or Gate Control theories) rather than release of strain through myofascial meridians (66, 67). Other reports relate increases in non-local range of motion and an attenuation of non-local pain to myofascial tissue meridians (68), but there is

little direct in vivo evidence or consensus for this mechanism and further studies are required to test for this possibility (65).

Stretching may also alter sympathetic/parasympathetic balance, and thus influence pain perception. Muscle stretching can activate exteroceptive and cutaneous receptors such as Pacinian (69) and Ruffini receptors (70), which contribute to sympathetic nervous system inhibition. Also, stretching can increase parasympathetic influence (71), increasing muscle relaxation and decreasing both heart rate and blood pressure (72). Additionally, interstitial type III and IV receptors, which can respond to the discomfort of stretching to the point of discomfort (73), have been shown to increase efferent sympathetic nerve activity and induce a withdrawal of parasympathetic nerve activity. Increased parasympathetic stimulation affects noradrenergic systems that modulate pain resulting in global analgesic effects (74) (Figure 1).

Another possible mechanism that may explain non-local pain modulation is diffuse noxious inhibitory control (DNIC), also known as "pain reduces pain" theory (75). With DNIC, a noxious stimulus such as stretching to, or near to, the point of discomfort could cause an inhibition of painful sensation through the endogenous pain modulatory pathway. This descending analgesic system involves nuclei within the periaqueductal (PAG) and periventricular (PVG) grey matter, which project collaterals to the locus coeruleus, all within the midbrain, as well as to the paragigantocellular reticular nuclei (reticular formation), and raphe nucleus magnus (brainstem) (76). These nuclei descend the Rexed lamina II and secrete endogenous opioids such as enkephalins, endorphins and dynorphins to decrease the sensation of pain (76-78). The PAG has been shown to connect to the somatosensory region of the cerebral cortex, which can also be activated through stretching non-local painful sites (79). In short, muscle stretching would elicit a noxious input to the central nervous system (global effect), activating the descending analgesic system, releasing endogenous opioids and

thus inhibiting pain sensation at the site of the stretched muscle as well as throughout the body (Figure 1).

Finally, there is also evidence for long-term synaptic plasticity. Activity-dependent long-term depression (LTD) of glumatergic transmission reduces the strength of synaptic connections, which could reduce nociceptive input. There is evidence that stimulation of cutaneous (and possible other afferents) afferents induces long-term depression, which can play a role in antinociception (80). Future research is required to elucidate the precise mechanisms; however, the current evidence suggests that static stretching may acutely reduce the sensation of pain, both locally and globally.

Effects of Chronic Stretching on Pain

The effects of stretching on pain reduction do not appear to be limited to the time immediately after stretching but instead appear to be chronically affected by periods of stretching training. The majority of studies support the contention that chronic stretching reduces pain in the neck (27-32), shoulder (33), chest (81), lower back (34, 41, 42), knee (35), ankle (36-39), and overall musculoskeletal system (40). While the vast majority of chronic stretching studies demonstrate pain relief, several studies have not reported a beneficial effect on pain (82-86).

Most studies have used SS as their preferred intervention for general non-pathological neck pain. Based on the data available, it seems that a duration of more than 2 weeks is necessary to achieve the desired effect of meaningful pain reduction. One study showed that 2 weeks of neck stretching three times daily was not sufficient to reduce pain pressure threshold or VAS scores (32). However, both pain pressure threshold and VAS scores improved after continuing for three months, indicating a reduction in pain symptoms as the training continued (32). It should also be noted that most studies reporting the effects of neck

stretching exercises used multi-directional stretching bilaterally to the muscles (27-31). The frequency of stretching was two (27) to three (29, 31) times per day with the total duration of 10 (27, 31) to 20 min (28).

The results regarding the influence of stretching on shoulder pain are less consistent. While one study showed a reduction in VAS scores after 6 weeks of self-stretching exercises of the shoulder muscles (33), another did not find any meaningful reduction in pain while doing a 20-min positional stretch for hemiplegic shoulder pain (85). Although the dissimilar responses could result from the different populations studied ('otherwise healthy' vs. hemiplegic), it is also possible that the stretch protocol itself affected outcomes, with the effective study implementing 3 sets of 5 repetitions of stretching on multiple muscles with 30-s holds (78) but the ineffective study imposing a continuous positional stretch for 20 min once per day (85). It seems possible that multiple repetitions of short duration stretching may benefit the individual more compared to a single prolonged stretching session, and this hypothesis should be explicitly tested in future research.

