Selective Effects of Manual Massage and Foam Rolling on Perceived Recovery and Performance: Current Knowledge and Future Directions Toward Robotic Massages

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Manual massage and foam rolling are commonly used by athletes for warm-up and recovery, as well as by healthy individuals for well-being. Manual massage is an ancient practice requiring the intervention of an experienced physiotherapist, while foam rolling is a more recent self-administered technique. These two topics have been largely studied in isolation from each other. In the present review, we first provide a deep quantitative literature analysis to gather the beneficial effects of each technique through an integrative account, as well as their psychometric and neurophysiological evaluations. We then conceptually consider the motor control strategies induced by each type of massage. During manual massage, the person remains passive, lying on the massage table, and receives unanticipated manual pressure by the physiotherapist, hence resulting in a retroactive mode of action control with an ongoing central integration of proprioceptive feedback. In contrast, while performing foam rolling, the person directly exerts pressures through voluntary actions to manipulate the massaging tool, therefore through a predominant proactive mode of action control, where operations of forward and inverse modeling do not require sensory feedback. While these opposite modes of action do not seem to offer any compromise, we then discuss whether technological advances and collaborative robots might reconcile proactive and retroactive modes of action control during a massage, and offer new massage perspectives through a stochastic sensorimotor user experience. This transition faculty, from one mode of control to the other, might definitely represent an innovative conceptual approach in terms of human-machine interactions.

Keywords: physiotherapy, manual massage, self-myofascial release, cobots, foam rolling, robotic, motor control

INTRODUCTION

In the last decades, work and recreational activities drastically affected our habits by increasing sedentary life (Choi, 2019). This is further a well-admitted harmful consequence of the overuse of computers and smartphones resulting in various disorders such as postural deformity, and neck and shoulder pain (Choi, 2019). It is also well-established that the repetition and prolonged
MANUAL MASSAGE

MM therapy is widely used as a warm-up method and cool-down process in sports (Weerapong et al., 2005). It is also administered in clinical populations for therapeutic purposes or well-being (Field et al., 2005). In the first case, therapeutic massage is practiced as part of therapeutic interventions targeting the symptoms of a specific pathology/disease. MM appears to be an effective treatment for infants of depressed mothers, and in elderly patients with severe dementia (Field et al., 1996; Suzuki et al., 2010). Also, world-class athletes benefit from MM to improve their performance and facilitate recovery (Espí-López et al., 2020). Noteworthy, the use of MM is not restricted to therapeutic or performance-enhancing interventions. Indeed, it is also used as a tool to promote well-being. Wellness massage is therefore not intended to treat patient, but also used for the sole purpose of enhancing perceived well-being across physical, mental, social and even spiritual domains (Andrade, 2013). The various maneuvers and pressures are performed on soft tissues by the hands of a qualified physiotherapist, who adjusts his MM routine based on the aim and time available for his intervention.
Dependent Variables
Psychometric and Behavioral Assessments
MM is an ancestral practice found in many civilizations. Beyond these origins, it is available in three forms: wellness, therapeutic, and sports MM. To appreciate its impact, researchers first collected subjective evaluations through self-report ratings. These tools are simple to use, cost-effective, and non-invasive. While monitoring objective data is likely to provide greater levels of precision, it remains costly and invasive. There are nonetheless several reports of behavioral assessments of the effects of MMs. Joint amplitude is assessed by means of goniometers and functional tests (Leivadi et al., 1999; Hilbert et al., 2003; Zainuddin et al., 2005; McKechnie et al., 2007; Arabaci, 2008; Arazì et al., 2012; Iwamoto et al., 2016; Table 1). Behavioral measures also enabled researchers to assess the impact of MM on strength production of athletes (Rinder and Sutherland, 1995; Tiidus and Shoemaker, 1995; Farr et al., 2002; Hilbert et al., 2003; Dawson et al., 2004; Zainuddin et al., 2005; Jakeman et al., 2010). The influence of MM was also examined in vertical and horizontal power production (Farr et al., 2002; McKechnie et al., 2007; Willems et al., 2009; Jakeman et al., 2010; Delextrat et al., 2013; Abrantes et al., 2019). Speed and agility qualities were checked, taking into account acceleration, deceleration (Mancinelli et al., 2006; Arabaci, 2008; Arazì et al., 2012; Delextrat et al., 2013; Table 1).

Neurophysiological Evaluations
Technological advances allowed investigation of changes occurring at the physiological level (Table 2). For instance, cutaneous temperature attesting changes in peripheral blood circulation was frequently collected (Drust et al., 2003; Hinds et al., 2004; Mori et al., 2004). It thus became possible to evaluate muscle temperature (Drust et al., 2003; Hinds et al., 2004), speed of blood circulation (Tiidus and Shoemaker, 1995; Hinds et al., 2004; Mori et al., 2004; Wiltshire et al., 2010), and blood pressure (Hinds et al., 2004; Arroyo-Morales et al., 2008; Wiltshire et al., 2010; Table 2). Some researchers also investigated the repercussions of MM on the activation of the sympathetic and parasympathetic nervous systems through monitoring of heart rate variability (Hemmings et al., 2000; Drust et al., 2003; Robertson et al., 2004; Arroyo-Morales et al., 2008; Wiltshire et al., 2010; Pinar et al., 2012; Table 2). More invasive procedures, such as biopsies and blood sampling, enable measures of changes in cortisol levels, markers of inflammation and metabolic products (Kaada and Torstein, 1989; Smith et al., 1994; Leivadi et al., 1999; Hemmings et al., 2000; Hilbert et al., 2003; Hinds et al., 2004; Robertson et al., 2004; Zainuddin et al., 2005; Ogai et al., 2008; Cupido, 2010; Rapaport et al., 2010; Wiltshire et al., 2010; Crane et al., 2012; Pinar et al., 2012; Iwamoto et al., 2016; Kargarfard et al., 2016; White et al., 2020; Table 2). This represents valuable information to prevent stress or inflammatory conditions that may ultimately lead to injury or a state of overtraining.

Short-Term Effects
MM therapy has supposedly many virtues (Calvert, 2002). Its positive effects have been extensively reported in the scientific literature (Weerapong et al., 2005; Best et al., 2008; Brummitt, 2008). A sensation of psychological well-being was frequently reported (Mancinelli et al., 2006; Visconti et al., 2015). MM is further supposed to alleviate mood and anxiety disorders (Leivadi et al., 1999; Sharpe et al., 2007; Nakano et al., 2019), improve the feeling of recovery, reduce physical fatigue (Hemmings et al., 2000; Mori et al., 2004; Robertson et al., 2004; Ogai et al., 2008; Carcano et al., 2010; Pinar et al., 2012; Delextrat et al., 2013; Jourdain, 2015).

Several authors reported range of motion (ROM) gains. Indeed, the dorsiflexion following MM ranged from 18.4° to 22.8°. Also, on a sit-and-reach box test, participants’ score increased from 11.8 to 12.7 cm, after only 15 min of MM (Arabaci, 2008; Iwamoto et al., 2016). More generally, MM were shown to induce short-term flexibility gains, similar to those induced by static stretching, without co-occurrence of negative effects on physical performance (McKechnie et al., 2007; Arazì et al., 2012). These notions of ROM and flexibility were combined to increase the suppleness of an athlete.

In terms of recovery, few studies measured the influence of manual therapy on muscle stiffness. To date, no consensus is clearly established. Authors observed, using a durnometer, a drop in stiffness between two intense efforts after a kneading MM (Ogai et al., 2008). Ultrasound shear wave elastography also showed progress in stiffness, but the benefits did not last more than 3 min (Eriksson Crommert et al., 2015). Some contradictory results, obtained with a rotary potentiometer or a myotonometry device, could be due to the very short observation time (Thomson et al., 2015; Kong et al., 2018). Before drawing general conclusions, further experimental studies are certainly required. Particular attention should be paid to the timing of the measurements. Manual therapy further appears to be effective to reduce adverse effects of exercise, likely to elicit delayed-onset muscle damage (DOMS). These benefits were obtained when MM is performed immediately after the effort, and up to 3 h afterward; Table 3). A recent meta-analysis concluded that MM could be the most efficient post-exercise intervention to prompt recovery. Compared to cryotherapy, cold-water immersion and compression garment, MM elicited a greater reduction in DOMS, perceived fatigue, and markers of inflammation (Dupuy et al., 2018). With regards to sport performance, MM was punctually found to positively affect the recovery of muscle power (Mancinelli et al., 2006; Willems et al., 2009) Table 1). However, other studies failed to detect such positive changes (Tiidus and Shoemaker, 1995; Farr et al., 2002), while others reported negative effects (Arabaci, 2008; Arazì et al., 2012). Similar inconsistent results were also reported by various meta-analytical reviews (Brummitt, 2008; Gaullier, 2015; Poppendieck et al., 2016). In another set of studies, MM was not found to promote force reduction after an exercise-induced muscle damage (Tiidus and Shoemaker, 1995; Farr et al., 2002; Hilbert et al., 2003; Zainuddin et al., 2005; Table 3). Based on these data, and despite some inconsistencies, we shall recommend the use of MM before a physical effort or even between two successive sporting events. Also, athletes immobilized due to injury could benefit from MM. In mice, Saitou et al. (2018) demonstrated...
### TABLE 1 | The effects of MM on performances.

| Author (year) | Study design | Sample | Targeted area | Massage intervention | Treatment time | Control | Others experimental groups | Outcome measures | Effects |
|---------------|--------------|--------|---------------|----------------------|----------------|---------|---------------------------|-----------------|---------|
| **Range of motion** | | | | | | | | | |
| Leivadi et al. (1999) | RCT | 30 dance students | Whole body | Effleurage, petrissage, friction | 30 min | No | Massage Relaxation therapy 2 times/week over 5 weeks | Neck and shoulder ROM | Long term effect: ↑ neck extension ROM ↑ shoulder abduction ROM |
| Arazi et al. (2012) | RCT | 20 college athletes | Main lower limb muscles | Effleurage, friction, petrissage, vibration and tapotment | 15 min | Yes | Swiss massage Static-stretching | Sit-and-reach | ↓ lower back and hamstrings flexibility |
| Hilbert et al. (2003) | RCT | 18 young and healthy subjects | Hamstrings | Effleurage, tapotement, petrissage | 20 min/post 2 h | Yes | Swedish massage Placebo massage | Straight leg raise test | NS change hamstring flexibility |
| McKechnie et al. (2007) | RC | 19 healthy and recreationally active | Plantar flexors | Effleurage and petrissage | 3 min/leg | Yes | Petrissage Tapotement at 4 Hz | Ankle joint flexibility | ↑ petrissage > tapotement ↑ ankle ROM |
| Arabaci (2008) | RC | 24 healthy and physically active | Main lower limb muscles | Effleurage, friction, petrissage, vibration, tapotment | 15 min | Yes | Swedish massage Stretching | Sit-and-reach | ↑ lower back and hamstrings flexibility |
| Iwamoto et al. (2016) | CT | 12 healthy students | Popliteal fossa | Small circle with thumb at 3 Hz | 2–3 min | No | Friction massage | Ankle joint flexibility | ↑ dorsiflexion NS change plantar flexion |
| **Power performance** | | | | | | | | | |
| Mancinelli et al. (2006) | RCT | 22 NCAA Division I basketball and volleyball players | Quadriceps, hamstrings | Effleurage, petrissage and vibration | 17 min/post 48 h | Yes | Western massage | CMJ | ↑ vertical power NS change horizontal power |
| Arazi et al. (2012) | RCT | 20 college athletes | Main lower limb muscles | Effleurage, friction, petrissage, vibration and tapotment | 15 min | Yes | Swiss massage Static-stretching | Vertical jump, 30 m sprint, agility-T test | ↓ horizontal and vertical power ↓ agility |
| Delextrat et al. (2013) | RCT | 8 basketball players | Main lower limb muscles and back | Effleurage, petrissage | 15 min/leg | Yes | Massage Cold-water immersion | CMJ | ↑ CMJ NS change repeated sprint ability |
| Farr et al. (2002) | RCT | 8 healthy and recreationally active | Main lower limb muscles | Effleurage, petrissage (no deep tissue massage) | 30 min/post 2 h | No | Leg massage Leg control | Single limb jumps | ↓ muscular power at 24 h |
| McKechnie et al. (2007) | RC | 19 healthy and recreationally active | Plantar flexors | Effleurage and petrissage | 3 min/leg | Yes | Petrissage Tapotement at 4 Hz | Drop-jump | NS change muscular power |
| Arabaci (2008) | RC | 24 healthy and physically active | Main lower limb muscles | Effleurage, friction, petrissage, vibration, tapotment | 15 min | Yes | Swedish massage Stretching | 30 m sprint Leg reaction time | ↓ horizontal and vertical power ↓ reaction time |

