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The Mechanisms of Massage and Effects on Performance, Muscle Recovery and Injury Prevention

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Abstract

Many coaches, athletes and sports medicine personnel hold the belief, based on observations and experiences, that massage can provide several benefits to the body such as increased blood flow, reduced muscle tension and neurological excitability, and an increased sense of well-being. Massage can produce mechanical pressure, which is expected to increase muscle compliance resulting in increased range of joint motion, decreased passive stiffness and decreased active stiffness (biomechanical mechanisms). Mechanical pressure might help to increase blood flow by increasing the arteriolar pressure, as well as increasing muscle temperature from rubbing. Depending on the massage technique, mechanical pressure on the muscle is expected to increase or decrease neural excitability as measured by the Hoffman reflex (neurological mechanisms). Changes in parasympathetic activity (as measured by heart rate, blood pressure and heart rate variability) and hormonal levels (as measured by cortisol levels) following massage result in a relaxation response (physiological mechanisms). A reduction in anxiety and an improvement in mood state also cause relaxation (psychological mechanisms) after massage. Therefore, these benefits of massage are expected to help athletes by enhancing performance and reducing injury risk. However, limited research has investigated the effects of pre-exercise massage on performance and injury prevention.

Massage between events is widely investigated because it is believed that massage might help to enhance recovery and prepare athletes for the next event. Unfortunately, very little scientific data has supported this claim. The majority of research on psychological effects of massage has concluded that massage produces positive effects on recovery (psychological mechanisms). Post-exercise massage has been shown to reduce the severity of muscle soreness but massage has no effects on muscle functional loss. Notwithstanding the belief that massage has benefits for athletes, the effects of different types of massage (e.g. petrissage, effleurage, friction) or the appropriate timing of massage (pre-exercise vs post-exercise) on performance, recovery from injury, or as an injury prevention method are not clear. Explanations are lacking, as the mechanisms of each massage technique have not been widely investigated. Therefore, this article discusses the possible mechanisms of massage and provides a discussion of the limited evidence of massage on performance, recovery and muscle injury prevention. The limitations of previous research are described and further research is recommended.

Massage has been used for rehabilitation and relaxation for thousands of years around the world. Recent research from the UK showed that in the past 11 years, massage treatment was administered for approximately 45% of the total time in physiotherapy treatment.[1] Massage is used in general approaches, such as preparation for competition, between competitions and in assisting recovery from competition, rather than treatment for specific problems.[1] The large proportion of massage application in sports events is due to many coaches and athletes holding the belief, based on observations and experiences, that massage can provide several benefits to the body such as increased blood flow, reduced muscle tension and neurological excitability, and an increased sense of well-being. There is limited scientific evidence, however, to support the use of massage for enhancing performance, enhancing recovery from injury, or for preventing muscular injury. There is a relative lack of good studies or information on massage and its potential to influence muscle recovery, injury prevention and physical performance. Many claims are made about massage, but few have any empirical data to back them up, and what little data there are tend to point more to the limitations of massage than to any significant effects. Rather, the possible mechanisms and the effects of massage usually result from authors' speculations based on general biomechanical, physiological or psychological knowledge. More scientific data on the benefits of massage are required.

This literature review outlines possible mechanisms of massage (biomechanical, physiological, neurological and psychophysiological), and evaluates the evidence for the benefits of massage in improving performance, enhancing recovery or preventing muscular injury.

Literature was located using three computer databases (PubMed, SPORT Discus and ProQuest 5000 International) in addition to manual journal searches. The computer databases provided access to biomedical and sport-oriented journals, serial publications, books, theses, conference papers and related articles published since 1964. The key search phases used included: 'sport massage', 'massage', 'performance', 'sport injury', 'delayed onset muscle soreness', 'injury prevention', 'range of motion' and 'muscle stiffness'. Articles not published in English nor in scientific journals, nor articles that focused on a specific type of massage (such as connective tissue massage, accupressure), nor articles that focused on the effects of massage in special populations, were not included in this review. The criteria for inclusion were:

- The article must have used normal, healthy participants. Age, sex and fitness differences were not excluding factors.
- The article must have used Swedish-type massage as an intervention. The massage technique such as effleurage and petrissage were not excluding factors.
- The article may have discussed the possible mechanisms of massage in relation to biomechanical and/or neuromuscular properties of muscle, sport performance, rate of injury and muscle soreness.
- The article may have been a review of previous research.

1. Types of Massage

Massage has been defined as "a mechanical manipulation of body tissues with rhythmical pressure and stroking for the purpose of promoting health and well-being".[2] Classic Western massage, or Swedish massage, is the most common form of massage currently used around the world for athletes with purported clinical advantages (see table I). There are a number of techniques in existence, and their use depends on the experience of the therapist and the intended clinical advantage desired. The majority of research has used a combination of Western techniques to investigate the effects of massage, with a few studies having used other techniques such as myofascial trigger point massage.

2. The Possible Mechanisms of Massage

The effects of massage are most likely produced by more than one mechanism.[3-6] A theoretical model of how biomechanical, physiological, neurological and psychological mechanisms[6,7] may be affected by massage is presented in figure 1. As stated earlier, the majority of these mechanisms are speculated by the authors with little empirical data to support the statement. For example, it has been

Table I. Summary of classic Western massage techniques

Technique	Definition	Application	Suggested clinical advantage
Effleurage	Gliding or sliding movement over the skin with a smooth continuous motion[3]	Beginning of a session During a break after applying a specific technique End of each session	Stimulate the parasympathetic nervous system and evoke the relaxation response Enhance venous return
Petrissage	Lifting, wringing, or squeezing of soft tissues in a kneading motion, or pressing or rolling of the tissues under or between the hands[3]	Following effleurage	Mobilise deep muscle tissue or the skin and subcutaneous tissue Increase local circulation Assist venous return
Friction	An accurately delivered penetrating pressure applied through the fingertips[4]	Used for a specific purpose such as to reduce muscle spasm	Treat muscle spasm or break up adhesions from old injuries
Tapotement	Various parts of the hand striking the tissues at a fairly rapid rate[5]	Finishing a section of the body Before and during a competition	Stimulate the tissues either by direct mechanical force or by reflex action