Other painful ailments such as costochondritis may also benefit from stretching. Pectoral stretching exercises performed 20 times a day for 30 s each prompted a reduction in VAS scores after 45 and 90 days from baseline in individuals with costochondritis pain (81). These results now require validation, and studies in similar populations are warranted.

The most prevalent stretching program for pain reduction is prescribed for non-specific low-back pain. Patients suffering from low-back pain showed improvement in their pain perception while performing twice-weekly SS of erector spinae, hamstrings, and triceps surae muscles for 6 weeks in 30 min sessions (34). Comparably, stretching for 12 months (3 per week for 50 min each with multiple SS exercises) reduced low-back pain during the menstrual cycle when compared to a control group (41), whilst a similar frequency and

duration SS for 6 months in nurses prompted a reduction in low-back pain compared to a control group (42). On the contrary, no positive effect of SS on low-back pain was reported with stretching of the quadriceps (82); typically, the hamstrings are a prime target for the low-back pain population (34, 41, 42). Another study with no positive pain outcomes had a lower training volume (1 min per week for hamstrings) and targeted different muscles (multiple muscles rather than hamstrings alone) (83). Collectively, the findings are indicative that the duration, and location, of stretch are likely important considerations for the efficacy to reduce low-back pain.

Only one study has demonstrated positive outcomes of stretching on patellofemoral pain, in which the patients underwent three weeks of bilateral quadriceps SS exercises (holding for 30 s for 5 sets daily), revealing an improvement in reported post-intervention pain (35). Results on the effects on plantar fasciitis are mixed with some reporting positive effects even after as little as seven days of stretching (37), but others reporting no pain reduction after 12 weeks of plantar fascia, triceps surae, and hamstrings stretching (86). The studies generally focused on stretching the lower leg muscles as well as the Achilles tendon, primarily using SS techniques (36-39, 86). The one study that did not show any effect on pain included hamstrings stretching in addition to calf muscle stretching in their protocol (86), while others mainly focused on calf muscles, Achilles tendon, and/or plantar fascia (36-39). It seems that the inclusion of muscles further from the painful site reduces the effects of stretching, although it is currently unclear why this is the case. Regardless, the muscles closest to the affected structure might be best targeted.

Based on the available literature, chronic stretching appears to alter the sensation or perception of discomfort (sensory theory) rather than promote substantive morphological or mechanical changes to the muscle structures (87-89). Sensory theory states that the endpoint

sensation is altered as a result of chronic stretching rather than the muscle torque/angle properties directly (indicative of structural changes) (87, 90). As the central nervous system adapts to the novel stretching sensation, it appears that the overall sensation of pain, regardless of stretching, would be accommodated, such that prior or initial discomfort becomes more tolerable (i.e., increased stretch tolerance) (88, 91)

Effects of Stretching on Delayed Onset Muscle Soreness (DOMS)

Current evidence for the effect of acute stretching on delayed onset muscle soreness (DOMS) is equivocal (92). While one study reported that stretching after the application of a DOMS-inducing protocol relieved muscle soreness (21), others tend to show no effect (44, 93-98). In the study of Apostolopoulos et al. (21), low-intensity (30-40%) passive SS of hamstrings, quadriceps and hip flexor muscles (18 min total) on each of three days after DOMS-inducing quadriceps exercise likely had a large magnitude benefit in reducing soreness (21). However, this result is not consistent with the findings of a meta-analysis (22), which found no effect of pre- or post-exercise stretching, usually only imposed on a single occasion after the exercise, on DOMS (10 studies included). Other studies published after the 2007 meta-analytical review also show no effect. For example, McGrath et al. (44) found no effect of SS or PNF performed after DOMS-inducing hamstrings exercise when measured 24-48 h post-exercise (44), although correlation analysis revealed that individuals who showed the greatest ROM increase after SS also had the least increase in DOMS (i.e., there was evidence of an individual response). In another study in which SS was performed immediately after DOMS-inducing exercise, no effect on perceived pain was detected in quadriceps muscles between the three groups that underwent either a single bout of passive stretch, repeated bouts of passive stretch, or no stretch (94). Similar findings were reported in two other studies in which stretching before DOMS-inducing exercise had no effect on pain

scores (93, 95). Based on the available evidence, and regardless of the stretching exercises performed or their relative timing (before or after the damaging exercise), acute stretching interventions appear to have no meaningful effect on pain after unaccustomed, DOMS-inducing exercise, although a small amount of evidence might suggest a small effect for some individuals, especially if stretching is performed multiple times in the days after exercise.