(Continued)
| Author (year)        | Study design | Sample details | Targeted area          | Massage intervention                | Control | Others experimental groups | Outcome measures | Effects          |
|---------------------|--------------|----------------|------------------------|-------------------------------------|---------|-----------------------------|-----------------|------------------|
| Jakeman et al.      | RCT          | 32 healthy and physically active | Main lower limb muscles | Effleurage, petrissage, tapotment and hacking | 30 min  | Yes                         | Sport massage + compression Compression alone (12 h) | CMJ, Squat jump (SJ) | ↑ horizontal and vertical power |
| Abrantes et al.     | RCT          | 39 physically active men | Finger/elbow Stick massage | Main lower limb muscles and chest | 8 min  | No                          | Manual massage (upper body) + Foam rolling (lower limbs) | Vertical and horizontal jump | ↑ vertical and horizontal power |
| **Strength performance** | | | | | | | | |
| Rinder and Sutherland (1995) | RC | 20 club member | Quadriceps | Effleurage and petrissage | 3 min/leg | Yes | Massage | Maximum number of leg extension at 50% 1RM | ↑ quadriceps performance |
| Tiidus and Shoemaker (1995) | RCT | 9 healthy students | Quadriceps | Superficial and deep effleurage | 10 min/post < 1 h | No | Leg massage Leg control | Isometric and isokinetic knee extension | NS change muscle strength |
| Zainuddin et al.    | RC           | 10 healthy subjects | Hand and main upper limb muscles | Effleurage, petrissage, friction | 10 min/post 3 h | No | Arm massage Arm control | Isometric and isokinetic elbow flexion | NS change muscle strength |
| Wilkins et al.      | RCT          | 7 healthy and moderately active | Main lower limb muscles | Effleurage, petrissage, tapotement | 25 min  | No | Leg massage Leg control | Single limb jumps | ↑ muscular power at 48 h |
| Jakeman et al.      | RCT          | 32 healthy and physically active | Main lower limb muscles | Effleurage, petrissage, tapotment and hacking | 30 min  | Yes | Sport massage + compression Compression alone (12 h) | Knee extension | ↑ isokinetic strength vs control group |
| Abrantes et al.     | RCT          | 39 physically active men | Finger/elbow Stick massage | Main lower limb muscles and chest | 8 min  | No | Manual massage (upper body) + Foam rolling (lower limbs) | Vertical and horizontal jump | ↑ vertical and horizontal power |

CT, Clinical trial; RCT, randomized controlled trial; RC, randomized crossover; CCT, controlled clinical trial; NR, not reported; ROM, range of motion; CMJ, countermovement jump; ↑ indicates increase; ↓ indicates decrease; NS, not significant.


| Author (year)          | Study design | Sample                          | Massage intervention                  | Control     | Others experimental groups | Outcome measures                                                                 | Effects                                                                 |
|------------------------|--------------|---------------------------------|---------------------------------------|-------------|----------------------------|----------------------------------------------------------------------------------|------------------------------------------------------------------------|
| Neurophysiological and physiological effects                   |              |                                 |                                       |             |                            |                                                                                  |                                                                        |
| Leivadi et al. (1999) | RCT          | 30 dance students               | Whole body                            | Effleurage, petrissage, friction     | 30 min/Slow | No Massage Relaxation therapy 2 times/week over 5-weeks                          | Salivary cortisol ↓ cortisol (stress hormones)                         |
| Hemmings et al. (2000)| RCT          | 8 amateur boxers                | Main lower limb muscles, back, shoulder and arms | Effleurage, petrissage               | 20 min      | Yes Massage therapy            | Blood analyzes NS change blood lactate, glucose concentration NS change heart rate |
| Kargarfard et al. (2016)| RCT         | 30 male bodybuilders            | Quadriceps                           | Effleurage, petrissage and vibration | 30 min/post 2 h | Yes Western massage group | Blood sample Massage vs control group : ↓ creatine kinase level from 48 h up to 72 h ↓ inflammation marker concentrations (↓IL-6) |
| White et al. (2020)   | RC           | 9 collegiate-level athletes     | Main lower limb muscles              | Effleurage and neuromymphatic        | 30 min      | Yes Massage therapy            | Blood sample ↓ neutrophils ↓ CK Less ↓ cortisol serum                     |
| Kaada and Torsteinb (1989)| CT           | 12 subjects with chronic pain   | Lumbo-sacral region                   | Connective tissue massage            | 30 min/Slow | No Connective tissue massage     | Blood sample ↑ relaxation substances (↑ ß-endorphins)                      |
| Smith et al. (1994)   | RCT          | 14 healthy but untrained subjects | Biceps, triceps                | Effleurage, shaking, petrissage, cross-fibre | 30 min/post 2 h | Yes Sham massage               | Blood analyzes ↑ neutrophils ↓ CK Less ↓ cortisol serum               |
| Tiidus and Shoemaker (1995)| RCT          | 9 healthy students              | Quadriceps                           | Superficial and deep effleurage      | 10 min/post < 1 h | No Leg massage Leg control | Arterial blood velocity NS change quadriceps muscle blood flow              |
| Drust et al. (2003)   | RC           | 7 healthy subjects              | Quadriceps                           | Deep effleurage                       | 5, 10, 15 min 52 strokes/min | No 3 groups of massage Ultrasound (5 min) | Heart rate monitor Skin and intramuscular temperature ↑ intra muscular and skin temperature at depths of 1.5 and 2.5 cm ↑ heart rate |
| Hilbert et al. (2003) | RCT          | 18 young and healthy subjects   | Hamstrings                           | Effleurage, tapotement, petrissage   | 20 min/post 2 h | Yes Swedish massage             | Blood sample NS change neutrophils                                      |

(Continued)
TABLE 2 | Continued

| Author (year)      | Study design | Sample | Targeted area          | Massage intervention       | Control | Others experimental groups | Outcome measures | Effects                                      |
|--------------------|--------------|--------|------------------------|-----------------------------|---------|-----------------------------|-------------------|----------------------------------------------|
| Hinds et al. (2004) | RCT          | 13 young healthy subjects | Quadriceps               | Deep effleurage and petrissage | Yes     | Massage | Blood flow | ↑ skin temperature, ↑ skin blood flow, NS change blood pressure, heart rate, lactate concentration and FABF |
|                    |              |        |                        | 2*6 min 50–60 strokes/min   |         |                 | Blood sample | Blood pressure, Heart rate                    |
| Robertson et al. (2004) | RC         | 9 healthy and recreationally active | Main lower limb muscles | Effleurage, kneading, picking up, wringing, rolling | Yes     | Massage | Blood sample | NS change lactate level and heart rate response |
| Zainuddin et al. (2005) | RC         | 10 healthy subjects | Hand and main upper limb muscles | Effleurage, petrissage, friction | No      | Arm massage, Arm control | Upper arm circumference | Blood sample |
| Arroyo-Morales et al. (2008) | RCT | 62 healthy active subjects | Whole-body myofascial release | Long stroke, cross hand, static pressure | Yes | Sham (ultrasound and magnetotherapy) | Heart rate variability, Blood pressure | ↓ heart rate variability index, ↓ diastolic blood pressure |
| Ogai et al. (2008) | RC          | 11 healthy and active students | Main lower limb muscles | Petrissage | Yes | Massage | Blood sample | NS blood lactate concentration |
| Cupido (2010)     | RC          | 13 young healthy and recreationally active | Quadriceps | Effleurage, petrissage, compression | No | Leg massage, Leg control | Blood sample | Muscle damage, Muscle glucose level, NS glycogen, lactate concentration and muscle damage |
| Jakeman et al. (2010) | RCT        | 32 healthy and physically active | Main lower limb muscles | Effleurage, petrissage, tapotment and hacking | Yes | Sport massage + compression, Compression alone (12 h) | Blood sample | NS creatine kinase activity |
| Rapaport et al. (2010) | RCT       | 53 healthy subjects | Full body | Effleurage, petrissage, kneading, tapotement and thumb friction | No | Swedish massage, Light touch | Blood analyzes T+5, +1 pre- min and post- T+1, 5, 10, 15, 30, 60 min | Massage > light touch, ↑ immune system (↑ circulating phenotypic lymphocyte, ↓ cytokine level, arginine-vasopressin and cortisol) |

(Continued)
| Author (year) | Study design | Sample | Targeted area | Massage intervention | Control | Others experimental groups | Outcome measures | Effects |
|--------------|-------------|--------|---------------|----------------------|---------|-----------------------------|-----------------|---------|
| Wiltshire et al. (2010) | RC | 12 healthy subjects | Forearm muscles | Effleurage, petrissage | 10 min | Yes | Massage | forearm blood flow | ↓ blood flow (impairing lactic acid removal) |
| Crane et al. (2012) | RCT | 11 young healthy and recreationally active | Quadriceps | Effleurage, petrissage, compression | 10 min/post | No | Leg massage | Blood analyzes | ↓ inflammation (cytokines TNF-a, interleukin-6, heat shock protein 27) |
| Pinar et al. (2012) | RC | 12 young healthy and recreationally active | Quadriceps, hamstrings | Effleurage, kneading, picking up, wringing, rolling | 24 min | Yes | Massage | Blood sample | ↑ mitochondrial biogenesis (focal adhesion kinase, ERK1/2, PGC-1a) |
| Iwamoto et al. (2016) | CT | 12 healthy students | Popliteal fossa | Small circle with thumb at 3 Hz | 2–3 min | No | Friction massage | Oxygenated hemoglobin | ↑ venous return (muscle oxygenation) |
| Psychological effect | | | | | | | | |
| Leivadi et al. (1999) | RCT | 30 dance students | Whole body | Effleurage, petrissage, friction | 30 min/slow | No | Massage | State-trait anxiety inventory | ↑ mood |
| Hemmings et al. (2000) | RCT | 8 amateur boxers | Main lower limb muscles, back, shoulder and arms | Effleurage, petrissage | 20 min 30–60 strokes/min | Yes | Massage | Numerical recovery scale | ↑ perceived recovery |
| Carcano et al. (2010) | CT | 96 national and international athletes | Main lower limb muscles | Superficial and deep effleurage, friction | 20–30 min/Slow | No | Swedish massage | Pain VAS-10 | ↓ muscle soreness |
| Delextrat et al. (2013) | RCT | 8 basketball players | Main lower limb muscles and back | Effleurage, petrissage | 15 min/leg | Yes | Massage | Overall fatigue VAS-10 | ↓ perceived fatigue |
| Author (year)          | Study design | Sample                        | Targeted area                        | Massage intervention                                      | Control | Others experimental groups                                                                 | Outcome measures                            | Effects |
|-----------------------|--------------|-------------------------------|--------------------------------------|-----------------------------------------------------------|---------|--------------------------------------------------------------------------------------------|---------------------------------------------|---------|
| Jourdain (2015)       | CT           | 11 young athletes             | Main lower limb muscles              | Longitudinal/ transverse deep sliding pressures, kneading and circular friction | 10 min/leg post 2 h | No Massage 1 time/week over 5-weeks                                                   | HPHEES Scale                                | ↓ perceived fatigue on waking NS change overall physical form |
| Visconti et al. (2015)| Pilot study  | 25 ultramarathon runners      | Main lower limb muscles              | Effleurage                                                 | 20 min | No Massage                                                                            | Numeric pain rating scale Patient global impression of change | ↓ muscle pain |
| Kargarfard et al. (2016)| RCT       | 30 male bodybuilders          | Quadriceps                           | Effleurage, petrissage and vibration                      | 30 min/post 2 h | Yes Western massage group | Pain VAS-10                                | ↓ muscle soreness from 24 h up to 72 h |
| Mori et al. (2004)    | RC           | 29 healthy students           | Lumbar and sacrum region             | Effleurage, kneading and compression techniques           | 5 min between two sets | Yes Massage | Fatigue VAS-10                        | ↓ perceived fatigue |
| Robertson et al. (2004)| RC         | 9 healthy and recreationnally active | Main lower limb muscles              | Effleurage, kneading, picking up, wringing, rolling       | 20 min/post-active recovery 5 min | Yes Massage | Fatigue index                        | ↓ perceived fatigue |
| Sharpe et al. (2007)  | RCT          | 54 elderly subjects (≥ 60 years) | Whole body                           | Swedish, neuromuscular, and myofascial techniques         | 50 min | No Massage therapy Guided relaxation 2 times/week over 4-weeks | General well-being schedule Perceived stress scale | ↓ anxiety, depression; ↑ vitality, general health and positive well-being vs guided relaxation group |
| Ogai et al. (2008)    | RC           | 11 healthy and active students | Main lower limb muscles              | Petrissage                                                 | 10 min between two sets | Yes Massage | Perceived fatigue VAS-10                       | ↑ perceived recovery between two high intensive exercises |
| Pinar et al. (2012)   | RC           | 12 young healthy and recreationnally active | Quadriceps, hamstrings               | Effleurage, kneading, picking up, wringing, rolling      | 24 min | Yes Massage Electrical muscle stimulation | Total quality of recovery Rating of perceived exertion | NS change psychological recovery after high intensity exercise |
| Nakano et al. (2019)  | RC           | 12 elderly people (65 years old) | Hands/Feet                           | Stroke                                                     | 15 min | No Hand massage | Likert scale                        | Both groups; ↑ pleasant, relaxed and refreshed feelings |

CT, clinical trial; RCT, randomized controlled trial; RC, randomized crossover; VAS, visual analogue scale; NR, not reported; ↑ indicates increase; ↓ indicates decrease; NS, not significant.
TABLE 3 | The effects of MM on delayed-onset muscle soreness.