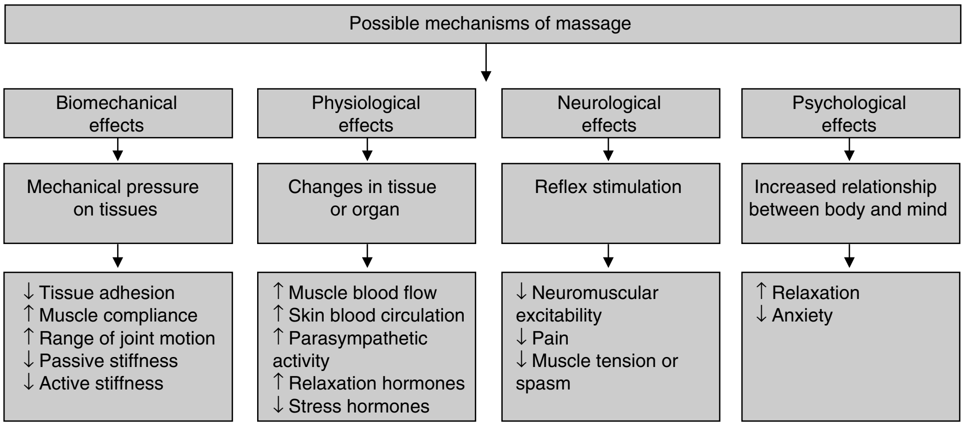

Fig. 1. Theoretical model of the expected mechanisms of massage. ↓ indicates decrease; ↑ indicates increase.

speculated that the possible increase in muscle blood flow, as well as the possible decrease in neuromuscular excitability resulting from mechanical pressure may be factors in any potential effectiveness of massage on muscle compliance. Speculations on the possible mechanisms are needed so further research can be developed to establish the true mechanisms and effects of massage.

2.1 Biomechanical Mechanisms

Massage involves the application of mechanical pressure on the muscle tissue in order to decrease tissue adhesion. Increased muscle-tendon compliance is believed to be achieved by mobilising and elongating shortened or adhered connective tissue. Improved muscle compliance results in a less stiff muscle-tendon unit.[8] Biomechanically, three main measures are used to assess muscle-tendon unit compliance: (i) dynamic passive stiffness; (ii) dynamic active stiffness; and (iii) static joint end range of motion.[9] A summary of the evidence for the effects of massage on muscle-tendon unit compliance as measured by passive stiffness, active stiffness and joint range of motion is presented in table II.

2.1.1 Passive Stiffness

Only one study[10] examined the effects of massage on passive stiffness. A 10-minute effleurage had no significant effects on passive gastrocnemius stiffness properties when compared with a 10-minute rest. The pressure of effleurage might not have been enough to produce the mechanical effects of massage, or if effleurage could produce a reflexive response the change in muscle properties might present in the contractile elements (active muscle stiffness) rather than passive elements of muscle. Further research is needed to investigate the effects of other massage techniques (e.g. petrissage, friction), which provide more mechanical pressure on muscle, on passive properties of muscles.

2.1.2 Active Stiffness

A search of the literature identified no research on the effects of massage on active stiffness. The level of active muscle stiffness depends on passive joint properties, the intrinsic muscle and joint properties, and the effects of stretch reflex.[14] Massage might be able to alter active muscle stiffness by changing the level of neurological activation. However, the optimal level of muscle stiffness that benefits both performance and injury prevention is still unknown.

2.1.3 Joint Range of Motion

Static flexibility is defined as the range of motion available to a joint or series of joints,[9] and is usually measured with a goniometer.[15] The majority of studies that have evaluated the effects of massage on muscle and connective tissue have been based on range of motion measurement.[11-13] For example, Leivadi et al.[11] investigated the effects of neck and back massage on neck extension and shoulder abduction after massage was applied to the posterior region of the neck. The range of neck

Table II. The effects of massage on muscle-tendon unit compliance as measured by passive stiffness, active stiffness and joint range of motion

Study	Trial design	Sample	Intervention	Outcome measures	Main results
Passive stiffness					
Stanley et al.[10]	RCT	19 healthy subjects	10 min effleurage on gastrocnemius	(a) Passive muscle stiffness (b) Maximum tension	NS
Active stiffness					
No published studies to date					
Range of motion					
Leivadi et al.[11]	RCT	30 dance students	(a) Massage (whole body – effleurage, petrissage, friction) (b) Progressive muscle relaxation exercise (30 min session, twice a week, five consecutive weeks)	Short-term: (a) STAI (b) POMS (c) Salivary cortisol Long-term: (a) Neck, shoulder ROM	Short-term: (a) Both groups S: ↓ STAI, POMS (b) Massage group S: ↓ cortisol Long-term: (a) Massage group S: ↑ ROM
Nordschow and Bierman[12]	CCT	25 normal subjects	Swedish and Hoffa massage on the back and at the back of lower limbs for 30 min	Finger to floor test	S: ↑ lumbar range of motion
Wiktorsson-Moller et al.[13]	CCT	8 healthy males	(a) Warm-up (b) Legs massage (kneading for 6–15 min) (c) Warm-up and massage (d) Warm-up and stretching	(a) ROM of lower extremities (b) Hamstrings and quadriceps strength	S: ↑ ankle dorsiflexion S: ↓ quadriceps and hamstrings strength

CCT = controlled clinical trial; **NS** = non-significant; **POMS** = Profile of Mood States; **RCT** = randomised controlled trial; **ROM** = range of motion; **S** = significant; **STAI** = State-Trait Anxiety Inventory; ↓ indicates decrease; ↑ indicates increase.

extension motion was limited by anterior muscles and ligaments and bony contact between spinous processes,[15] therefore, neck extension was not a good outcome measure for the effectiveness of massage in this study. In another study,[12] finger to floor distances increased significantly after massage of the back and lower extremities; however, this study did not provide an appropriate control group and did not blind the examiner to whether the subject had massage or control. The massage therapist measured the distance between the fingers and the floor, which may have caused bias during measurement. When the effects of massage on lower extremity range of motion were compared with the other pre-exercise activities such as warm-up and stretching,[13] massage increased only ankle dorsiflexion range of motion while stretching significantly increased all lower extremity range of motion measurements. Thus, the effectiveness of massage on range of motion is still questioned, especially when compared with more economical techniques like stretching.

2.2 Physiological Mechanisms

2.2.1 Increased Skin and Muscle Temperature

Superficial skin friction increases local heating, and consequently, causes hyperaemia within the massaged area. Local heating increases local blood circulation.[16] There is published evidence that skin and muscle temperature increased after massage application (effleurage technique). Longworth[17] reported an increase in skin temperature during a 6-minute back massage, but skin temperature returned to baseline level after 10 minutes. Recently, Drust et al.[18] reported an increase in skin and intramuscular temperature (at 1.5 and 2.5cm) of the vastus lateralis muscle irrespective of massage duration (5, 10 and 15 minute of effleurage). Even though massage was shown to increase skin[17] and intramuscular temperature,[18] such effects on skin and intramuscular temperature might not be relevant to muscle blood flow.

It is still questionable whether increased skin and intramuscular temperature[18] without increasing muscle blood flow[19,20] and muscle compliance[10] would be beneficial to enhance performance or prevent injuries. The other limitations evident from effleurage technique administration were that skin temperature quickly returned to baseline level[17] and muscle temperature did not increase in deep muscle temperature (deeper than 2.5cm).[18] This leads to the implication that massage (effleurage technique) may not be suitable as a preparation and/or preventative strategy for exercise.