On the other hand, studies that imposed several weeks of stretching have reported decreases in both DOMS symptoms and general soreness (43, 99, 100). Performing SS on seven different lower extremity muscles over 12 weeks both before and after distance running generally reduced the soreness in the legs, buttocks and back compared to a non-stretch control group (43). In this randomized, controlled study, participants (N=2125) self-reported soreness outcomes, with participants in the stretching group having a 24.6% chance of developing "bothersome soreness" compared to 32.3% in the control group (43). Additionally, the mean soreness severity decreased 0.4 points on a 0-10 scale for the stretching group (43). In another study, it was discovered that forcibly stretching the active quadriceps muscles on an isokinetic dynamometer (i.e., active stretching, without holding at a long muscle length) for 6 weeks led to a significant reduction in DOMS after a bout of downhill running (99). Furthermore, 8 weeks of SS or PNF hamstrings stretching training before a single session of DOMS-inducing exercise reduced (~40%; see their Figure 4) pain severity compared to a non-stretching control group (101). Although the PNF group reported a slightly higher mean muscle soreness pain score than the SS group, the difference was not statistically significant (101).

However, there are conflicting reports on the effectiveness of flexibility training on DOMS in the literature. Brusco et al. (102) did not find any difference in soreness reduction after 6 weeks of hamstrings stretching exercise in individuals with limited hamstrings

flexibility. This study differed from the study of Chen et al. (101) in that the stretching was not performed with maximal intensity (stretches were performed to a constant joint angle, rather than to maximum tolerance). Future research might examine the importance of stretch intensity on the propensity for DOMS reduction. LaRoche and Connolly (103) implemented four weeks of either ballistic or static hamstrings stretching before DOMS-inducing exercise, but did not find an effect on soreness. However, a toe touching exercise was used to target the hamstrings, yet this exercise tends to incorporate to a greater extent the muscles acting on trunk flexion than the hamstrings (104), which might explain the lack of pain attenuation in the hamstrings even after four weeks of stretching. Lund et al. (105) assessed the extent of quadriceps soreness from a series of eccentric contractions followed by a 7-day stretching protocol (3 × 30 s passive-static stretching of the quadriceps). They concluded that seven days of quadriceps stretching after a DOMS-inducing exercise did not reduce pain (105). Another study showed a similar lack of pain reduction when groups were assigned to either dynamic or static calf stretching for five days after a DOMS-inducing exercise (106). Compared to other chronic stretching studies in which muscle stretching was performed for several weeks before the DOMS-inducing exercise, it appears that stretching after the exercise is less effective. Factors such as stretch intensity and type of exercise may speculatively influence the magnitude of the effect, and the effects of these variables should be explicitly studied in order to allow for improved prescription of stretching for DOMS reduction.

There are at least two possible reasons as to why chronic stretching is effective in reducing DOMS after unaccustomed (especially eccentric) exercise. First, stretching may influence psychological aspects of pain. As mentioned above, stretching exercises are commonly performed to the point of discomfort such that the individual experiences a painful or discomforting sensation. Being exposed to this sensation over the course of several weeks

may alter the tolerance of an individual to pain perception. Similarly, people with a history of painful experiences, such as those occurring during contact sports, are known to be more tolerant of pain than those who participate in non-contact sports (107). This may also partly explain why athletes can tolerate more pain compared to their inactive peers (108). Thus, the repeated discomforting sensation induced by stretching over the course of several weeks may increase pain tolerance and alter pain perception following a bout of unaccustomed exercise. A second possibility is that chronic stretching promotes adaptations in the parallel elastic component in muscles, and particularly the extracellular matrix (109, 110) and that this provides a protective effect against damage and thus reduces pain sensitivity in the collagenous connective tissues. Recent studies have observed that DOMS resides predominately within the collagenous connective tissues of the muscles, including the fascia (111-113). A single bout of eccentric exercise is sufficient to trigger connective tissue remodelling, and this contributes strongly to a protective effect for the next bout, often called the repeated bout effect (114). Other activities that might promote connective tissue reorganization might therefore also influence muscle soreness after exercise. As muscle stretching is thought to trigger remodelling of the connective tissue structures within the muscles, the possibility exists that stretch-evoked connective tissue adaptations contribute to the reduction in DOMS observed after unaccustomed exercise. These hypotheses remain to be explicitly studied.

A limitation of the research lies in the severity of the exercise-induced muscle damage protocols used, which are usually far more intense than would be imposed in typical exercise bouts. Hence, the ecological validity of the DOMS-inducing protocols as well as the effectiveness of stretching in these more extreme circumstances might be questioned. Furthermore, there is little research comparing the effect of differing stretch intensities on DOMS. The Apostolopoulos et al. study (21) reported greater effectiveness of light post-

exercise stretching on DOMS attenuation. If exercise-induced damage is largely directed to the extracellular matrix (109, 110), then high intensity post-exercise stretching may further exacerbate DOMS. However, lower intensity stretching may activate pain reducing pathways without incurring further damage and pain. Further research is necessary to examine this possibility.