| Author (year) | Study design | Sample | Targeted area | Massage intervention | Nature of the exercise | Control | Others experimental groups | Outcome measures | Effects |
|---------------|--------------|--------|---------------|----------------------|------------------------|---------|---------------------------|-----------------|---------|
| Mancinelli et al. (2006) | RCT | 22 NCAA Division I basketball and volleyball players | Thigh | Effleurage, petrissage, vibration | 17 min/post 48 h | Intense strength training and drills | Yes | Western massage | PPT in quadriceps femoris Muscle soreness VAS-10 Vertical jump | ↓ DOMS ↑ tenderness ↑ vertical power |
| Kargarfard et al. (2018) | RCT | 30 male bodybuilders | Quadriceps | Effleurage, petrissage and vibration | 30 min/post 2 h | 5 sets of squat until exhaustion at 75% of 1-RM | Yes | Western massage | Pain VAS-10 OMJ Blood sample Isometric torque pre- and post- T0, T+24, 48 and 72 h | Massage ↓ muscle soreness at 24, 48 and 72 h ↓ creatine kinase from 48 h ↑ vertical power and muscle strength at 48 h |
| Smith et al. (1994) | RCT | 14 healthy but untrained subjects | Biceps, triceps | Effleurage, shaking, petrissage, cross-fibre | 30 min/post 2 h | Biceps and triceps eccentric exercise | Yes | Sport massage Sham massage | Clarkson Scale Blood creatine kinase concentration pre- and post- T0, T+8, 24, 48, 72, 96, 120 h Blood analyses (neutrophils and cortisol) pre- and post- T0, T+8 h (30-minute intervals) | ↓ DOMS intensity Peak DOMS at 24 h ↓ markers damage and inflammation (creatine kinase, cortisol) ↑ neutrophils activity |
| Tiidus and Shoemaker (1995) | CCT | 9 healthy students | Quadriceps | Superficial and deep effleurage | 10 min/post < 1 h | Quadriceps eccentric exercises | No | Leg massage Leg control | Numerical pain-rating scale Isometric and isokinetic knee extension pre- and post- T+15 min, T+24, 48, 72, 96 h | Tendency ↓ perception of DOMS from 48 h Peak DOMS at 24 h NS change muscle strength |
| Farr et al. (2002) | RCT | 8 healthy and recreationally active | Main lower limb muscles | Effleurage, petrissage (no deep tissue massage) | 30 min/post 2 h | 40 min downhill treadmill walk loaded | No | Leg massage Leg control | Clarkson Scale PPT Isometric and isokinetic knee extension Vertical jump pre- and post- T0, T+24, 48, 72, 96, 120 h | Tendency ↓ DOMS magnitude ↓ muscle tenderness attenuate the decrease of strength and vertical power |

(Continued)
### TABLE 3 | Continued

| Author (year) | Study design | Sample | Targeted area | Massage intervention | Nature of the exercise | Treatment time | Control | Others experimental groups | Outcome measures | Effects |
|---------------|--------------|--------|---------------|----------------------|------------------------|-------------------|---------|-----------------------------|-----------------|---------|
| Hilbert et al. (2003) | RCT | 18 young and healthy subjects | Hamstrings | Effleurage, tapotement, petrissage | 20 min/post 2 h | Hamstrings eccentric exercises | Yes | Swedish massage Placebo massage | Differential descriptor scale intensity of soreness Blood sample Eccentric hamstring contraction pre- and post- T0, T+2, 6, 24, 48 h | ↓ perception of DOMS from 48 h Peak DOMS at 24 h NS change neutrophils, ROM and peak torque |
| Zainuddin et al. (2005) | RC | 10 healthy subjects | Hand and main upper limb muscles | Effleurage, petrissage, friction | 10 min/post 3 h | Elbow flexors eccentric exercises | No | Arm massage Arm control | Pain VAS-10 Isometric and isokinetic elbow flexor strength Blood sample pre- and post- T0, T+1, 2, 3, 4, 7, 10, 14 days | ↓ DOMS magnitude for palpation and joint mobilization ↓ creatine kinase activity NS change muscle strength |
| Willems et al. (2009) | RCT | 7 healthy and moderately active | Quadriceps | Effleurage, petrissage | 25 min | 20 min downhill treadmill walking at 25% decline | No | Leg massage Leg control | Quadriceps pain VAS-10 Single limb jumps pre- and post- T+24, 48, 72 h | ↓ DOMS vastus lateralis and rectus femoris at 48 h ↑ vertical power at 48 h |

CT, clinical trial; RCT, randomized controlled trial; RC, randomized crossover; CCT, controlled clinical trial; DOMS, delayed onset muscle soreness; NR, not reported; ↑ indicates increase; ↓ indicates decrease; NS, not significant.
that mechanical interventions mimicking MM could modulate inflammatory responses by local effects on interstitial fluid dynamics. The pressure exerted would induce a shear stress exertion on macrophages in situ, attenuating the phenomenon of muscle atrophy by a lymphatic and immune response (Saitou et al., 2018; Sakitani et al., 2019). In animal models, MM induces numerous neurophysiological changes. In fact, MM was associated with modulations in neural, lymphatic, and genetic responses (Lima et al., 2020). For example, abdominal massage improves transit in rats, i.e., reduced time to first fecal discharge in response to mechanical pressures. At the endocrine level, it was also shown that MM reduced the levels of gastrointestinal hormones, i.e., insulin, gastrin and somatostatin (Lima et al., 2020). MM also had modulatory effects at the neural level, since its analgesic effects were associated with changes in descending pain modulation circuits (Vigotsky and Bruhns, 2015). Nonetheless, the lack of consistency in the experimental findings in humans might be explained by a weak methodological rigor, as few protocols were reproduced and tested, hence supporting that there is no clear and precise design ensuring effectiveness of the intervention. The high variability of the studies is well-illustrated by the use of effleurage and petrissage techniques, while others also used friction, picking up, and shaking techniques. Likewise, the number of areas treated and the effective time of sport MM could fluctuate from 5 to 30 min (Brummitt, 2008; Poppendieck et al., 2016). Similarly, very few studies specified the intensity, the speed and the gestural frequency exerted by the therapist during the MM. Although these data are difficult to quantify, these parameters remain essential, as is the experience of the therapist, which has a main influence on MM effectiveness, and should be more rigorously controlled. Accordingly, Moraska (2007) provided evidence that therapist with 950 h of didactic training achieved significantly better results in muscle soreness than with 450 or 700 h of training. Although MM is an ancestral practice, this therapy, which is above all empirical, retains a certain number of gray areas, particularly in terms of sports massage, and the standardization of a sport MM protocol is warranted.

**Long-Term Intervention**

To prepare the body for an intense exercise or to facilitate the post-exercise recovery, longer-term repeated MM interventions have extensively been administered within a span of 2–5 weeks. One to two weekly MM sessions of 20–30 min were found to reduce the level of stress and fatigue (Leivadi et al., 1999; Jourdain, 2015). After a long-term exercise, a difference was noticed by the athletes after receiving a one-sided manual leg massage. According to the participants, the perception of recovery of the side massaged was greater than the control (Dawson et al., 2004). With regards to well-being, it seems that a regular MM makes increase neck and shoulder ROM (Leivadi et al., 1999; Yang et al., 2012). MM finally contributed to decrease the level of salivary cortisol after a period of 5 weeks, after a design including two massages per week (Leivadi et al., 1999). These various effects concurred with increased relaxation resulting from the activation of the parasympathetic nervous system.

**Experimental Procedures**

MM is universally appreciated. Classical guidelines emphasized the importance of dynamic movements for stimulating the soft tissues (e.g., vibration and tapotement). Slow gestures (e.g., effleurage, kneading, sliding pressure and friction) were recommended for well-being and relaxation. When the MM is designed to promote post-exercise recovery, effleurage and kneading should rather be preferred (Standley et al., 2010). Incorporating tapotements was further relevant to reduce DOMS and joint amplitude recovery, whereas vibration facilitated blood circulation and friction promoted relaxation (Standley et al., 2010). A cool-down MM routine using might last between 15 and 30 min to allow physiological changes (Standley et al., 2010). Despite guidelines, future experimental designs should consider and study the pressure levels and the gestural speed of the practitioner during MM to compensate for the lack of data.

**FOAM ROLLING**

FR is a self-myofascial release technique requiring direct contact with the skin, where fingers or tools are used to slowly press the fascial tissue. FR have extensively been adopted in fitness and conditioning communities in recent years (Cheatham and Stull, 2018a,b). Because of its simplicity and measurable effects, FR is administered as part of warm-up and recovery routines (Fleckenstein et al., 2017). Practically, FR administered using a foam roller, a roller massager, sticks or balls with varying sizes and density, further became very popular to improve functional outcomes such as ROM and pain pressure threshold (PPT). The first technique consists in performing simple back and forth movements, thus exerting mechanical pressures on soft tissues via the weight of the body (or the force of the upper limbs). A second technique, called ischemic pressure, requires a static pressure during a 6–30 s period, below the individual pain tolerance threshold (Abels, 2013; Myers, 2013; Kalichman and Ben David, 2017). This complementary approach is designed to reduce pain felt and improve ROM, but requires greater expertise with FR (Kalichman and Ben David, 2017). For users, the goal is to get closer from MM practice of the physiotherapist, more specifically to reproduce the method of Rolfing.

Although the scientific literature addressing the effects of FR remains sparse, this research topic is currently gaining attention (Cheatham et al., 2015; Wiewelhove et al., 2019; Figure 1). There is an emerging consensus that FR positively affects athletic performances such as power, strength, agility, balance and flexibility (Schroeder and Best, 2015). FR also yielded beneficial effects in rehabilitation settings with elderly populations or patients suffering from locomotor disorder such as genu varus (Jafarnezhadgero et al., 2018; Lee and Lim, 2018), round shoulder posture (Choi, 2019), or spastic diplegia (Patole et al., 2019). In the same vein, recent FR studies investigated its potential effectiveness in the context of rehabilitation (i.e., tendinopathies, friction syndrome of the iliotibial band, fibromyalgia, myofascial pain syndrome, or postural correction) (Grieve et al., 2013; Aboodarda et al., 2015; Chan et al., 2015; Ceca et al., 2017; Lee et al., 2017; Jafarnezhadgero et al., 2018). The theoretical rationale
advanced as an account to the benefits of FR largely overlaps that for traditional MM.

**Dependent Variables**

**Psychometric and Behavioral Assessments**

As for MM, experimental designs seeking to assess the effectiveness of FR involved psychometric, behavioral and physiological measures. Subjective measures primarily consisted in standardized questionnaires and self-reports ratings on Likert-type scales to quantify pain and quality of life (Healey et al., 2014; Cavanaugh, 2016; Fleckenstein et al., 2017; Table 4). Researchers also used Borg scales or numerical ratings scale as means to collect perceived recovery (Healey et al., 2014; Peacock et al., 2015; Fleckenstein et al., 2017; Kalén et al., 2017; Rey et al., 2017; Beier et al., 2019; Table 4). Considering that pain is not objectively measurable, these different scales offer a simple solution to assess the quality and speed of recovery of DOMS (Jay et al., 2014; MacDonald et al., 2014; Romero-Moraleda et al., 2017, 2019; Naderi et al., 2019; Table 5). The algometer is also used to measure the PPT reliably, both at the muscular and joint levels, after FR routine. It is also used after exercise induced muscle damage and FR recovery (Pearcey et al., 2015; Correira, 2016; Casanova et al., 2017; Drinkwater et al., 2019; Table 5). Likewise, just like MM, functional tests, such as the sit-and-reach or weight-bearing lunge tests, are usual tools to assess the effectiveness of FR on ROM (Peacock et al., 2015; Škarabot et al., 2015; Kelly and Beardsley, 2016; Patel et al., 2016; Boguszewski et al., 2017; Grabow et al., 2017; Jung et al., 2017; Paz et al., 2017; Sağiroğlu, 2017; García-Gutiérrez et al., 2018; Phillips et al., 2018; Guillot et al., 2019; Pathania and Muragod, 2019; Somers et al., 2019; Williams and Selkow, 2019; Table 6). Other clinical examinations, such as the Thomas test or the straight leg raise test, are also regularly used to quantify flexibility with manual or electric goniometers after FR (MacDonald et al., 2014; Mohr et al., 2014; Cho et al., 2015; Vigotsky et al., 2015; Su et al., 2017; Do et al., 2018; Killen et al., 2018; Madoni et al., 2018; Guillot et al., 2019; Jeong et al., 2019; Kyranoudis et al., 2019; Lim and Park, 2019; Oranchuk et al., 2019; Table 6). Applied to FR research, goniometer/inclinometer index gains in terms of degrees of freedom of the joints (Peacock et al., 2015; Škarabot et al., 2015; Fairall et al., 2017; Le Gal et al., 2018; Table 6). In addition to such flexibility tests, evaluating the effects of FR on physical qualities such as muscular power/strength, agility, and muscular activation, remains crucial (Mikesky et al., 2002; Fama and Bueti, 2011; Healey et al., 2014; Peacock et al., 2014, 2015).