2.2.2 Increased Blood Flow

One expected benefit of massage with respect to enhancement of athletic performance is the increase in blood circulation. A variety of controlled clinical trials have used venous occlusion pethysmography, the ^{133}Xenon wash-out technique, or pulsed Doppler ultrasound velocimetry to examine the effects of massage on blood flow (see table III). Although several authors have agreed that massage could increase blood flow,[7,21-24] study results have been inconclusive largely because of their design limitations. Besides small sample size[7,23,24] most of these studies had no reported statistical analysis,[7,21-24] nor did they use a control group.[7,21-24] These limitations make it hard to differentiate the changes from normal variations. More importantly, the venous occlusion pethysmograph and ^{133}Xenon wash-out techniques used in these studies had their own limitations. The venous occlusion pethysmograph demonstrated underestimation of blood flow due to the inflation of the cuff and was very sensitive to movement artefacts.[19,20] The changes of blood flow could not be expressed quantitatively.[23] Moreover, the venous occlusion pethysmograph technique could not be used to measure blood flow during actual massage.[25] The ^{133}Xenon wash-out technique overestimated blood flow because of the local trauma from injection of the tracer.[19,20,24,25] Pulsed Doppler ultrasound has been used to investigate muscle blood flow and has indicated that manual massage did not affect blood flow in the muscle after treatment of the muscle.[19,20] However, the ultrasound used in these studies detected changes in the large artery and vein but did not detect microcirculation in muscle that could be affected by massage. In summary, there is a lack of confirming evidence that massage does anything significant (with a few exceptions) for the blood flow physiological response. The only studies to look at blood flow with limited technique problems[19,20] have shown no change in total muscle blood flow. This indicates that there is

Table III. The effects of massage on blood flow

Study	Trial design	Samples	Intervention	Outcome measures	Main results
Venous occlusion pethysmograph					
Bell[7]	CCT	Unknown	10 min effleurage and kneading on calf muscle	Venous blood flow	↑ blood flow 2 times for 40 min[a]
^{133}Xenon wash-out technique					
Dubrovsky[21]	CCT	12 class I and II athletes	Not known	(a) Muscle blood flow (b) Venous blood flow (c) Muscle tone (d) Arterial blood saturation	↑ muscle blood flow[a] ↑ venous blood flow[a] ↓ muscle tone[a] ↑ arterial blood saturation[a]
Dubrosky[22]	CCT	28 class II and III athletes	Classical whole body massage (stroking, rubbing, kneading, vibration) for 15–35 min	(a) Lung ventilation (b) Venous pressure (c) Microcirculation (d) Circulating blood volume	Only stroking, rubbing, kneading: ↑ muscle blood flow for >3h[a]
Hansen and Kristensen[23]	CCT	12 healthy volunteers (n = 4 for each intervention)	(a) Effleurage on calf muscle (b) Ultrasound (c) Short wave diathermy (all for 5 min)	(a) Muscle blood flow on right calf (b) Subcutaneous blood flow on left calf	↑ muscle blood flow immediately and returned to baseline 2 min after massage[a]
Hovind and Nielsen[24]	CCT	9 healthy volunteers	(a) Petrissage on one calf and forearm (b) Tapotement on another calf and forearm	Muscle blood flow	↑ muscle blood flow and lasted for 10 min after tapotement on both forearm and calf[a]
Pulsed Doppler ultrasound velocimetry					
Shoemaker et al.[20]	CCT	10 healthy volunteers	5 min effleurage, petrissage and tapotement (5 min rest between each treatment) on right forearm and quadriceps	(a) Brachial artery (b) Femoral artery	NS
Tiidus and Shoemaker[19]	CCT	9 healthy volunteers (one leg for massage, one leg for control)	10 min effleurage on leg on 3 days before, immediately after, and repeated on day 2 and 3 after quadriceps eccentric exercise	(a) Muscle strength (b) Arterial blood velocity (c) Venous blood velocity (d) DOMS perception	NS

a No statistical analysis.

CCT = controlled clinical trial; **DOMS** = delayed-onset muscle soreness; **NS** = non-significant; ↓ indicates decrease; ↑ indicates increase.

likely little real effect of massage on muscle blood flow (microcirculatory changes excepted).

2.2.3 Hormones

Mechanical pressure of massage might stimulate parasympathetic activity as shown by reducing saliva cortisol levels (an indirect measure of parasympathetic activity). Changes in hormonal levels (serotonin and cortisol) after massage have been reported mostly in specific conditions such as patients with low back pain,[26] HIV positive patients[27] and depressed adolescent mothers,[28] which are beyond the scope of this literature review. A reduction of saliva cortisol (stress hormones) in dance students has also been reported.[11] The dancers, who were randomly assigned to massage or relaxation therapy groups, received treatment for five consecutive weeks. Saliva cortisol levels were investigated after the session on the first and last days of the study. Both groups reported less anxiety and depressed mood after their sessions, but only the massage group showed a decrease in cortisol levels. A reduced pre-participation anxiety (nervousness) after massage may have large implications for performance. The mechanisms responsible for reducing cortisol levels after massage application are still unknown as the evidence for cortisol changes is weak.

2.2.4 Parasympathetic Activity

Massage has shown some evidence of increasing parasympathetic activity by reducing heart rate, reducing blood pressure,[17,29-32] increasing relaxation substances such as endorphins[33] and increasing heart rate variability.[34] The majority of research in this area has been conducted in nursing using a specific sequence of massage called 'back rub', and has been performed in older people.[29-31] One study investigated people with chronic pain,[33] while other studies used connective tissue massage[33] and myofascial trigger point massage.[34] Therefore, only two studies that met the criteria (participants were healthy people and Swedish massage was used as the intervention) were reviewed.

The effects of back massage on several psychophysiological indices of arousal such as heart rate, blood pressure, galvanic skin response, electromyography, skin temperature and psycho-emotional response (using the State-Trait Anxiety Inventory [STAI][35]) were examined in 32 female staff and students in a nursing school.[17] The participants were massaged on the back for 6 minutes using a slow stroke technique (effleurage). Heart rate, blood pressure and skin temperature increased after the massage, indicating an increase in autonomic arousal level. The galvanic skin response increased, indicating a lower level of sympathetic stimulation. The inconsistency in responses of the psychophysiological parameters might be due to individuals having a unique response pattern. The participants in the study were healthy females and were not in a stressful situation, so it may have been difficult to show a great relaxation response.

In another study,[36] there were no significant changes in blood pressure, pulse and temperature after a 30-minute Swedish back massage in nine female medical students 1 day before an academic examination. Only respiratory rate was significantly reduced. These results might support the unique response pattern or simply mean that massage could activate only some parameters indicating parasympathetic responses in healthy female participants.