Conclusions

The few studies investigating the acute effects of muscle stretching on pain show a trend towards pain reduction, which may be associated with pain modulatory mechanisms such as gate control theory, DNIC or myofascial chain meridians. Nonetheless, there is extensive evidence for the positive effects of chronic stretching on various types of pain, which may be related to an increased sensory (pain) tolerance (Figure 2). Muscle stretching may therefore be implemented in individuals suffering from acute or chronic pain, as long as the stretching does not itself contribute to the pathology underlying the pain. The literature regarding the effects of different stretching modalities on various types of pain is scarce and it is encouraged that future studies focus on how different stretching techniques (i.e., static, ballistic, PNF) compare with respect to pain reduction. Finally, whilst acute (pre- or post-exercise) stretching does not appear to affect muscle pain (DOMS) after unaccustomed (especially eccentric) exercise, the evidence indicates a moderate positive effect of chronic stretching training in the weeks before DOMS-inducing exercise (Figure 2). Given that some studies have not reported a benefit of chronic stretching, more research is required to specifically determine the critical programming parameters (e.g., stretch duration, stretch intensity, program duration, etc.) influencing the effect of stretching on DOMS.

Sidebar #1

Stretching prescriptions for:

Pain reduction

1. With the scant literature evaluating the acute effects of stretching on pain reduction, an appropriate and valid stretching prescription cannot be offered.
2. From the wide variety of chronic stretching protocols in the literature it seems that the minimum static stretching prescriptions involved ≥3-6 weeks, 2-3 times per week, of 5-20 repetitions (or 10-30 min) held for 30 s.

Attenuating Delayed Onset Muscle Soreness (DOMS)

1. Static stretching is ineffective with only a single bout of stretching after DOMS.
2. Acute static stretching before DOMS-inducing exercise is also ineffective in reducing DOMS.
3. Static stretching for ≥3 weeks prior to DOMS-inducing exercise attenuates DOMS.

Compliance with Ethical Standards

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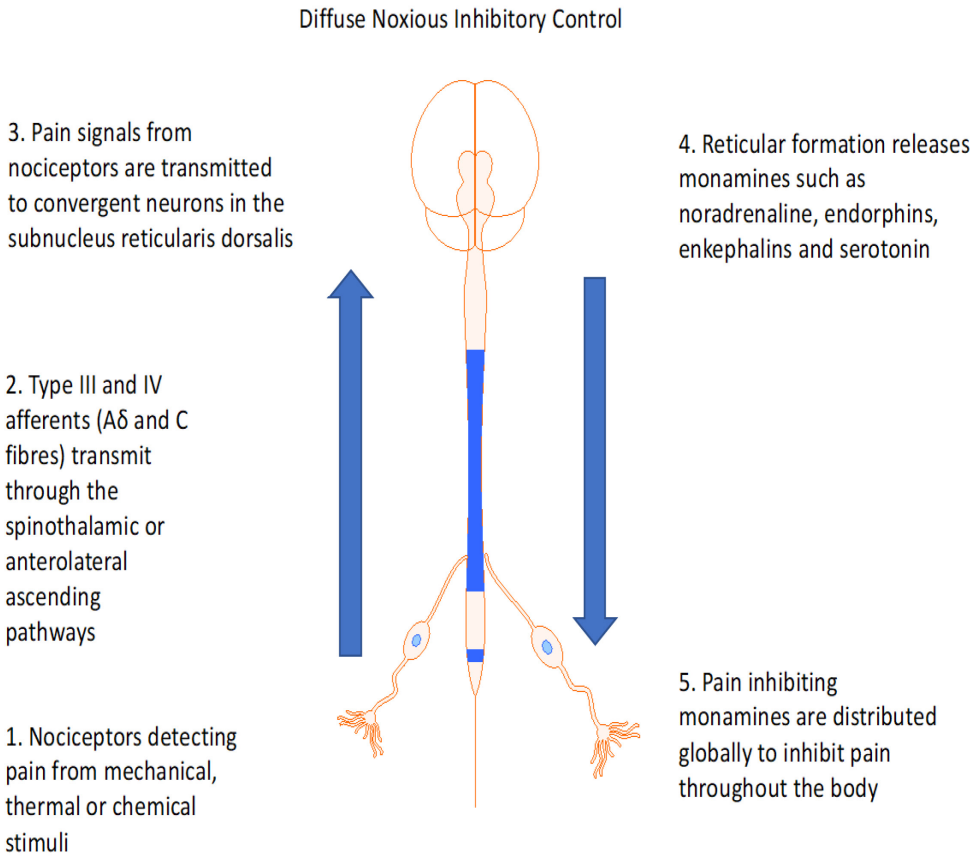
World Health Organization.