**Neurophysiological Evaluations**

To this end, researchers used surface electromyography (EMGs) to appreciate whether muscle activation increase was associated with better performance, and further reduced the risk of injury (Macgregor et al., 2018). EMGs were recorded non-invasively by positioning electrodes directly on a shaved skin cleaned with alcohol (Ginszt et al., 2017; Romero-Moraleda et al., 2017; Hodgson et al., 2018; Madoni et al., 2018; Beier et al., 2019; Capobianco et al., 2019; Kim et al., 2019; Mazzei, 2019; Ye et al., 2019; Table 7). Recently, the development of tensiomyography allowed rapid and reliable non-invasive investigations of the contractile properties of the skeletal muscle (Martínez-Cabrera and Núñez-Sánchez, 2016; Murray et al., 2016; Schroeder et al., 2017; Macgregor et al., 2018; Table 7).

To complement the measurements made on the peripheral nervous system, other research was undertaken to increase the current understanding of the effects of FR to a more fundamental level. Researchers hypothesized that this technique was not limited to local changes in muscle tissues, but might also affect the vascular function. Some researchers collected blood analyses to measure concentrations of blood cortisol, lactate, oxytocin or even nitric oxide (Kim et al., 2014; Okamoto et al., 2014; D’Amico and Paolone, 2017; Kalén et al., 2017; Table 7). To overcome invasive constraints, they used an automatic blood pressure monitor, simple and quick to manipulate. This medical device consists of an inflatable cuff positioned on the arm. This device measures blood pressure by the oscillatory method, i.e., the heartbeats, pulse wave velocity, systolic and diastolic pressures (Okamoto et al., 2014; Lastova et al., 2018; Table 7). To achieve a more detailed analysis of both superficial and deep blood flow, ultrasound Doppler recordings were further used. This exploration is certainly more precise but requires specific knowledge in medical semiology as well as good adjustments of the device (Thistlethwaite et al., 2016; Hotfiel et al., 2017; Table 7). Formerly designed and reserved for the medical field, these advanced measurements are now gradually made available to applied research and extend current knowledge to FR. This recent spread comes in particular from a surge of recent interest from physiotherapists and rehabilitation professionals. Researchers therefore did not restrain their evaluation to functional tests for monitoring flexibility and muscle performance.

**Short-Term Effects**

Positive short-term FR effects, measured at a single-session level, were found to substantially reduce muscle pain (Schroeder and Best, 2015), in particular after exercise-induced muscle damage (Jay et al., 2014; MacDonald et al., 2014; Pearcey et al., 2015; Table 7).
| Author (year) | Study design | Sample | Foam rolling intervention | Control | Others experimental groups | Outcome measures | Effects |
|--------------|--------------|--------|---------------------------|---------|-----------------------------|-----------------|---------|
| Peacock et al. (2015) | RC | 16 athletically trained adult | High density FR | Main lower limb muscles and lower back | NR | Sagittal plane FR Frontal plane FR | No change rate of perceived exhaustion |
| Kalén et al. (2017) | RC | 12 surf lifeguards | High density FR | Main lower limb muscles per leg | 7/10 | Running Passive recovery | No change rate of perceived exhaustion |
| Rey et al. (2017) | RCT | 18 professional soccer players | High density FR | Main lower limb muscles | Self-selected | Foam rolling Planking exercises | ↑ feelings of recovery ↓ perceived muscle soreness at 24 h post-training |
| Beier et al. (2019) | RC | 11 resistance trained subjects | Stick massage | Rectus femoris and gluteus maximus | Heavy pressure | Recovery scale-10 | NS change perceived recovery |
| Healey et al. (2014) | RC | 26 healthy college-aged and recreationally active | High density FR | Main lower limb muscles and upper back | Self-selected | Fatigue VAS-10 Muscle soreness VAS-10 | ↓ fatigue NS difference muscle soreness |
| Cavanaugh (2016) | RC | 12 healthy and recreationally active | Roller massager | Plantar flexors | 7/100/10 | Pain VAS-10 | ↓ pain perception with heavy foam-rolling |
| Cheatham et al. (2017) | RCT | 45 healthy subjects | High density FR | Quadriceps | Moderate | Quadriceps PPT All groups: ↑ muscle tenderness |
| Cheatham et al. (2019) | RCT | 45 healthy and recreationally | Vibrating foam roller Non vibrating foam roller | Quadriceps | Moderate | Quadriceps PPT Both groups ↑ knee ROM ↑ muscle tenderness (vibrating > non-vibrating) |
| Cheatham and Baker (2017) | RCT | 20 healthy subjects | High density FR | Quadriceps | 1 inch per second | Quadriceps and hamstrings PPT | ↑ muscle tenderness (crossover effect on contralateral quadriceps) |

(Continued)
| Author (year)          | Study design | Sample description | Foam rolling intervention | Control | Others experimental groups | Outcome measures | Effects |
|-----------------------|--------------|---------------------|---------------------------|---------|-----------------------------|------------------|---------|
| Fleckenstein et al. (2017) | RCT          | 55 healthy and recreationally active | High density FR | Mam lower limb muscles | 1 × 30 s/muscle 60 bpm | 7/10 | Yes | Prevention Regeneration | Fatigue VAS-10 Pain VAS-10 | ↓ perceived fatigue (regeneration > prevention) |
| Han et al. (2017)     | RCT          | 30 students patients will trigger point | Vibrating FR Non-vibrating FR | Mam lower limb muscles | 1 × 20 min | NR | No | Vibrating FR (62 Hz) Non-vibrating FR 3 times/week over 4-weeks | Iliotibial-band, gluteus, rectus femoris, hamstrings PPT | ↑ muscle tenderness in ITB Trend ↑ for others muscles |
| Cheatham and Stull (2018a) | RCT          | 21 healthy subjects | High density FR | Quadriceps | 1 × 120 s 1 inch per second | Moderate | No | Foam rolling leg Control leg + knee mobilizations | Quadriceps and hamstrings PPT | ↑ muscle tenderness (crossover effect on contralateral quadriceps) |
| Cheatham and Stull (2018a) | RCT          | 36 healthy and recreationally active | Soft FR Medium FR Hard FR | Quadriceps | 1 × 120 s 1 inch per second | NR | No | Soft density FR Medium density FR Hard density FR + knee mobilizations | Quadriceps PPT | Three groups ↑ muscle tenderness |
| Cheatham and Stull (2018b) | RCT          | 30 healthy and recreationally active | High density FR | Quadriceps | 1 × 120 s 1 inch per second | NR | No | Foam rolling only Foam rolling + knee mobilizations | Quadriceps PPT | ↑ muscle tenderness (foam rolling with knee mobilizations > foam rolling only) |
| Cheatham et al. (2019) | RCT          | 45 healthy and recreationally active | Vibrating FR Non-vibrating FR | Quadriceps | 1 × 120 s 1 inch per second | NR | Yes | Vibrating FR(33 Hz) Non-vibrating FR Static stretching | Quadriceps PPT | ↑ muscle tenderness (vibrating > non-vibrating FR) |

RC, randomized crossover; RCT, randomized controlled trial; FR: foam roller; NR, not reported; bpm, beats per minute; ↑ indicates increase; ↓ indicates decrease; VAS, visual analogue scale; PPT, pain pressure threshold; NS, not statistically significant.
| Author (year)          | Study design | Sample                                                                 | Foam rolling intervention          | Nature of exercise | Control Others experimental groups | Outcome measures                                                                 | Effects |
|------------------------|--------------|------------------------------------------------------------------------|-----------------------------------|--------------------|-----------------------------------|---------------------------------------------------------------------------------|---------|
| Casanova et al. (2017)| RC           | 10 athletes                                                            | Roller massager, Plantar flexors  | 6 x 45 s 30 bpm   | NR                                | 1 test session 5 x 201-leg calf raise at BW                                     | ↑ muscle tenderness ↑ ankle ROM NS change muscle oxygenation (HHb concentration) NS change muscle morphology NS change muscle performance |
| Jay et al. (2014)      | RCT          | 22 healthy untrained                                                   | Roller massager, Hamstring         | 1 x 10 min 15-30 bpm | Moderate NR                       | 10 x 10 stiff-legged deadlift up to 32 kg                                       | ↑ muscle tenderness up to 60 min ↓ muscle soreness up to 60 min ↑ ROM at 10 min Controlateral effect ↓ muscle soreness Trend ↑ muscle tenderness Trend ↑ ROM |
| MacDonald et al. (2014)| RCT          | 20 healthy and recreationally active                                    | High density FR, Main lower limb muscles  | 2 x 60 s/muscle | NR                                | 10 x 10 squat at 60% of 1-RM                                                    | ↓ muscle soreness ↑ performances ↑ muscle activity |
| Pearcey et al. (2015)  | RC           | 8 healthy and physically active                                         | High density FR, Main lower limb muscles | 2 x 45 s/muscle 50 bpm | Much pressure as they could       | 10 x 10 squat at 60% of 1-RM                                                    | ↑ muscle tenderness ↑ physical performance decrements |
| Correia (2016)         | RC           | 10 healthy and recreationally active                                    | Roller massager, Plantar flexors   | 6 x 45 s 30 bpm   | Much pressure as they could       | 1 test session 5 x 201-leg calf raise at BW                                      | ↑ muscle tenderness at T+24 h, 48 h, 72 h NS change ROM NS change muscular performance NS change morphology NS change muscle oxygenation |

(Continued)
### TABLE 5 | Continued

| Author (year) | Study design | Sample | Foam rolling intervention | Nature of exercise | Control Others experimental groups | Outcome measures | Effects |
|---------------|--------------|--------|---------------------------|--------------------|-----------------------------------|-----------------|---------|
| Romero-Moraleda et al. (2017) | RCT | 32 healthy and moderately active | High density FR | Quadriceps | 5 × 60 s | Much pressure as they could | 5 × 20 0.5 m drop jumps | No | Neurodynamic mobilization Foam rolling | Both groups: ↓ muscle pain Foam roller group ↑ muscle strength |
| Drinkwater et al. (2019) | RC | 11 healthy young males | High density FR | Main lower limb muscles | 1 × 180 s/muscle 60 bpm | Much pressure as they could | 6 × 25 eccentric knee extensors at 120°/s | Yes | Foam rolling post-T0 and before each testing point at T+24, 48, 72 h | ↑ muscle tenderness at T+48h NS change circumference NS change knee ROM ↑ vertical jump at 72 h NS change strength |
| Naderi et al. (2019) | RCT | 80 healthy physically active male | High density FR | Quadriceps | 4 × 120 s 30 bpm | Much pressure as they could | 4 × 25 eccentric knee extensors at 60°/s | Yes | Foam rolling post-T0, T+1, 24, 48, 72 h | ↓ muscle pain ↑ muscle tenderness ↑ proprioception ↓ force decrements up to 48h |
| Romero-Moraleda et al. (2019) | RCT | 38 healthy and moderately active | Vibrating FR Non-vibrating FR | Quadriceps | 5 × 60 s | Much pressure as they could | 10 × 10 inertial flywheel eccentric squat | No | Foam rolling with vibrating roller (18Hz) Foam rolling with classic roller | Vibrating > non-vibrating FR ↑ muscle tenderness ↓ pain perception ↑ passive hip extension Both FR ↑ muscle oxygenation (SmO2) ↑ vertical power ↑ active hip and knee ROM |

RC, randomized crossover; RCT, randomized controlled trial; FR, foam roller, BW, body weight; VAS, visual analogue scale; PPT, pressure pain threshold; NR, not reported; bpm, beats per minute; NS, not significant; ↑ indicates increase; ↓ indicates decrease.
**TABLE 6** | The effects of foam rolling on range of motion.