2.3 Neurological Mechanisms

2.3.1 Neuromuscular Excitability and the Hoffman Reflex

Massage is believed to stimulate sensory receptors and decrease muscle tension by reducing neuromuscular excitability as measured by changes in the Hoffman reflex (H-reflex) amplitude.[37-40] H-reflex is considered to be the electrical analogue of the stretch reflex.[41] In a study by Morelli et al.,[37] one-hand petrissage for 3–6 minutes decreased H-reflex amplitude, but the amplitude returned to baseline levels immediately after the termination of massage. The reduction of H-reflex amplitude was considered to be due to a decrease in spinal reflex excitability[38] and showed specificity to the muscle group that had received the massage.[40] The inhibitory effects of massage on the soleus H-reflex amplitude did not originate from mechanical stimulation of cutaneous mechanoreceptors.[39] Therefore, the inhibitory effects of massage might originate from muscle or other deep tissue mechanoreceptors.

The potent inhibitory effects of massage on neuromuscular excitability might be one of the explanations for the reduction of muscle tension or spasm after massage application. However, the reduction of H-reflex after massage (petrissage technique) might not be the reason for reduction of muscle strength as reported by Wiktorsson-Moller et al.[13] (see section 3.1) because the H-reflex amplitude returned to baseline levels immediately after massage termination.[37] Therefore, further research is needed to investigate the relationship between the neurological effects of massage and performance, and the effects of other types of massage application on neuromuscular excitability.

2.3.2 Pain and Muscle Spasm

Massage has been applied in order to relieve pain.[11,26,42-44] The possible responsible mechanisms are neurological (gate-control theory), physiological (biochemical substances) and mechanical (realignment of muscle fibres). Massage may reduce pain by activating the neural-gating mechanism in the spinal cord. Tactile information from massage might stimulate large fast nerve fibres and then, block the smaller, slower nerve fibres that detect pain. This effect presumably results from local lateral inhibition in the spinal cord[45] and explains why touching the painful area is an effective strategy for relieving pain. However, there are no objective data to support this idea. Massage can increase biochemical substances such as serotonin,[11] which is a neurotransmitter that plays a role in reducing pain.[45]

Physiotherapists usually use massage to break the vicious cycle that causes muscle spasm, and consequently, muscle pain. Muscle spasm causes muscle pain directly by stimulating mechanosensitive pain receptors or indirectly by compressing the blood vessels resulting in ischaemia.[45] Massage might help to rearrange muscle fibres and increase microcirculation. The realignment of fibres helps to reduce muscle spasm that stimulates pain receptors and helps to reduce the pressure on blood vessels. The increase in blood microcirculation helps to increase nutrition to the damaged area. However, there is no scientific evidence to support these ideas because massage is unlikely to increase muscle blood flow and there is no published study on the effects of massage on the realignment of fibres.

2.4 Psychophysiological Mechanisms

Various mechanisms for the cause of the relaxation response resulting from massage have been proposed. These include an increase of plasma endorphins,[33] decreased arousal level,[17] decreased stress hormone levels[11,26-28] or an activation of the parasympathetic response.[32,34,46] This section will focus on the effects of Swedish massage on psycho-emotional responses in normal populations (see table IV for a summary of studies).

2.4.1 Anxiety

The majority of research in the psychological area has reported that massage provided positive effects on anxiety. Most studies have used the STAI[35] to measure anxiety. Studies of the effects of massage on anxiety, however, had several limitations such as no control group,[36] an inappropriate control group[11] and small sample size.[36] For example, the anxiety levels after being massaged on the day before an academic examination were assessed for nine medical students.[36] The mean STAI score decreased significantly after the massage intervention and the respiratory rate was also significantly decreased between pre- and post-massage measures. The small sample size and lack of a control group make the effectiveness of acute single massage treatments unclear.

The long-term effects of a 30-minute massage, twice a week for four consecutive weeks were examined in 30 dance students.[11] A progressive relaxation therapy group was used for comparison. Both groups reported lower state anxiety levels and depressed mood subscale of the Profile of Mood States (POMS);[50] however, only the massage group revealed a significantly lower saliva cortisol level after the massage session. The study did not state the time of blood collection, therefore, the cortisol level should be interpreted carefully because of the effects of circadian rhythm.[45] The progressive relaxation therapy was not an appropriate control group as it was an active relaxation technique that the participants had to carry out by themselves, while massage therapy was a passive relaxation technique applied by the massage therapist. The relaxation group completed their exercises at home by following a recorded tape, which raises the issue of compliance to the intervention. Therefore, further studies on the ef-

Table IV. The effects of massage on psychological variables

Study	Trial design	Samples	Intervention	Outcome measures	Main results
Anxiety					
Leivadi et al.[11]	RCT	30 dance students	(a) Massage (whole body – effleurage, petrissage, friction) (b) Progressive muscle relaxation exercise (30 min session, twice a week, five consecutive weeks)	Short-term: (a) STAI (b) POMS (c) Salivary cortisol Long-term: Neck, shoulder ROM	Short-term: (a) Both groups S: ↓ STAI, POMS (b) Massage group S: ↓ cortisol Long-term: (a) Massage group S: ↑ ROM
Zeitlin et al.[36]	CCT	9 female medical students	Whole body Swedish massage (effleurage, petrissage, friction) for 1h	(a) Vital signs (b) STAI (c) VAS (d) WBC (e) T cell (f) NKCA	S: ↓ RR, WBC, T-cell S: ↑ NKCA
Relaxation					
Weinberg et al.[47]	RCT	279 university students	(a) Massage (full body Swedish massage) [n = 40] (b) Swimming (n = 39) (c) Jogging (n = 47) (d) Racquet ball (n = 52) (e) Tennis (n = 45) (f) Rest (n = 56)	(a) POMS (b) STAI (c) Thayer's adjective checklist	S: ↑ POMS, STAI, Thayer's adjective checklist
Perceived recovery					
Hemmings[48]	CBD	9 boxers	(a) Whole body massage (effleurage, petrissage) (b) Touching control (c) Rest control (all for 20 min)	(a) Perceived recovery (b) Saliva flow rate	S: ↑ perceived recovery
Hemmings et al.[49]	CBD	8 amateur boxers	(a) Massage (20 min effleurage and petrissage whole body) (b) Passive rest	(a) HR (b) Blood lactate (c) Blood glucose (d) Perceived recovery scale (e) Boxing performance	NS: HR blood glucose, blood lactate, boxing performance S: ↑ perceived recovery

CBD = crossover balance design; **CCT** = controlled clinical trial; **HR** = heart rate; **NKCA** = natural killer cell activity; **NS** = nonsignificant; **POMS** = Profile of Mood States; **RCT** = randomised controlled trial; **ROM** = range of motion; **RR** = respiratory rate; **S** = significant; **STAI** = State-Trait Anxiety Inventory; **VAS** = Visual Analogue Scale; **WBC** = white blood cell; ↓ indicates decrease; ↑ indicates increase.

fects of massage on anxiety need to provide more appropriate control groups.