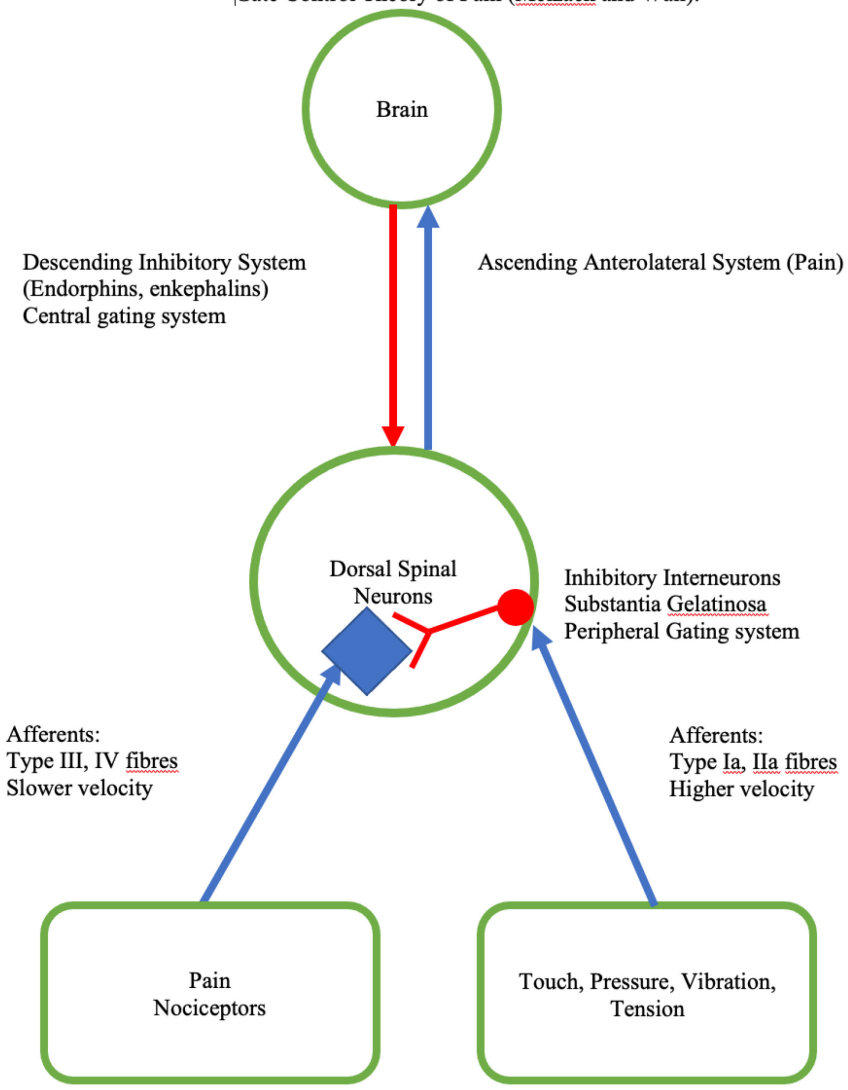
https://www.who.int/news-room/fact-sheets/detail/musculoskeletal-conditions

Figures

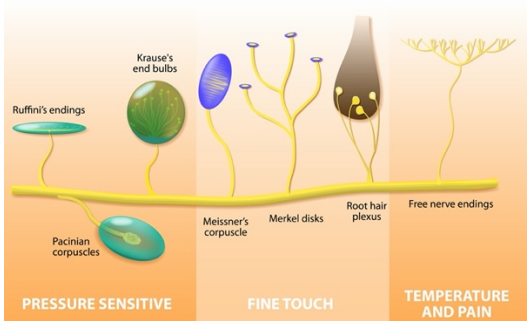
Figure 1: Possible pain modulatory mechanisms associated with stretching



Gate Control Theory of Pain (Melzack and Wall).



Cutaneous Receptors



Stretching effects on cutaneous receptors contribute To sympathetic nervous system inhibition, greater parasympathetic influences increase muscle relaxation decrease heart rate and blood pressure, and affect noradrenergic systems that modulate pain, resulting in global analgesic effects.

More research is needed on the effects of myofascial chains / meridians

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