| Author (year)       | Study design | Sample                                                                 | Foam rolling intervention | Control | Outcome measures | Effects |
|---------------------|--------------|----------------------------------------------------------------------|--------------------------|---------|------------------|---------|
|                     |              |                                                                      |                           |         |                  |         |
| Peacock et al. (2015)   | RC           | 16 athletically trained                                              | High density FR          | NR      |                  | Mediolateral plan |
|                      |              |                                                                      | Main muscle of the body   | NR      |                  | Anteroposterior plan |
|                      |              |                                                                      | 1 x 30 s/muscle           | NR      |                  | SBRT    | Mediolateral FR plan |
|                      |              |                                                                      | 10 bpm                    | NR      |                  | ↑ lower back and hamstring flexibility |
| Škarabot et al. (2015) | RC           | 11 adolescents trained swimmers                                     | High density FR          | NR      |                  | WBLT    |
|                      |              |                                                                      | Plantar flexors           | NR      |                  |         |
|                      |              |                                                                      | 3 x 30 s                  | NR      |                  |         |
|                      |              |                                                                      | 7/10 VAS                  | NR      |                  |         |
|                      |              |                                                                      | 6-months                  | NR      |                  |         |
| Fairall et al. (2017)  | RCT          | 12 adult amateur softball players with shoulder ROM                  | Lacrosse ball             | No      |                  | FR + SS and SS > FR |
|                      |              |                                                                      | 60 s                      | No      |                  | ↑ shoulder ROM at |
|                      |              |                                                                      | NR                       | No      |                  | 5-weeks |
| Le Gal et al. (2017)   | RCT          | 11 adolescent advanced tennis players                               | Tennis ball               | NR      |                  |         |
|                      |              |                                                                      | Infraspinatus             | NR      |                  |         |
|                      |              |                                                                      | 3 x 60 s/muscle           | NR      |                  |         |
|                      |              |                                                                      | 60 s/muscle as they could | NR      |                  |         |
|                      |              |                                                                      | 3 times/week over 5-weeks | NR      |                  |         |
| Sagirolu (2017)        | RC           | 22 well-trained soccer players                                       | Vibrating FR              | No      |                  |         |
|                      |              |                                                                      | Main lower limb muscles   | No      |                  |         |
|                      |              |                                                                      | 2 x 30 s/muscle           | No      |                  |         |
|                      |              |                                                                      | 10 bpm                    | No      |                  |         |
| Guillot et al. (2019)  | RCT          | 30 professional rugby players                                        | High density FR          | No      |                  |         |
|                      |              |                                                                      | Main lower limb muscles   | No      |                  |         |
|                      |              |                                                                      | 1 x 20–40 s/muscle        | No      |                  |         |
|                      |              |                                                                      | 20 s/muscle               | No      |                  |         |
|                      |              |                                                                      | 21 bpm                    | No      |                  |         |
|                      |              |                                                                      | Much pressure as they could | No      |                  |         |
|                      |              |                                                                      | 1 test session            | No      |                  |         |
| Oranchuk et al. (2019) | RC           | 22 female NCAA Division II lacrosse and soccer athletes              | High density foam roller  | No      |                  |         |
|                      |              |                                                                      | Hamstrings                | No      |                  |         |
|                      |              |                                                                      | 3 x 60 s                  | No      |                  |         |
|                      |              |                                                                      | 30 bpm                    | No      |                  |         |
|                      |              |                                                                      | Much pressure as they could | No      |                  |         |
|                      |              |                                                                      | 1 test session            | No      |                  |         |
|                      |              |                                                                      | Yes                      | No      |                  |         |

(Continued)
| Author          | Study (year) | Sample                                                                 | Foam rolling intervention | Control | Others experimental groups | Outcome measures                                      | Effects |
|-----------------|--------------|-------------------------------------------------------------------------|---------------------------|---------|---------------------------|--------------------------------------------------------|---------|
| Sullivan et al. | RCT 2013     | 17 healthy and recreationally active                                     | Roller-massager           | Hamstrings | 1–2 x 5–10 s 120 bpm      | 13 kg                                                   | No      |
|                 |              |                                                                         |                           |          | Expertise                 | Foam rolling                                          |         |
|                 |              |                                                                         |                           |          |                           | 1 set of 5 s                                          | Yes     |
|                 |              |                                                                         |                           |          |                           | 2 sets of 5 s                                          |         |
|                 |              |                                                                         |                           |          |                           | 1 set of 10 s                                          |         |
|                 |              |                                                                         |                           |          |                           | 2 sets of 10 s                                          |         |
|                 |              |                                                                         |                           |          |                           | SRBT                                                   |         |
|                 |              |                                                                         |                           |          |                           | ↑ lower back and hamstring flexibility                 |         |
|                 |              |                                                                         |                           |          |                           | FR 10 s > FR 5 s                                      |         |
| Halperin et al. | RC 2014      | 14 healthy and recreationally active                                     | Roller-massager           | Plantarflexors | 3 x 30 s 30 bpm           | 7/10 VAS                                               | No      |
| Mohr et al.     | RCT 2014     | 40 subjects with less than 90° of passive hip-flexion                    | Bio-foam roller           | Hamstrings | 3 x 60 s 30 bpm           | Much pressure as they could                           | 1 test session |
|                 |              |                                                                         |                           |          | Expertise                 | Foam rolling                                          |         |
|                 |              |                                                                         |                           |          |                           | Static Stretching                                     |         |
|                 |              |                                                                         |                           |          |                           | Combined techniques                                   |         |
|                 |              |                                                                         |                           |          |                           | 3 times/week over                                     |         |
|                 |              |                                                                         |                           |          |                           | 2-weeks                                                |         |
| Grieve et al.   | RCT 2015     | 24 healthy subjects                                                     | Tennis ball                | Sole     | 1 x 120 s/sole            | Much pressure as they could                           | NR      |
| Vigotsky et al. | RCT 2015     | 23 healthy students                                                     | High density FR            | Quadiceps | 2 x 60 s/Slowly          | NR                                                    | NR      |
|                 |              |                                                                         |                           |          | Expertise                 | Foam roller                                            |         |
|                 |              |                                                                         |                           |          |                           | Static stretching                                      |         |
|                 |              |                                                                         |                           |          |                           | Modified Thomas test                                  |         |
| Kelly and       | RCT 2016     | 26 healthy and recreationally active                                     | High density FR            | Plantar flexors | 3 x 30 s 15 bpm          | Much pressure as they could                           | 1 test session |
| Beardsley       |              |                                                                         |                           |          | Expertise                 | Foam rolling leg                                       |         |
|                 |              |                                                                         |                           |          |                           | Control leg                                            |         |
|                 |              |                                                                         |                           |          |                           | WBLT pre- and post-                                    |         |
|                 |              |                                                                         |                           |          |                           | T0, T+5, 10, 15, 20 min                                |         |
| Patel et al.    | RCT 2016     | 30 subjects with active knee extension deficit                          | Tennis ball                | Sole     | 1 x 120 s/foot            | Much pressure as they could                           | NR      |
| Boguszewski et  | RCT 2017     | 37 healthy and recreationally active                                     | Foam roller – not reported | Main lower limb muscles | 1 x 20 min/muscle       | NR                                                    | Yes     |
|                 |              |                                                                         |                           |          | Expertise                 | Foam rolling                                           |         |
|                 |              |                                                                         |                           |          |                           | 2 times/week over                                     |         |
|                 |              |                                                                         |                           |          |                           | 8-weeks                                                |         |
|                 |              |                                                                         |                           |          |                           | Single leg                                             |         |
|                 |              |                                                                         |                           |          |                           | SRBT                                                   |         |
|                 |              |                                                                         |                           |          |                           | Active knee extension                                  |         |
|                 |              |                                                                         |                           |          |                           | ↑ lower back and hamstring flexibility                 |         |
|                 |              |                                                                         |                           |          |                           | ↑ hamstrings flexibility                              |         |

(Continued)
| Author (year)          | Study design | Sample | Foam rolling intervention | Control | Others experimental groups | Outcome measures | Effects |
|------------------------|--------------|--------|---------------------------|---------|----------------------------|------------------|---------|
| Garcia-Gutiérrez et al. (2017) | RCT          | 33 healthy and moderately active | Vibrating FR | Plantar flexors – dominant leg | 5 × 20 s | 15 bpm | Much pressure as they could | 1 test session | Vibrating foam roller (32 Hz) Non-vibrating foam roller | WBLT | Maximal voluntary contraction plantar flexion/dorsiflexion Both legs | Both groups ↑ ankle ROM with a crossover effect NS difference between groups NS change strength |
| Grabow et al. (2017)   | RCT          | 12 healthy and recreationally active | Foot roller | Sole | 3 × 60 s | 30 bpm | 7/10 VAS | NR | No | Foam rolling leg Control leg | Modified SRBT WBLT | NS change dorsiflexion ROM NS change lower and hamstrings flexibility on ipsilateral and contralateral leg |
| Hsuan Su et al. (2017) | RC           | 30 college students physically active | High density FR | Quadriceps and hamstrings | 3 × 30 s/muscle | Much pressure as they could | 1 test session | Yes | Static stretching Foam rolling Dynamic stretching | SRBT | Modified Thomas test | ↑ quadriceps and hamstring flexibility |
| Jung et al. (2017)     | RC           | 22 healthy subjects | Wooden stick | Suboccipital region, hamstrings and sole | 1 × 4 min/muscle | NR | No | No | Foam rolling suboccipital Foam rolling hamstrings Foam rolling sole | SRBT | | Three groups ↑ lower and hamstrings flexibility |
| Do et al. (2018)       | RCT          | 31 healthy and recreationally active | Micro foam roller | Plantar fascia | 1 × 5 min | Much pressure as possible | NR | Yes | Foam rolling Sham group | Toe touch test Passive SLR | ↑ lower back and hamstring flexibility |
| Killen et al. (2018)   | RCT          | 23 healthy subjects | High density FR | Hamstrings | 10 × 30 s | 30 bpm | NR | 1 test session | No | Static Stretching Foam rolling on dominant leg | SLR | Both groups ↑ contralateral hip ROM |
| Madoni et al. (2018)   | RWS          | 22 healthy and recreationally active | High density FR | Hamstrings | 3 × 30 s | Much pressure as they could | 1 test session | Yes | Foam rolling | SLR | ↑ hamstring flexibility |
| Phillips et al. (2018) | RC           | 24 healthy and recreationally active | Foam roller – not reported | Quadriceps, plantar flexors | 1 × 60 s/muscle | 10 bpm | Much pressure as they could | 1 test session | Yes | Foam rolling : 60 s Foam rolling : 5 min Planking on a heating pad | Modified WBLT | ↑ dorsiflexion ROM ↑ quadriceps flexibility 5 min > 60 s foam rolling |
| Jeong et al. (2019)    | RC           | 30 young women | Massage ball | Hamstrings | 3 × 30 s/zone | NR | NR | No | Foam rolling Self-stretching | 90–90 SLR pre- and post-T+5, 30 min | Both groups ↑ ROM |

(Continued)
### TABLE 6 | Continued

| Author(s) (year) | Study design | Sample | Foam rolling intervention | Control | Others experimental groups | Outcome measures | Effects |
|------------------|--------------|--------|---------------------------|---------|-----------------------------|-----------------|---------|
| Lim and Park (2019) | RCT | 20 healthy college students | Vibrating FR | NR | No | Active SLR | Vibrating > non vibrating FR |
| Pathania and Muragod (2019) | RCT | 45 elderly subjects with hamstring flexibility deficit (65–75 years of age) | High density FRM2T blade | NR | No | Passive knee extension SBT | ↓ lower back and hamstring flexibility |
| Smith et al. (2019) | RCT | 44 healthy and recreationally active | High density FR | NR | No | Ankle dorsiflexion ROM | Three groups |
| Somers et al. (2019) | RCT | 42 physical therapy students | Foam roller – not reported | NR | No | WBLT | NS change in ankle ROM |
| Williams and Selkow (2019) | RC | 15 healthy collegiate students | High density FR Lacrosse ball | NR | No | SRBT | Three techniques |

RC, randomized crossover; RCT, randomized controlled trial; FR, foam roller; NR, not reported; bpm, beats per minute; † indicates increase; ‡ indicates decrease; SRBT, sit-and-reach box test; WBLT, weightbearing lunge test; SLR, straight leg raise; NS, not significant.
### TABLE 7 | The effects of foam rolling on neurophysiological and physiological variables.

| Author (year) | Study design | Sample | Foam rolling intervention | Control | Others experimental groups | Outcome measures | Effects |
|---------------|--------------|--------|---------------------------|---------|---------------------------|-----------------|---------|
| **Neurophysiological and physiological effects** |
| Martínez-Cabrera and Núñez-Sánchez (2016) | RCT | 7 professional soccer players | High density FR | Rectus femoris | 4 × 15 s / 30 bpm | NR | No | Foam rolling leg / Control leg | Muscle contractile properties (TMG) | Maintains muscle contractile properties |
| Murray et al. (2016) | RC | 12 squash players | High density FR | Quadriceps | 1 × 60 s / 30 bpm | NR | Yes | Foam rolling leg / Control leg | Muscle contractile properties (TMG) / Superficial temperature | NS change muscle contractile properties / NS change skin temperature |
| Casanova et al. (2017) | RC | 10 athletes | Roller massager | Plantar flexors | 6 × 45 s / 30 bpm | NR | Yes | Foam rolling leg / Control leg | Muscle oxygenation (HHb concentration) / Muscle morphology | NS change muscle oxygenation / NS change muscle morphology |
| D’Amico and Pacione (2017) | RC | 16 trained males | High density FR | Main lower limb muscles per leg | 1 × 30 s/muscle / 6 bpm | NR | Yes | Foam rolling | Blood sample / VCO2 pre- and post-each run | NS change blood lactate concentration / NS change VCO2 |
| Kalén et al. (2017) | RC | 12 surf lifeguards | High density FR | Main lower limb muscles per leg | 2 × 60 s | 7/10 | Yes | Foam rolling / Running | Blood sample | Both groups | ↓ blood lactate clearance |
| Beier et al. (2019) | RC | 11 resistance trained subjects | Stick massage | Rectus femoris and gluteus maximus | 1 × 120 s/muscle | Heavy pressure | No | Foam rolling / Dynamic warm-up | Muscle activation (EMGs) | NS change muscle activation |
| Mazzei (2019) | RCT | 15 NCAA Division I swimmers | Vibrating FR / Non-vibrating FR | Plantar flexors | 3 × 30 s / 30 bpm | NR | No | Vibrating foam rolling (1200 to 3600 rpm) / Non-vibrating foam rolling | Muscle activation (EMGs) | Both groups | NS change muscle activation |
| Kim et al. (2014) | RCT | 22 healthy subjects | FR–not reported | Main lower limb muscles and back | 1 × 3–6 min | NR | Yes | Foam rolling | Blood sample | Both groups | ↓ cortisol |