2.4.2 Relaxation

The effects of massage on relaxation have been investigated by using valid questionnaires such as the POMS;[50] however, the use of the POMS for indicating the level of relaxation is questionable as the questionnaire is composed of six scales: tension, depression, anger, vigour, fatigue and confusion.[50] Only the tension, vigour and fatigue subscales are appropriate for relaxation measurement. POMS is also considered too long to complete[51] as there are 65 items in the original version and 72 items in the bipolar version. Therefore, the POMS is not an appropriate questionnaire from which to measure relaxation. Interestingly, there are no questionnaires available to allow a direct investigation of the level of relaxation.

Weinberg et al.[47] reported a preliminary study on the effects of massage on mood enhancement in 183 physical education students. Massage intervention was compared with several physical activities such as swimming, jogging, tennis and racquetball. The students completed a battery of psychological questionnaires before and after each intervention including the POMS, the State Anxiety Inventory (SAI),[35] and the high and general activation subscales from Thayer's adjective checklist.[52] Interestingly, only the massage and running groups reported a significant positive mood enhancement with significant decreases in tension, confusion, fatigue, anxiety, anger and depression. Only the massage group showed a significant decrease in the Thayer's high activation subscale and the SAI scores. In a similar study, Hemmings[53] compared the psychological effects of massage, lying resting, or touching control using the POMS during boxing training. Massage application during training improved the tension and fatigue subscales of the POMS, which are applicable to measurement of relaxation. The studies by both Weinberg et al.[47] and Hemmings[53] showed significant positive psychological effects attributable to massage despite the mood state of the participants.

2.4.3 Recovery from Fatigue

Positive perceived psychological benefits of massage using the Perceived Recovery linear scale have been shown during the recovery phase of boxing performances and after a training session.[49,53] Despite no changes in physiological fatigue indicators such as blood lactate and heart rate, nine boxers reported that massage positively affected the perception of recovery following boxing performance and seemed to be a useful recovery strategy. The Perceived Recovery scale is a useful questionnaire to indicate recovery because it is short and easy to understand. However, the Perceived Recovery scale has not been widely used in research studies. To date, there is no published article reporting the correlation between the Perceived Recovery scale and physiological markers of fatigue.

2.5 Summary of the Mechanisms of Massage

Massage is believed to benefit athletes by enhancing performance and recovery, as well as promoting relaxation through biomechanical, physiological, neurological and psychological mechanisms. Despite the general belief of the benefits of massage, there are limited empirical data on possible mechanisms of massage. Mechanical pressure from massage is believed to increase muscle compliance. Several studies reported an increase in static flexibility, as measured by joint range of motion, but these studies were methodologically flawed.[11-13] One study reported poor effects of massage (effleurage technique) on dynamic flexibility as measured by passive stiffness.[10] Studies on physiological mechanisms such as the changes of blood circulation,[19,20] hormonal levels[12] and psychophysiological parameters (e.g. blood pressure and heart rate)[29-34] are still inconclusive. The explanations might be due to the unique response pattern of individuals and the variations of massage interventions (i.e. massage technique, duration of massage and pressure of massage) used in each study. The effects of massage on neurological mechanisms have been reported to reduce the amplitude of the H-reflex;[37-40] however, results were limited to the petrissage technique. Many studies have reported that massage can promote relaxation by improving psychophysiological response. Therefore, further studies are needed to investigate the biomechanical, physiological, neurological and psychological mechanisms for each massage technique. The results will help to provide appropriate massage applications for specific sports purposes.

3. The Evidence for Massage on Performance, Recovery or Muscular Injury Prevention

Sport massage has been used for centuries in an attempt to prevent and cure injuries.[4,6,54,55] Massage is considered to enhance muscle relaxation,[12,13] reduce muscle tension[21] and soreness,[19,56] promote the healing process,[57] and consequently, improve athletic performance.[58-60] Massage is also thought to provide a soothing, sedative, invigorating feeling and can give the athlete confidence by the positive reaction that takes place within the body.[47-49,53] Massage might be an effective way to prevent acute injuries resulting from abnormal tissue conditions (e.g. muscle tears in tight muscle) and chronic injuries caused by wear and tear (e.g. tendinosis)[61] by rearranging the muscle fibres.[62] As a result of these suggested benefits, manual massage may be a useful modality to enhance performance and prevent injury for athletes who use their muscles vigorously.

Sport massage may help to optimise positive-performance factors such as healthy muscle and connective tissues and normal range of motion.[61] Massage is used to minimise negative-performance factors such as dysfunctional muscle and connective tissue, restricted range of motion, and pain and anxiety.[61] Therefore, preventive massage is commonly recommended to help athletes prepare both physically and mentally for a forthcoming event.[3] In addition, sports massage is believed to decrease injury-potential factors. Even though massage has benefited several injury-risk factors such as increased range of motion,[11-13] reduced pain[42,63] and anxiety,[11,47] there have been no intervention studies to assess the effects of these possible injury prevention strategies. There is no clear evidence that massage can actually improve performance, enhance recovery or prevent muscular injury. In addition, the cost to benefit ratio of massage compared with other methods such as jogging or stretching has not yet been investigated.

3.1 The Effects of Massage on Performance

Sport massage is used both pre- and post-event in an attempt to increase athletes' performance, overcome fatigue and help recovery.[54] An increase in muscle blood flow would hasten the delivery of oxygen, increase muscle temperature and buffer blood pH, which would then aid in the performance of exercise.[2] Increased muscle blood flow, theoretically, should help to remove waste products after exercise and should enhance delivery of protein and other nutrients needed for muscle repair.[25] Increased lymph flow, could, in theory, reduce post-exercise swelling and stiffness by reducing muscle interstitial content and thereby reduce muscle discomfort.[55] However, there are no data to support these ideas, and the few studies on massage and blood flow have shown no increases in blood flow.

A search of the literature identified only two studies on the effects of pre-exercise massage on performance. Wiktorsson-Moller et al.[13] found that 6–15 minutes of petrissage, with the aim of promoting relaxation and comfort, reduced muscle strength. However, Wiktorsson-Moller et al.[13] used isokinetic movement to test muscle strength. Research has shown that the tests of muscular function were not suitable to monitor performance.[64] There were no relationships between the percentage changes in the tests of muscular function (concentric and eccentric contraction of isoinertial and isokinetic tests) and the changes in performance (sprinting and cycling) after an 8-week weight-training programme.[64] Another study on the effects of 30 minutes of pre-exercise whole-body Swedish massage (including effleurage, petrissage and tapotement) in 14 sprinters[65] showed that mean stride frequencies were not significantly different between massage and control groups. However, it should be noted that the highest absolute stride frequency was obtained in the trial immediately following massage. Stride frequency needs to be combined with stride length to determine performance. Therefore, the effects of pre-exercise massage on performance are still inconclusive due to the lack of well controlled studies.