(Continued)
| Author (year)                  | Study design | Sample                          | Foam rolling intervention | Control | Others experimental groups | Outcome measures | Effects |
|-------------------------------|--------------|---------------------------------|---------------------------|---------|---------------------------|-----------------|---------|
| Okamoto et al. (2014)         | RC           | 10 healthy subjects             | Polystyrene roller        |         | NR                        | Foam rolling    | Arterial stiffness |
|                               |              |                                 | Main lower limb muscles   | 20      | NR                        | Blood sample    | ↓ brachial-ankle pulse wave velocity |
|                               |              |                                 | 20 repetition/muscle       | NR      | Yes                       |                 | ↑ vasoactive substance |
|                               |              |                                 |                           |         |                           |                 | ↑ nitric oxide concentration |
| Thistlethwaite et al. (2016)  | Pilot test   | 6 subjects                      | PVC pipe                  |         | NR                        | Foam rolling    | Endothelial function |
|                               |              |                                 | iliotibial band, adductors, hamstrings, quadriceps | | No | Foam rolling leg | Blood flow |
|                               |              |                                 | 1 × 180 s/muscle           | NR      |                           |                 | ↑ diameter of the femoral artery |
| Ginszt et al. (2017)          | Pilot test   | 20 healthy adults               | High density FR           |         | Much pressure as they could | Foam rolling leg | Muscle activation |
|                               |              |                                 | Right quadriceps          | 1 × 60 s| No | Control leg | (EMGs) |
| Hotfiel et al. (2017)         | RCT          | 21 healthy students             | High density FR           |         | Much pressure as they could | Foam rolling    | Arterial tissue perfusion post- T0, T+30 min |
|                               |              |                                 | iliotibial band            | 3 × 45 s| No | Foam rolling | ↑ arterial blood flow up to 30 min |
| Romero-Moraleda et al. (2017) | RCT          | 33 healthy and moderately active| High density FR            |         | More of their body weight | Foam rolling    | Muscle activation |
|                               |              |                                 | Quadriceps                | 5 × 60 s| No | Neurodynamic mobilization | (EMGs) |
| Schroeder et al. (2017)       | RC           | 12 healthy and recreationally active | High density FR           |         | Weight training            | Muscle contractile properties |
|                               |              |                                 | Hamstrings, gluteus, lower back | 3 × 60 s| No | Stretching | (TMG) |
| Hodgson et al. (2018)         | RCT          | 23 healthy and recreationally active | Roller massager           |         | High frequencies            | Muscle activation |
|                               |              |                                 | Quadriceps and hamstrings | 4 × 30 s/muscle | Yes | (6 times/week) | (EMGs) |
|                               |              |                                 | 60 bpm                     | 7/10    |                           | Knee flexors, extendors MVIC |
|                               |              |                                 | 15 bpm                     |         |                           | NS change muscle activation |
| Lastova et al. (2018)         | RCT          | 15 healthy and recreationally active | High density FR           |         | NR                        | Foam rolling    | Blood pressure |
|                               |              |                                 | Main lower limb muscles and lower/upper back | | Yes | Foam rolling | Heart rate variability |
|                               |              |                                 | 1 × 40 s                   |                  |                              |                 | pre and post- T0, T+10, T+30 min |

(Continued)
### TABLE 7 | Continued

| Author (year) | Study design | Sample | Foam rolling intervention | Control | Others experimental groups | Outcome measures | Effects |
|---------------|--------------|--------|---------------------------|---------|-----------------------------|------------------|---------|
|               |              |        |                           |         |                             |                  |         |
| Macgregor et al. (2018) | RC | 16 healthy recreationally active males | High density FR | Quadriceps | 1 × 120 s 60 bpm | 6/10 | Yes | Foam rolling over 3 consecutive days | Muscle activation (EMGs) | Muscle contractile properties (TMG) | ↓ muscle activity |
| Madoni et al. (2018) | RCT | 22 healthy and recreationally active | High density FR | Hamstrings | 3 × 30 s | Much pressure as they could | Yes | Foam rolling | Muscle activation (EMGs) | Maximal knee extension/extension | NS change muscle activation |
| Capobianco et al. (2019) | RC | 30 young and middle-aged adults | Therapy ball | Calf | 3 × 60 s/leg 15 bpm | >5/10 discomfort level | No | Static stretching Foam rolling + static stretching | Muscle activation (EMGs) | Subcutaneous tissue thickness | ↑ muscle activation |
| Kim et al. (2019) | RC | 30 participants with neck pain (age: 65.9 ± 3.4 years) | Soft inflatable rubber ball Hard massage ball | Suboccipital region | 1 × 10 secs | NR | Yes | Soft inflatable rubber ball Hard massage ball | Muscle activation (EMGs) | Radiography (compressed soft tissue thickness and neck extension ROM) | Soft inflatable rubber ball vs hard massage ball Less muscle activity Less compressed soft tissue thickness |
| Ye et al. (2019) | RC | 34 healthy and physically active | High density FR | Hamstrings | 10 × 30 s 30 bpm | NR | Yes | Yes | Muscle activation (EMGs) | Knee flexors MVIC | NS change muscle activity and strength |

RC, randomized crossover; RCT, randomized controlled trial; FR, foam roller; NR, not reported; bpm, beats per minute; † indicates increase; ‡ indicates decrease; MVIC, maximal voluntary isometric contraction; EMGs, surface electromyography; TMG, tensiomyography; NS, not significant.
Romero-Moraleda et al., 2017; Table 5). Regardless the tools’ use, a foam roller, a massage stick, golf or tennis balls, the FR intervention yielded increased flexibility and ROM gains (Cheatham et al., 2015; Grieve et al., 2015; Brengesjö and Lohaller, 2017; Monteiro et al., 2017, 2019). Foam roller and roller massager, for instance, were shown to elicit comparable increased ROM (Monteiro et al., 2017, 2019). This effect would be reinforced by few additional degrees with vibrating foam rollers. Frequencies between 33 and 62 Hz would guarantee higher ROM and PPT elevations, compared to a non-vibrating foam roller (Cheatham et al., 2017, 2019; Han et al., 2017; Table 4). In addition, ROM benefits would depend on a dose-response effect of FR (120 vs. 60 s) (Monteiro et al., 2017, 2019). More surprisingly, FR would also demonstrate the ability to have a delocalized effect. For example, FR of sole or hamstring muscles might positively influence lower back and hamstring flexibility by improving the sit-and-reach test scores, with a wooden stick or a tennis ball (Grieve et al., 2015; Jung et al., 2017; Table 6).

The most supported hypothesis to explain these changes would be a modification of the autonomic nervous system responses (Joshi et al., 2018; Dębski et al., 2019; Wiewelhove et al., 2019). The slow deep pressure would induce a decrease in the tone of related skeletal motor units by stimulating mechanoreceptors. This chain reaction would elicit a parasympathetic-dominant neurophysiological state, thus eliciting a greater relaxation (Schleip, 2003b). Mechanical pressure applied during FR would elicit similar effect. For example, in participants with rounded shoulder, both trapezius and pectoralis major muscles activity decreased after a FR intervention. This progress was accompanied by a reduction in shoulder height (Choi, 2019). These findings represent a useful source of information to guide FR practitioners. Indeed, local FR treatment therefore does not seem to be limited to a single element, but may impact all surrounding structures, even the whole body. This particularity represents a particular interest for physiotherapists to correct certain postural imbalances and/or muscular flexibility deficit.

Commonly used to improve ROM, FR has also been tested during warm-up to improve the physical qualities of athletes such as muscle power, strength or agility. However, unlike ROM, performance results obtained were not always clearly established (Burk et al., 2019; Hughes and Ramer, 2019; Skinner et al., 2020). Some studies recorded improvements in muscle power, strength or agility, after a single session of FR (D’Andrea, 2016; Sagirolgu, 2017; Stroiney et al., 2020). Other came to different conclusions. For example, FR was not shown to bring any significant improvement in performance (Burk et al., 2019). Few protocols have been tested and replicated enough to lead to real consensus. Indeed, between the protocols, many parameters differed such as outcome measures, FR tool, target muscles, type of population, participants’ FR experience, and FR instructions (e.g., pressure level, duration and rate of treatment) (Burk et al., 2019; Dębski et al., 2019). It is likely that this experimental disparity justifies the heterogeneity of the results reported in the literature. Until a reliable consensus is reached, the use of FR for warm-up should certainly not be contraindicated. In fact, unlike static stretching, there was no loss of physical capacity (Halperin et al., 2014; Bradley et al., 2016; Grabow et al., 2017; Su et al., 2017).

For the same reasons of reproducibility and the lack of sufficient data, effects of post-training FR on physiological markers remain inconclusive. In laboratory conditions, excluding physical exertion, first results revealed a decrease in brachial-ankle pulse wave velocity (from 1202 ± 105 to 1074 ± 110 cm/s) and an increase in plasma nitric oxide concentrations (from 20.4 ± 6.9 to 34.4 ± 17.2 µmol/L), reflecting an improvement in endothelial functions and arterial stiffness (Okamoto et al., 2014). Another study also observed an increase in the arterial blood flow. Compared to a baseline recording, the mean peak flow increased of 73.6% immediately after FR and 52.7% 30 min post-treatment (Hotfiel et al., 2017). The drop in blood pressure was also observed up to 30 min after FR, confirming the hypothesis of a positive effect of FR on cardiovascular protective effect and health (Lastova et al., 2018; Table 7). In training conditions, FR has been shown to be ineffective on the muscular re-oxygenation in the treated leg after a bilateral exercise inducing muscular damage (Casanova et al., 2017). Some indirect markers such as cortisol and lactate confirmed, by their fall, this positive influence of FR on blood circulation (Kim et al., 2014; Kalén et al., 2017). In conclusion, comparison of results between studies is delicate due to the singular nature of each experiment, increasing the difficulty of interpreting certain acute effects which are still undecided. Indeed, few protocols have been reproduced and sufficiently tested to establish a consensus and therefore an optimal FR program. In response to this uncertainty, two recent systematic reviews of literature proposed a framework to guide practitioners and researchers for future experiments (Dębski et al., 2019; Hendricks et al., 2019). According to these authors, acute effects identifiable by gains in ROM, increase in the PPT, reduction in DOMS, or even better vascular function, would be made possible by respecting certain rules of practice. It would therefore be wise for FR tool users to repeat each exercise 1–3 times at a rate of 20 bpm. A set of rolling should last between 30 and 120 s and followed by a 30 s recovery period. Pressure, on the other hand, has an individual character and a part of subjectivity. However, the application force should not exceed the pain tolerance threshold. On a pain scale, a 7/10 indicator or the following instruction, “as large as possible” is commonly used to guide practitioners for pressure (Dębski et al., 2019; Hendricks et al., 2019). FR tools, such as foam roller, roller massager or ball, should therefore be firm enough (Cheatham et al., 2015), and ischemic pressure is advised on sensitive areas until a feeling of release is obtained (Dębski et al., 2019; Hendricks et al., 2019). To complete this information, we argue that two additional parameters should be taken. To begin with, user experience in the practice of FR is required as FR requires some experience to master the level of pressure on the tool. Poor management can elicit excessive discomfort or pain, and bias the effects of FR technique. The second determining criterion is the number of areas treated. It seems that the effects of FR are short-lived, 10–20 min depending on the studies (MacDonald et al., 2013; Halperin et al., 2014; Jay et al., 2014; Škarabot et al., 2015; Kelly and Beardsley, 2016). It is therefore essential to ensure the effective duration of the routine so as not
to exceed this period and risk seeing the effects dissipate in the first target areas.

**Long-Term Interventions**

The effects of FR were investigated within a span of several days or weeks. The paradigms either involved the follow-up of the effects of FR after a single session, or administered regular FR sessions along the intervention period. Protocols usually involved 2–5 sessions per week delivered within a span of 3–8 weeks. The use of a ball or foam roller demonstrated its usefulness for improving shoulder, knee, or ankle ROM (Le Gal et al., 2018; Smith et al., 2019), without harmful consequences on physical performance (Hodgson et al., 2019). Regular combination of FR and static stretching may have an additional effect for increasing ROM (Mohr et al., 2014; Škarabot et al., 2015). The effects of FR may be due to neural changes, the pressure exerting on the soft tissues increasing the tolerance to stretching, and therefore promoting performance gains (Škarabot et al., 2015).

With regard to vascular function, delayed beneficial effects were observed for a frequency of three FR sessions per week during a 6-week period (Thistlethwaite et al., 2016). A drop in blood pressure, heart rate variability, and sympathovagal balance, has also been reported (Chan et al., 2015; Lastova et al., 2018). Although this is premature to draw any firm conclusion, FR therefore appears effective to stimulate the organism and maintain better health.

**Procedures**

FR techniques involve two main maneuvers which can be combined in a single routine. The pressure depends on the tool used, its density, and the target area (Miller and Rockey, 2006; Sullivan et al., 2013; Cheatham et al., 2015). Few studies recorded the pressure applied during FR with a specific designed constant pressure roller apparatus. Two experiments measured muscle strength and flexibility after a continuous pressure of 13 kg on the hamstrings (Sullivan et al., 2013), as well as 20 kg on the quadriceps, with roller massager (Bradbury-Squires et al., 2014). However, with a foam roller, these values usually range from 27 to 68% of the body weight, depending on the muscle and the position (e.g., bilateral, unilateral) of the participants (MacDonald et al., 2013; Murray et al., 2016; Macgregor et al., 2018; Baumgart et al., 2019). Research remains sparse on pressure level, and no specific value is recommended. However, the literature demonstrated the existence of a dose-dependent response to FR. Some authors reported a significant improvement between two treatments of different durations (Bradbury-Squires et al., 2014; Monteiro et al., 2017a; Phillips et al., 2018), whereas others did not corroborate an effect of the routine duration (Sullivan et al., 2013; Guillot et al., 2019; Table 6). Despite divergent results on its optimal use, FR practice systematically resulted in improved ROM and PPT (Jay et al., 2014; Cavanaugh, 2016; Kelly and Beardsley, 2016; Casanova et al., 2017; Cheatham and Baker, 2017; García-Gutiérrez et al., 2018; Killen et al., 2018), trending approach consisting in the combination of active joint mobilization (e.g., knee flexion-extension movement) with FR practice (Cheatham and Baker, 2017; Cheatham et al., 2017, 2019; Cheatham and Kolber, 2018; Cheatham and Stull, 2018a,b; Table 4). Such combination provided promising early effects on ROM gains (Cheatham et al., 2017; Han et al., 2017).

For safe and effective FR interventions, literature-driven guidelines should now be outlined and conceptualized. Quantifying the biomechanical workload applied through the FR routine is of critical importance. While higher mechanical compressions on the underlying tissues might be exerted using FR, compared to MMs, a potentially harmful impact on connective tissues, nerves, vessels and bones, should not be excluded. Deleterious effects must be controlled in future designs (Fleckenstein et al., 2017). External biomechanical loads should also be quantified to determine to which extent FR differs from MM in terms of pressures. Regular practice might be more suitable than longer session durations. Prolonged FR beyond 90 s of treatment in the same area might not bring any additional benefit (Monteiro et al., 2017a), and excess may even cause harmful effects. Eventually, practitioners should certainly adjust FR practice to their own sensations. For instance, PPT should never be exceeded to prevent injuries.

**MANUAL MASSAGE AND FOAM ROLLING AT THE SCOPE OF MOTOR CONTROL FRAMEWORKS**

**From Resemblance to Dissimilarity**

MM and FR are both likely to positively affect psychometric, behavioral and physiological variables. As mentioned in the previous sections, experimental data extensively confirmed their respective beneficial effects. The same organs and tissues are targeted by both techniques, which might account for the congruent pattern of beneficial results on well-being and motor performance. Furthermore, both techniques appeared to promote motor recovery, with similar body effects during warm-up and post-exercise recovery. They are associated with increased well-being and give the opportunity to temporarily improve ROM and PPT, without altering physical performance (i.e., power, strength, agility). In practice, however, MM and FR are highly distinct. During MM, athletes have no control over the massage parameters, whereas during FR, they produce voluntary movements to complete the routine, by regulating the level of pressure exerted and the speed of execution. While this may be considered an advantage inherent to the technique, the lack of standardization of FR protocols represents an obstacle to the development of clinical applications. Indeed, the few existing guidelines do not provide medical professionals the necessary levels of reproducibility and reliability for application of such routines in clinical populations (Cheatham et al., 2015; Schroeder and Best, 2015). Classically, a MM lasts between 15 and 30 min (Standley et al., 2010), compared to 30–120 s per muscle group for FR. This difference is explained by the more holistic approach of the body during MM. More muscle groups are manually massaged, and several techniques can be used in a single area, hence increasing the whole duration of treatment. Conversely, in most FR studies, one or two muscle groups are mainly involved for 30–120 s each (Dębski et al., 2019).
Motor Control Implications

There is currently no hypothesis or conceptual approach that distinguishes MM from FR, even though a fundamental distinction between the two types of massaging interventions stems from the nature of their requirements in terms of motor control strategies. The person receiving a MM remains passive, lying on the massage table, usually in dorsal or ventral decubitus. The routine and the pressures derive from the physiotherapists’ experience and available sensory feedback from the MM routine or provided by the patient. The gestures of the physiotherapist cannot be anticipated by the person, thus resulting in a retroactive mode of action control with an ongoing central integration of proprioceptive feedback (Hasegawa et al., 2001). Although the participant can adjust muscle tone at his convenience, he is primarily confronted with a retroactive mode of action control (Braver, 2012). Conversely, when performing FR, the person directly exerts pressures through voluntary actions to manipulate the massaging tool. FR thus requires a predominant proactive mode of action control, where proactive operations of forward and inverse modeling, which do not require sensory feedback from the periphery, are involved (Cervin et al., 2002).

Although with tools such as balls or foam roller, where the individual simply uses the body weight to achieve the desired effects, it remains a comparable proactive mode of action control. If necessary, the person always has the possibility to use retroactive operations to adjust FR parameters. Contrary to MM, the sensory consequence of voluntary motor commands during FR can therefore be anticipated by means of the efferent copy derived from the forward model that associates motor commands with their sensory consequences. According to the dual mechanisms of motor control framework (Braver, 2012), MM and FR can thus be distinguished by the implementation of two distinct motor control strategies. These two interventions, with opposite modes of action, do not seem to offer any compromise. The user is unable to migrate from one mode of action to another. Interestingly, this limit could be easily resolved with technological advances and the appearance of collaborative robots. By its unique functionalities, this new generation of robot might conceptually reconcile the opposition of MM and FR. Indeed, the autonomy and real-time interaction capabilities of these robots with the user offer new perspectives in terms of motor control that have yet to be explored.

ROBOTIC MASSAGE: AN EMERGING PARADIGM

The Instrumentalization of Massage

To the best of our knowledge, there is yet no massage technique allowing for an actual combination of the retroactive and proactive modes of action control. The advent of intelligent robotic massage might contribute to integrate these two types of motor control within single massaging routines, and therefore provide a unique and complete approach to the massage experience. Spurred by an economic purpose, and to overcome limits of human faculties, several assisting devices offering massage programs are already available in beauty salons and physiotherapists’ offices (e.g., LPG endermologie®, H2O Body system®, wellsystm®). Such devices offer a relevant alternative to the MM, due to the fatigue of the physiotherapist, and the loss of efficiency resulting from repetitive practice. Accordingly, many professionals suffer from pathologies such as musculoskeletal disorder due to the amount of exposure to repeated uncomfortable postures, maneuvers and manipulations (Albert et al., 2008; Murali et al., 2014; Rossettini et al., 2016).

Another strength of robotic devices delivering massages is the opportunity to homogenize massage techniques, such as the palate-rolling in the context of antecellulite (Xiaoqin and Yonggen, 2010; Mezencevová et al., 2017). In the case of a purely robotic massage routine, participants for now remain in a passive situation, and thus exclusively engage retroactive modes of action control. Despite obvious advantages, first robotic devices failed to provide interactivity options of users toward the system, still requiring the presence and action of a physiotherapist, and remain somewhat expensive.

The Limits of Standardization

Following pain and pathologies linked to the practice of MM for physiotherapist, a second wave of full automated systems has rapidly emerged. Although apparently similar, these tools were distinct by the substitution of the physiotherapist by a qualified operator specific to each machine. Unlike other devices, once turned on, some of these apparatus operate independently and therefore no longer required the intervention of a third person. Unfortunately, a standardized protocol was implemented without providing real adjustments to/by the user. Currently, several commercials devices, such as intermittent sequential pneumatic (Zelikovski et al., 1993), warm underwater water-jet massages (Vitasaalo et al., 1995), and whole body vibrations (Edge et al., 2009), are thus available (Poppendieck et al., 2016). Unlike MM, during which the physiotherapist may encounter difficulties in applying constant pressures, techniques and durations, these devices providing whole body vibrations allow a deep control of vibration frequency, duration, and amplitude (Edge et al., 2009).

In practice, these devices demonstrated limited effectiveness on physical performance (e.g., running performance, strength) and inconclusive results on recovery and physiological markers such as creatine kinase activity, pH, and lactate after intense effort (Zelikovski et al., 1993; Edge et al., 2009; Lau and Nosaka, 2011). We assume that individualization of the massage, incorporating morphology and expectations of the user, would certainly provide greater benefits. While some devices allow users to adjust few parameters of the massage, such modifications are not yet ergonomic (Golovin et al., 2018). Likewise, adjusting the program remains often impossible once the routine initiated. In all cases, the interaction between the user and the device therefore remains restricted to a retroactive motor control strategy for the user.

The Challenges of Robotics

Advances in robotics gradually spread within the field of medicine (Petrescu et al., 2016). Like the da Vinci surgical robot and the ROSA™ spine robot, it is clearly established that robots can assist surgeons with precision during minimally invasive
procedures such as arthroscopy or laparoscopic splenectomy (Chapman et al., 2002; Lopez et al., 2013; Lefranc and Peltier, 2016). The increasing amount of robotic intervention should be considered within a broader framework. Indeed, once purely human, several medical interventions now seem to involve increasing amounts of robotic solutions. Massage interventions, for instance, could be envisioned as part of a continuum extending from purely robotic to purely human interventions. Nonetheless, robotic solutions remain insufficient and suffer from several limitations, particularly in terms of the complexity and specificities of clinical interventions, it seems difficult to purely replace the massage delivered by a physiotherapist by a robot. There are multiple degree of adjustments to the patient's characteristics that remain difficult (not to say impossible) to implement in a robot. For these reasons, innovation in terms of robotic massages quickly spread to the field of wellness, less demanding and easier to reproduce. In this context, massage robots can be regarded as an important support, albeit emphasizing that the robot remains a tool, and not a possible avatar that could substitute actual human interventions.

Two similar projects, one Russian in 19981, and a second in Israel, developed back massage robots, but failed to move from the project stage to commercial production (Nissim, 2001). In Japan, the Waseda University and Asahi Roetgen company developed the Waseda Asahi Oral-Rehabilitation Robot 1 (WAO-1) (Takanishi et al., 2008, 2009). This robotic device, originally designed to promote recovery of temporomandibular disorders, was highly technical, very expensive, and targeted a specific population. Experiments provided useful information on the pressure exerted on masseter and temporal muscles, with values ranging from 100 g to 1.5 kg (Koga et al., 2008; Ariji et al., 2009a,b, 2010; Ishii et al., 2009; Obokawa et al., 2009; Solis et al., 2009; Hiraiwa et al., 2013; Table 8). The most effective pressure inducing a better easy-mouth opening was 800 g on small facial muscles. This robot also increased perceived comfort of users, muscle pain management, increased perceived heat, and promoted functional motor recovery (e.g., mouth opening, blood circulation, saliva production, muscle thickness (Koga et al., 2008; Ariji et al., 2009a,b, 2010, 2015, 2016; Ishii et al., 2009; Obokawa et al., 2009; Solis et al., 2009; Hiraiwa et al., 2013; Table 8). Other similar robotics projects provided promising results with a drop in lumbar strain, heart rate and muscle activity (Peng et al., 2010; Luo and Chang, 2011; Hu et al., 2013; Table 8). Finally, a robotic massage system achieved attractive performance on relaxation by a respective decrease and increase of beta and alpha powers (Luo et al., 2016; Table 8). However, due to the small sample sizes and the complex study design, more experimental investigation remained needed to validate these results. A critical strength of these automated devices is the autonomy and the lack of external intervention of a physiotherapist, but they do still not allow individualizing the massage per se. For instance, the intensity of the massage did not integrate the pain threshold tolerated by the user and the preprogrammed trajectories did not really adapt to the morphology of each person. The available robotic massages therefore positioned the user in a passive situation, once again favoring a retroactive control mode, similar to that elicited by the MM. Furthermore, by treating a single relatively restricted area, the robot ended up repeating the same trajectories. In view of these circumstances, the lack of human/robot interaction prevents from real anticipation of the massage maneuvers by the user, hence reducing a switch from a retroactive to a proactive control mode. For these reasons, and given the high cost of these solutions, such devices have not yet reached the market.