3.2 The Effects of Massage on Recovery

3.2.1 Performance Recovery

It is believed that one of the greatest advantages of sport massage is to overcome fatigue and reduce recovery time, especially during periods of competition, and consequently, enhance performance at the next event. Even though many elite athletes believe that massage is an important part of their success,[62,66] the effects of massage itself are still questioned. Massage can improve some physiological markers[67] but some studies have shown no effect on any recovery parameters.[49] A summary of the effects of massage on performance recovery is presented in table V.

To investigate the effects of massage on recovery, several studies provided massage between sport sessions. However, there were some limitations in these studies leading to inconclusive data. For example, Monedero and Donne[69] administered combination treatments (active exercise and massage) so the true benefits of individual massage treatments are still unclear. Some studies had problems with credible data including small sample size[49,68] and lack of statistical analysis.[67] An appropriate design (such as a crossover design), use of a control group (placebo treatment), and maximisation of motivation of participants in both control and massage groups are factors that need to be considered in massage studies in order to minimise psychological effects.

Curative massage can facilitate soft tissue healing in a number of ways. Massage may help reduce both primary oedema and the possibility of secondary oedema caused by the pressure of increased fluid in the area of trauma.[6,57] Starkey[57] found that combination treatments including cold, exercise and mechanical massage could reduce total time lost from practice by approximately 2 days when compared with the normal ice, compression and elevation treatment. Unfortunately, the published report showed neither the results section nor the statistical analysis. Therapists apply massage to the injured area because they expect massage to improve blood circulation to the injured area and, consequently, to help enhance healing. The mechanical pressure from massage is generally used to treat adherent or contracted connective tissue in order to restore fibres to a more normal alignment. Nevertheless, there are no data to support these suggested mechanisms.

3.2.2 Blood Lactate Removal

Blood lactate has been used as a marker for fatigue and recovery.[49,69-72] A summary of the effects of massage on blood lactate removal is presented in table VI.

Only one study has reported that massage treatment could increase blood lactate removal after strenuous exercise.[70] Cool-down, however, produced a superior blood lactate removal rate than massage therapy. Other studies showed no benefit from massage.[49,69,71,72] Therefore, there is little empirical evidence to support the effectiveness of massage for blood lactate removal despite participants reporting less fatigue after massage application.[48,49,53,69,71,72] If an elevated muscle blood flow is the aim of treatment then light exercise would be more beneficial than massage.[20,25,55] If psychological effects of fatigue are to be considered then massage might provide some benefit. However, no studies have compared the psychological effects of massage and cool-down.

3.3 The Effects of Massage in Preventing Muscular Injury

3.3.1 Delayed-Onset Muscle Soreness

Delayed-onset muscle soreness (DOMS) is a very important problem for coaches and athletes because it causes chronic pain and diminishes muscle function and ability to participate in sport.[73] DOMS commonly occurs between 24 and 72 hours after unaccustomed eccentric exercise.[74-77] The consequences of damage to muscle function include prolonged loss of muscle strength,[76,78-81] soreness sensation,[77,80,81] decreased range of motion,[79] increased muscle stiffness,[77,78] increased resting metabolic rate[82] and perturbed athletic performance.[83-86] These changes might increase the risk of sports injury.

The sequence of DOMS events consists of the mechanical stress of exercise on muscle fibres,[74,75,87-90] causing sarcomeres to rupture[91] followed by calcium homeostasis disturbance. The damage of sarcoplasmic reticulum or muscle membrane can increase intracellular calcium and trigger calcium-sensitive pathways.[92,93] Calpain, the calci-

Table V. The effects of massage on performance recovery

Study	Trial design	Samples	Intervention	Outcome measures	Main results
Balke et al.[67]	CT	7 healthy subjects	15–20 min (a) Manual massage (b) Mechanopercussive massage	(a) Max MET (b) Max HR (c) Max BP (d) Leg muscle endurance (e) Leg muscle strength	Both types of massage can reduce both physiological and muscular fatigue
Boone and Cooper[68]	CT	10 healthy subjects	(a) Massage of lower extremities (b) Rest (all for 30 min)	(a) $\dot{V}O_{2max}$ (b) HR (c) SV (d) Q (e) $(a\text{-}v)O_2$	NS
Hemmings et al.[49]	CT	8 amateur boxers	(a) Massage (20 min effleurage and petrissage whole body) (b) Passive rest	(a) HR (b) Blood lactate (c) Blood glucose (d) Perceived recovery scale (e) Boxing performance	NS: HR, blood glucose, blood lactate, boxing performance S: ↑ perceived recovery
Monedero and Donne[69]	CT	18 male cyclists	(a) Passive recovery (b) Active recovery (c) Massage (effleurage, stroking, tapotement on legs) (d) Combined treatment (all for 15 min)	(a) Performance time (b) Blood lactate (c) HR	S: (a) Combined treatment in ↑ performance time (b) Combined treatment and active recovery in ↑ blood lactate removal
Rinder and Sutherland [58]	CT	20 healthy subjects	(a) Massage (effleurage, petrissage on both legs) (b) Rest (for 6 min)	Maximal number of leg extensions against half max lift leg extension	S: ↑ no. of leg extensions more than control group

$(a\text{-}v)O_2$ = arterial-venous oxygen difference; **BP** = blood pressure; **CT** = counterbalance trial; **HR** = heart rate; **max** = maximum; **MET** = metabolic equivalent; **NS** = non-significant; **Q** = cardiac output; **S** = significant; **SV** = stroke volume; **$\dot{V}O_{2max}$** = maximum oxygen consumption; ↑ indicates increase.

Table VI. The effects of massage on blood lactate removal

Study	Trial design	Samples	Intervention	Outcome measures	Main results
Bale and James[70]	CT	9 male athletes	(a) Massage on leg (b) Warm down (c) Passive rest (all for 17 min)	(a) Blood lactate (b) Flexibility (c) Stiffness	S: ↓ blood lactate and stiffness at 12h after massage treatment
Dolgener and Morien[71]	RCT	22 runners	(a) Passive recovery (n = 7) (b) Bicycle recovery (n = 7) (c) Massage recovery (n = 8), effleurage and petrissage on legs (all for 20 min)	Blood lactate before, 3, 5, 9, 15, 20 min after treatment	NS
Gupta et al. [72]	CT	10 male athletes (all subjects performed all interventions, interval period 48h)	(a) Passive recovery (40 min) (b) Active recovery (40 min) (c) Massage recovery (10 min of kneading and stroking)	(a) Blood lactate (b) Gas exchange ($\dot{V}O_{2max}$ and $\dot{V}CO_{2max}$) (c) HR	NS
Hemmings et al.[49]	CT	8 amateur boxers	(a) Massage (20 min effleurage and petrissage whole body) (b) Passive rest	(a) HR (b) Blood lactate (c) Blood glucose (d) Perceived recovery scale (e) Boxing performance	NS: HR, blood glucose, blood lactate, boxing performance S: ↑ perceived recovery
Monedero and Donne[69]	CT	18 male cyclists	(a) Passive recovery (b) Active recovery (c) Massage (effleurage, stroking, tapotement at legs) (d) Combined treatment (all for 15 min)	(a) Performance time (b) Blood lactate (c) HR	S: (a) Combined treatment in ↑ performance time (b) Combined treatment AND active recovery in ↑ blood lactate removal

CT = counterbalance trial; **HR** = heart rate; **NS** = non-significant; **RCT** = randomised controlled trial; **S** = significant; $\dot{V}CO_{2max}$ = maximum carbon dioxide production; $\dot{V}O_{2max}$ = maximum oxygen consumption; ↓ indicates decrease; ↑ indicates increase.