### The Perspectives of an Interactive and Autonomous Robotics

In this review, we shall consider a conceptual approach intended as a preamble to an original and timely research topic. Beyond a conceptual comparison, we question the possibility of an emerging solution to really match the two modes of control of the participant receiving the massage. Through incorporation of sensors into each axis, the last generation of devices, called collaborative robots, offer promising and innovative solutions which might definitively resolve the main issues mentioned previously. A Singaporean startup (AiTreat) developed since 2015 a device, called EMMA, specialized in the ‘Tui Na’ therapeutic massage. Although this massage robot uses some principles of artificial intelligence to customize massage trajectories, it is not entirely autonomous. The machine still requires the intervention of a health professional to identify the treatment areas and set the robot (Qiu et al., 2019). A Spanish company, Adamo Robot, then developed a physiotherapeutic robotic treatment solution since 2015. This device has the particularity of operating with compressed air, therefore without direct contact with the user (Jimenez, 2019). In the same massage robotic field, Massage Robotics, an American startup, developed a concept dedicated to massage centers, but the patent accompanying this project has been abandoned (Mackin, 2017). Indeed, based on a patent already existing in the field, their patent was refused after an analysis by a validation office, due to a lack of innovative character (Nissim, 2001). Finally, Capixis Robotics, a French startup, developed since 2016 a solution with a iYU® robot, intended for full autonomy and back muscle relaxation. The robotic device, equipped with a 3D sensor and coupled to its generic model, is expected to reproduce trajectories on any type of morphology (Eyssautier and Gibert, 2018). These different projects represent emerging solutions to make massages accessible to as many people as possible in the gym or workplace, for example. However, to our knowledge, no study has been carried out to demonstrate the effectiveness of massages provided by such collaborative robot. This issue may be critical in ageing population. Japan is the first concerned with the highest rates of aging (Anderson and Hussey, 2000; Koga et al., 2008), and the country anticipates an increased in needs for medical care (Koga et al., 2008). Robotic solutions are scalable and robotic devices allow non-therapeutic and therapeutic interventions with standardized routines, including automatic adaptation to the morphology of the person through preliminary configuration recordings. Interestingly, the most recent robotic solutions also allow for manual control to adjust the pressure applied by the device in real-time.

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1http://medicalrobot.narod.ru/articles.html
| Author          | Study design | Sample | Robotic massage intervention | Control | Others | Test – outcome measures | Effects |
|----------------|--------------|--------|-------------------------------|---------|--------|-------------------------|---------|
| Koga et al. (2008) | CCT          | Head model 11 healthy subjects | WAO-1 | Effleurage, petrissage (rotation and rubbing) | 1 × 1–5 min/parotid gland | 1–10 N | No | Robotic massage Manual massage | Level of force Saxon test Skin temperature Size of masseter muscle |
| Obokawa et al. (2009) | CCT          | 29 healthy subjects 26 subjects with TMJ disorders | WAO-1 | Effleurage, petrissage (rotation and rubbing) | 1 × 10 min | 1–10 N | No | Robotic massage | Comfort VAS-10 Perceived warmth VAS-10 Easy-mouth opening VAS-10 Perceived lameness VAS-10 |
| Ishii et al. (2009) | CCT          | 18 healthy subjects | WAO-1 | Effleurage, petrissage (rotation and rubbing) | 1 × 120 s/parotid gland 5 N | No | Robotic massage Manual massage | Saxon test Skin temperature Width of masseter muscle |
| Ariji et al. (2009a) | CCT          | 6 healthy subjects 6 subjects with TMJ disorders | WAO-1 | Effleurage, petrissage (rotation and rubbing) | 7 × 60 s/muscle–12 N | No | Robotic massage | Pain VAS-10 Impediments of daily life VAS-10 Perceived comfort VAS-10 Perceived warmth VAS-10 Easy-mouth opening VAS-10 |
| Ariji et al. (2009b) | CCT          | 16 healthy subjects 2 subjects with TMJ disorders | WAO-1 | Effleurage, petrissage (rotation and rubbing) | 7 × 60 s/muscle–12 N | No | Robotic massage | Pain VAS-10 Easy-mouth opening VAS-10 Perceived comfort VAS-10 Masseter stiffness index |

(Continued)
| Author          | Study design | Sample details | Study design | Sample Robotic massage intervention | Control | Others | Test – outcome measures | Effects                        |
|-----------------|--------------|----------------|--------------|-------------------------------------|---------|--------|------------------------|--------------------------------|
| Solis et al.    | CCT          | 12 healthy subjects | WAO-1        | Masseter and temporalis Effleurage, petrissage (rotation and rubbing) | 1 × 60 s/muscle\(\times\)12 N | No | Robotic massage WAO-1R | WAO-1R > WAO \(\downarrow\) require time \(\uparrow\) muscle thickness Trend \(\uparrow\) mouth opening NS change skin temperature |
| Ariji et al.    | CCT          | 15 subjects with single or bilateral TMJ disorders | WAO-1        | Masseter and temporal Effleurage, petrissage (rotation and rubbing) | 7–10 \(\times\) 60 s/muscle\(\times\)8–12 N | Unilateral robotic massage Bilateral robotic massage 3 times/week over 6-weeks | Masseter thickness Intramuscular sonographic appearance Pain VAS-10 Perceived comfort VAS-10 Perceived warmth VAS-10 Easy-mouth opening VAS-10 | \(\downarrow\) muscle thickness for symptomatic side \(\downarrow\) muscle pain \(\downarrow\) anaechoic areas \(\uparrow\) comfort \(\uparrow\) warmth \(\uparrow\) easy-mouth opening |
| Peng et al.     | RCT          | 1 healthy man Ronot – not reported Back muscles | Ronot – not reported | Pushing, picking-up and kneading | NR | NR | No | Robotic massage Heart rate Breathing rate Skin temperature | \(\downarrow\) heart rate NS change breathing rate NS change skin temperature |
| Luo and Chang   | RCT          | 5 healthy adults | Multi-finger robot hand | Shoulder Grasp-kneading | 1 \(\times\) 10 min\(\times\)1–20 N | Yes | Hand massage Robot hand massage | Muscle activity Both groups \(\downarrow\) muscle activity |
| Hiraia et al.   | RCT          | 16 patients with myofascial pain 24 healthy subjects | WAO-1        | Masseter and temporal Effleurage, petrissage (rubbing movement) | 7–10 \(\times\) 60 s/muscle\(\times\)6–14 N | Yes | Hand massage Robot hand massage | Patients1 1 time/week or 2 weeks over 6–12 weeks | Maseter PPT Pain VAS-10 Impediments of daily life VAS-10 Perceived comfort VAS-10 Perceived warmth VAS-10 Easy-mouth opening VAS-10 every 3 sessions | \(\downarrow\) sensitivity only in patients \(\downarrow\) muscle pain \(\uparrow\) comfort \(\uparrow\) warmth \(\uparrow\) easy-mouth opening |

(Continued)
| Author (year) | Study design | Sample | Robotic massage intervention | Control experimental groups | Test – outcome measures | Effects |
|---------------|--------------|--------|-------------------------------|-----------------------------|-------------------------|---------|
| Lei Hu et al. (2013) | RCT | 30 patients with lumbar muscle strain | NR | Latissimus dorsi and erector spinae | Rolling, thumb kneading, pinching, pressing and vibrating | 3 techniques with interval about 5 min | No | Robotic massage (based on the expert database) | Lumbar PPT | Lumbar strain VAS-10 | ↓ lumbar sensitivity ↓ lumbar strain |
| Ariji et al. (2015) | RCT | 41 patients with temporomandibular disorder | WAO-1 | Masseter and temporalis | Effleurage, petrissage (rotation and rubbing) | 7 × 60 s/muscle 14 N | No | Effective group | Muscle thickness Pain VAS-10 Maximal mouth opening Impediments of daily life VAS-10 Perceived comfort VAS-10 Perceived warmth VAS-10 Easy-mouth opening VAS-10 all 3 sessions | ↑ frequency of visibility of the distinct intramuscular echogenic bands ↓ elasticity index ratio ↑ maximal mouth opening |
| Ariji et al. (2016) | RCT | 37 patients with TMJ disorders | WAO-1 | Masseter and temporalis | Effleurage, petrissage (rotation and rubbing) | 7 × 60 s/muscle 0 N | No | Effective group | Muscle thickness Pain VAS-10 Maximal mouth opening pre- and post-treatment T0, T+1, 5 weeks | ↑ delta power ↓ alpha power (suggesting relaxation) |
| Luo et al. (2016) | RCT | 7 healthy subjects | Robot – not reported | Back | Pressing, rubbing and stroking | 1 × 10 min | NR | No | Massage robotic | Electrical activity of the brain pre- and post-treatment | ↑ delta power ↓ alpha power (suggesting relaxation) |

RCT, randomized controlled trial; CCT, controlled clinical trial; TMJ, temporomandibular joint; WAO1-R, Waseda Asahi Oral Rehabilitation Robot 1; N, Newton; NR, not reported; ↑ indicates increase; ↓, indicates decrease; NS, not significant.
To our knowledge, iYu® robot is the first device allowing users to implement such options, hence conceptually conciliating the proactive and retroactive modes of action control. From a conceptual viewpoint, such advent in robotic solutions might be a pioneering birth for a new kind of massages combining these two modes of action control. A major innovation of such devices would offer the opportunity to navigate from automated massage routines to user-controlled massage routines. When the robot operates based on a predetermined massage mode selected by the user, a primary retroactive motor control strategy would be engaged as long as the trajectories cannot be predicted by the participant, i.e., such as during a MM. By interacting with the machine and controlling the parameters of the massage with a remote-control device, the user could switch to a proactive mode of action control, such as during FR. This transition faculty, from one mode of control to the other, definitely represents an innovative conceptual approach in terms of human-machine interactions.

Limits and Perspectives

To date, with the development of collaborative robotic massage, it is possible to see a novel stochastic sensorimotor user experience. These robots are now less expensive and provide multiple advantages for users such as increased precision, availability, privacy and user choices. The addition of a remote user control, as in the case of iYu® Pro, would complete the device and the whole extent of possible fields. In this context, an opportunity to interact with the device during the session would be offered, reconciling the two motor control strategies. Although these emerging solutions and the idea of conceptual bridge are attractive, extreme caution should be exercised and critical aspects questioning both users’ safety and benefits of the massage are awaiting experimental investigation. This freedom of use certainly offers new perspectives, but also implies special attention to the level of autonomy granted, so as not to represent any risk for users. Pressure levels and/or trajectories cannot be randomly administered, and these parameters should be predetermined and supervised by a professional. Also, therapeutic massages require consideration of the histological structure and physiological processes occurring in the body (Lima et al., 2020). This aspect represents a major issue since these limits are different from one person to another, depending on the muscle mass, the habit of self-massage and the presence of dysfunctions requiring medical considerations. For both safety and individualization reasons, purely replacing therapeutic massage interventions classically administered by physiotherapists by a robotic device appears impossible. It is indeed necessary to obtain feedback during the massage routine, directly from the patient and as a result of palpation performed by the therapist. Nonetheless, new types of robotic massages should continue being tested in experimental studies, in particular to differentiate the effects of robotic massages in a so-called preventive/wellness context, from those encountered in a therapeutic context.

In addition, from an ethical standpoint, robotic replicates of MM could easily be considered an inappropriate substitute to actual human interventions. Nonetheless, this should not condemn the potential relevance of robotic solutions. These offer many advantages, particularly from a preventive viewpoint. Considering the important workload for physiotherapists and frequent limited medical resources, robotic devices represent a solid alternative to provide assistance in their tasks (Golovin et al., 2018). They may alleviate part of the workload faced by medical professionals, and be used to administer simple and reproducible preliminary manipulations. A compound benefit would be allowing physiotherapists to focus on more complex and demanding interventions which cannot be performed by a robot (e.g., joint mobilization, stretching and strengthening exercises). For instance, a collaborative and intelligent robot could be an efficient tool to reduce the risk of musculoskeletal injuries associated with the lack of joint mobilization (e.g., thumb, wrist, shoulder, neck and low back pain). Robotic solutions would also provide an opportunity to democratize access to the practice of massage or self-massage, and thus contribute to improve well-being, health and therapeutic outcomes (Golovin et al., 2018).

Nonetheless, the use of a robotic device for curative massage interventions is questionable. It raises the issue of whether the actual experience of a physiotherapist can be robotized. Physiotherapists adjust their manipulations based on the reaction of their patient. Apart from the massage of scar tissue, MM requires intense and repetitive work by the practitioner. The fine adjustments derived from ongoing feedback, which are continuously available to the physiotherapist, remain essential to the treatment efficacy. MM remains, in this view, a specific form of human interaction that cannot be restricted to mechanical pressures, and robots remain, at this point, a tool at the disposal of medical practitioners.

Eventually, the presence of a remote control allowing to interact in real-time with the robotic device during the massage may hamper the benefits of the massage. For instance, in a clinical context, the patient could avoid the necessary amount of pain associated with pain in edema resorption routines. Also, each control command of the user on the remote requires cognitive operations. Requirements for cognitive control during the massage might preclude optimal states of relaxation. During MM, the user usually manages to detach himself from the effects of the routine by practicing the so-called “letting go” (Cornner et al., 1995; Richards, 1998). Among the main unresolved questions, researchers still have to determine whether users are able to relax despite the cognitive mobilization required by the remote control and the interaction with the device. Researchers should also question whether a robotic massage may perceived as being as effective as a MM performed by a physiotherapist for wellness purposes, whether its benefits are similar to those of FR or MM, and whether it may influence psychological (e.g., perceived relaxation, fatigue, pain) and physiological variables (e.g., decrease in perceived anxiety, decreased arousal) in a similar way. Resolving these issues will undoubtedly be an exciting focus of research in the coming years.

AUTHOR CONTRIBUTIONS

YK, AG and FDR designed the conceptual background of the review and wrote the manuscript. YK, CE, AG, and FDR read, amended, and approved the final version.
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Conflict of Interest: CE was employed by the company Capsix Robotics.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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