Table VII. The effects of massage on muscle soreness

Study	Trial design	Samples	Intervention	Outcome measures	Main results
Farr et al.[115]	CT	8 healthy males (one leg massage, one leg control)	30 min leg massage (effleurage and petrissage) 2h after 40 min treadmill walk	(a) Muscle strength (b) Plasma CK (c) Vertical jump (d) Soreness (e) Tenderness	S: ↓ soreness and tenderness at 48h post-eccentric exercise
Hasson et al.[111]	RCT	16 healthy subjects (no specific sex)	(a) Retrograde massage (n = 6) (b) Placebo massage (n = 5) (c) Control (n = 5) (treatment 24h post-exercise)	(a) Max isotonic KE (b) Max concentric KE (c) Max eccentric KE (d) Max 1-leg jump (e) Max 2-leg jump (f) Soreness perception	NS
Hilbert et al. [116]	RCT	18 healthy volunteers	(a) Swedish massage (7 min of effleurage, 1 min of tapotement, 12 min of petrissage) (b) control (placebo lotion applied and rest for 20 min) Intervention performed 2h after hamstrings eccentric exercise	(a) POMS (b) ROM (c) Peak torque (eccentric contraction) (d) DDS (e) Neutrophils	S: ↓ soreness at 48h post-eccentric exercise
Lightfoot et al.[113]	RCT	31 healthy volunteers (12M, 19F) [n = 10 for each group]	(a) Massage (10 min of petrissage) immediately and 24h post-exercise on the left calf muscle (b) Stretching (c) Control	(a) DOMS scale (b) Lower leg volume (c) CK level	NS
Rodenburg et al.[109]	RCT	50 untrained males (n = 27 for experimental group)	(a) Warm-up, stretching, massage (15 min of effleurage, tapotement, petrissage) (b) Control	(a) DOMS scale (b) Maximal isotonic force (c) Flexion angle of elbow (d) Extension angle of elbow (e) CK level (f) Mb concentration	S: ↓ DOMS (extensor muscles), CK, flexed arm angle S: ↑ maximal isotonic force
Smith et al.[56]	RCT	14 untrained males (n = 7 for each intervention)	(a) 30 min of effleurage, shaking, petrissage, cross-fibre (b) Control Intervention performed 2h after biceps and triceps eccentric exercise	(a) Muscle soreness rating (b) Blood CK, neutrophils, cortisol	S: ↓ DOMS and CK S: ↑ neutrophils

Continued next page

Table VII. Contd

Study	Trial design	Samples	Intervention	Outcome measures	Main results
Tiidus and Shoemaker[19]	CCT	9 healthy volunteers (5F, 4M) (one leg massage, one leg control)	10 min effleurage on leg 3 days before, immediately after, and repeated on day 2 and 3 after quadriceps eccentric exercise	(a) Muscle strength (b) Arterial blood velocity (c) Venous blood velocity (d) DOMS perception (follow up 5 consecutive days)	S: ↓ soreness at 48h post-eccentric exercise
Weber et al.[112]	RCT	40 untrained F (n = 10 for each group)	(a) Massage (effleurage, petrissage) (b) Microcurrent electrical stimulation (c) Upper body ergometry (d) Control (all for 8 min)	(a) Soreness scale (b) Maximal isometric contraction (c) Peak torque	NS
Wenos et al.[110]	CCT	9 untrained participants (no specific sex) [one quadriceps as control, the other was massaged0	Unknown	(a) Torque (b) ROM-hip flexion, extension, abduction, adduction (c) Soreness perceptions	NS

CCT = controlled clinical trial; **CK** = creatine kinase; **CT** = counterbalance trial; **DDS** = Differential Descriptor Scale; **DOMS** = delayed onset muscle soreness; **F** = female; **KE** = knee extension; **M** = male; **max** = maximum; **Mb** = myoglobin; **NS** = non-significant; **POMS** = Profile of Mood States; **RCT** = randomised controlled trial; **ROM** = range of motion; **S** = significant; ↓ indicates decrease; ↑ indicates increase.

um-activated neutral protease, plays a role in the ultrastructural muscle damage.[76] The inflammatory response to damaged muscle fibres causes a transfer of fluid and cells to the damaged tissue.[94] The increased fluid produces swelling after injury. Neutrophils and macrophages migrate to the inflammatory sites and play a role in both the damage and repair processes.[76] The exact mechanisms to explain how soreness develops and why there is a delay in pain sensation is not fully understood.[15,87,95,96]

Several treatments that aim to prevent and/or reduce the severity of muscle damage have been investigated including acupuncture,[97] ultrasound,[98,99] cryotherapy,[100] compression,[78,101] anti-inflammatory drugs,[102,103] hyperbaric oxygen therapy,[104] warm-up,[105,106] stretching[106-108] and massage.[19,56,109-113] These treatments have been applied as a prophylactic and/or a therapeutic intervention. However, the benefits of these treatments are still inconclusive. From a clinical point of view, the treatment given prophylactically is more desirable for reducing or preventing injury, and consequently, for producing a reduction in further injuries, chronic pain, cost of injury treatment and time lost from training activities.

Massage is one of the treatments commonly used to alleviate DOMS because it is thought to increase local blood and lymph flow, decrease oedema and reduce pain. Significant reductions in soreness perception of DOMS after massage have been reported.[19,56,70,109] Some studies explained the mechanism of DOMS reduction by the increase of neutrophils[56] and the reduction of blood creatinine kinase,[56,109] while some researchers failed to explain the mechanism at all.[19,70] Many researchers, however, reported that massage was not beneficial in reducing DOMS.[110-114] A summary of studies that have investigated the effects of massage on muscle soreness is presented in table VII.

The inconclusive data on the effects of massage on DOMS may be due to the limitations of previous research. The majority of studies used small sample sizes, which limited the statistical power of the studies.[19,56,70,110-113] Some studies used another limb as a control group that could have introduced intrasubject bias.[19,110] One study used a combination of treatments making it difficult to establish the effectiveness of each of the treatments alone.[109] Two studies were reported only in abstract form.[110,111] The different sexes of participants might affect the results[19,113] because of the different patterns of DOMS between males and females as reported in the literature.[117] The wide variation of massage techniques, duration of massage application, area of the body massaged and outcome measures also affect the conclusions that can be drawn from the studies.

The unclear mechanisms of massage may also lead to inappropriate massage application. In practice, massage is often applied immediately after exercise in order to enhance blood circulation. The effects of massage on blood circulation are still questionable as described in section 2.2.2. The eccentric exercise, which induced muscle damage, does not produce waste products that require extra blood flow. Research that investigated the effects of massage immediately after exercise found a decrease of DOMS 48 hours after exercise but did not find any change in blood circulation.[19] Some studies have not found any effects of massage immediately after exercise.[110,112]

Some researchers have speculated that massage may reduce DOMS sensation by decreasing muscle oedema. However, in studies by Hasson et al.[111] and Lightfoot et al.,[113] leg volume and soreness sensation did not change after massage immediately after exercise and/or 24 hours after exercise. Massage performed 2 hours post-exercise was reported to benefit DOMS by reducing an inflammatory process.[56] The neutrophil values in the massage group were significantly higher than in the control group at 8 and 24 hours. The authors speculated that the elevation of the neutrophil counts was the result of the mechanical action of massage by the shearing of the neutrophils from the vessel walls. The increased blood flow from the proposed physiological mechanism of massage might prevent the migration of the neutrophils from the circulation into the injury sites. Thus, the neutrophil values would be elevated in the blood count.

Two studies used the protocol of Smith et al.[56] to examine the effects of massage application 2 hours after eccentric exercise.[115,116] Farr et al.[115] and Hilbert et al.[116] reported that massage performed 2 hours post-exercise was effective in reducing soreness sensation. It is important to note that the study by Farr et al.[115] investigated massage on one leg and used the other leg as the control group. Therefore, it is likely that massage might provide a psychological advantage as only soreness sensation (the subjective measure reported by the participants) was reduced after massage application. However, there was no benefit of massage for preventing muscle strength and function loss (as determined by isometric and isokinetic tests and jumping height, respectively).[115,116] Interestingly, both research studies did not find any change in neutrophil count.

It is hypothesised, that if the mechanical effect of massage can increase muscle flexibility and reduce muscle stiffness, enhance local microcirculation and lymph flow, and increase muscle compliance, massage should be applied before eccentric exercise in order to lower the initial mechanical overload of eccentric exercise. A theoretical model of the expected mechanism of massage on the severity of DOMS is presented in figure 2.

3.4 Summary of the Evidence for Massage Improving Performance, Enhancing Recovery or Preventing Muscular Injury

There are relatively few, well controlled studies that have examined the potential for massage to influence performance, recovery or injury risks. Limited research has investigated the effects of pre-exercise massage on performance. The results are inconclusive because of the inappropriate massage techniques and outcome measures used. There is no research that has looked at the effects of pre-exercise massage on injury-prevention. Massage is widely administered between events because it is believed that massage might help to enhance recovery and prepare athletes for the next coming event. Unfortunately, very little scientific data has supported this claim. A large number of studies of massage have reported the psychological benefits of massage between events. Several research studies have reported that post-eccentric exercise massage could help to reduce muscle soreness sensation but could not affect muscle functional loss.

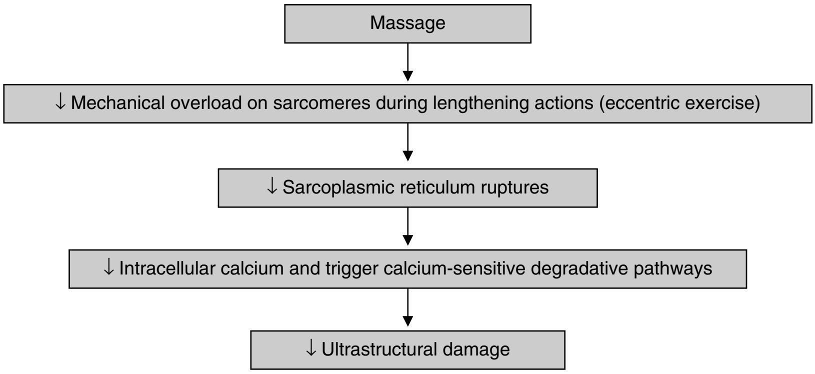

Fig. 2. Theoretical model of the expected mechanisms of massage on the severity of muscle soreness. ↓ indicates decrease.

4. Conclusions

Massage is believed to benefit athletes through its biomechanical, physiological, neurological and psychological mechanisms. Research has reported the effects of massage on physiological (investigated by blood flow and blood-borne substance), neurological (investigated by H-reflex) and psychological (investigated by questionnaire and psychophysiological parameters such as heart rate, blood pressure) mechanisms. There are limited data on the possible mechanisms of massage, especially mechanical mechanisms of pressure and motion of massage on muscle properties such as passive or active muscle stiffness.

There are several limitations of previous research on the effects of massage on performance and injury prevention that have lead to inconclusive results. Further research is clearly needed to establish the possible benefits of massage. The unclear effects of massage on muscle blood flow lead to uncertain benefits for performance and recovery from fatigue. Only petrissage has been studied and shown to reduce the H-reflex. Other massage techniques have not been examined in terms of their neurological effects. Therefore, there is no evidence to support the claim that some massage techniques (e.g. tapotement, vibration) can increase neuromuscular excitability. The lack of studies on the mechanical effects of massage on muscle properties such as active and passive stiffness provides unclear information on the biomechanical mechanisms of massage. The understanding of the mechanism of exercise-induced muscle soreness, as well as the mechanisms of massage, will help to select the appropriate massage technique, duration of massage application and time to apply massage. Therefore, more research on the effects of massage is needed to clarify whether massage is beneficial for enhancing performance, enhancing recovery from injury or reducing the risk of muscular injury.

The effects of different types of massage (e.g. petrissage, effleurage) or the appropriate timing of massage (pre- vs post-exercise) on performance, recovery from injury, or as an injury prevention method also needs to be examined.

5. Recommendations

Research has not shown any clear benefits of massage on sport performance or injury prevention. The use of massage before training and competition to enhance performance is, therefore, questionable. Future research should address the following questions:

- Can massage increase muscle blood flow, muscle temperature, neuromuscular excitability or muscle flexibility?
- Can massage increase performance such as sprinting, jumping or endurance athletic events?
- What type of massage can produce benefits? How long should massage be applied? When should athletes receive massage?
- Are the effects of massage universal or are they specific to each massage therapist?
- Is the cost and time for massage appropriate when a warm-up or cool-down may be as, or more, effective?

In order to overcome limitations of previous research, massage studies should consider these points:

- An appropriate control group should be provided. The ideal control group for a massage study should be passive therapy where the participants receive the same attention in terms of time from the therapists as the massage group. However, the therapists should not apply any pressure on the muscle. Some physiotherapy equipment might be appropriate such as a sham shortwave diathermy.
- Studies should be designed as a counterbalance design in order to minimise the different responses of individual participants.
- Appropriate outcome measures and massage techniques should be used in the study.

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